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Earthquake-Resistant Wooden Connection System in *Sasak* Traditional Buildings in *Sade Village*, Lombok, Indonesia

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Abstract Traditional settlements on the island of Lombok still survive in several places, namely in Senaru, Karang Bajo, Segenter, Limbungan, Ende and Sade. Bale is another name for the house. Each has a different term. Bale Mangina for the name bale in Senaru, while in other places, it is better known as Bale Tani. Bale Tani is an ordinary dwelling house for the people of Dusun Sade which has an exciting characteristic when viewed from its construction system. Construction systems that are centuries old can adapt to disasters and changing times. This bale is one of several traditional bales that are earthquake resistant. There have been several earthquakes in the field in 2018. As a result, the building structure did not suffer any damage. This research aims to purpose of this research is to study earthquake-resistant wooden connection systems in traditional buildings that must be maintained. Besides that, tests were carried out using SAP (structural analysis program). The method used in this research is a qualitative approach—direct survey data collection techniques to the field. This study concludes that the Bale Tani building is an earthquake-resistant building. The connection system uses pegs and purus, which is a knockdown system. The foundation uses a clamp system, and a wooden connection system is a joint system. From the test results, it can be seen that the post and purus connection system can withstand earthquakes. All of this supports the building's responsiveness to earthquakes as an effort to mitigate natural disasters. So this system is excellent to be applied to areas with a moderate to high scale potential for earthquakes. Besides that, the knockdown model is also suitable for application and development for small-type residential buildings. Of course, there needs to be additional technological engineering in the future.

Keywords Bale Tani, Traditional Building, Earthquake-Resistant, Wooden Connection System

1. Introduction

The Sasak settlements on Lombok Island are located in three districts, the Sasak Segenter, Karang Bajo-Bayan, and Senaru settlements in North Lombok Regency; Limbungan in East Lombok Regency and Sade in Central Lombok Regency [1][2] and in Sembalun – East Lombok Regency. In general, these settlements are still oriented towards macro and microcosmic beliefs in arranging the layout and direction of the houses. It causes the settlement to have a regular and symmetrical pattern [3]. Its layout considers the concept of cosmology. It maintains a balance

between the sun's trajectory and the position of Mount Rinjani, which is believed to be the place of origin of the ancestors of the Sasak tribe.

Sade village, where the traditional community lives, is a community that is attached to the culture and values of local wisdom. A house is a form of a cultural community that is interpreted as an artifact. In this residential stage, climatological-geographical challenges, socio-cultural-economic factors, and material engineering are the primary reasons for making architecture a place of safety, comfort, and social status [4]. The environment with the nuances of local wisdom plays a role in preserving the environment [5]. Over time, the government designated Dusun Sade as a tourist village. A village has several related to its uniqueness and how the community participates in maintaining its culture [6]. Where this hamlet is the work of an architect, when viewed from a tourism perspective, it is an artificial figure that can become an attraction [7]. It also impacts the influx of foreign cultures that have affected Sade's environment, both urban cultures and foreign cultures, due to globalization, which impacts the degradation of regional cultural values [8]. However, several research results show that local wisdom in housing is still maintained [9]-[14]. We can see from the bale (a term for a house in the Sasak language) that there has been no change physically.

The Sade people in building houses, arranging the space, and the materials forming the space refer to the sacred (profane) principles. They also build houses adapted to their function in the community environment. Therefore, there are several names of bale/houses, namely: Bale Tani, Bale Bontar, Bale Kodong, Berugaq, and Bale Lumbung. These bales are part of Indonesian culture through a process of trial and error and have become one of the identities of the Indonesian nation. For example, in Bali, how is Meru part of a culture that should be preserved through trial and error [15]. The characteristic of traditional buildings is that they do not apply construction theories or principles to buildings but rather how they can adapt to the existing environment and climate. One of them is that this traditional building (bale) is a building that is responsive to earthquakes [16]. It shows that since ancient times the Sasak people have known technology that is adaptive to earthquakes.

A Traditional House is a building that has evolved and is inseparable from changes in cultural and technological developments [17]. Likewise, the Bale Tani house, also called the Bale Jamaq, is one of the traditional houses. Tani means farmer's work, and jamaq means ordinary. So, it can be assumed that farmers occupy the house as ordinary people. *Bale Tani* is the dominant house in *Sade village* [18]. The original form of *Bale Tani* is the roof directly above the ground. As shown in Figure 1.

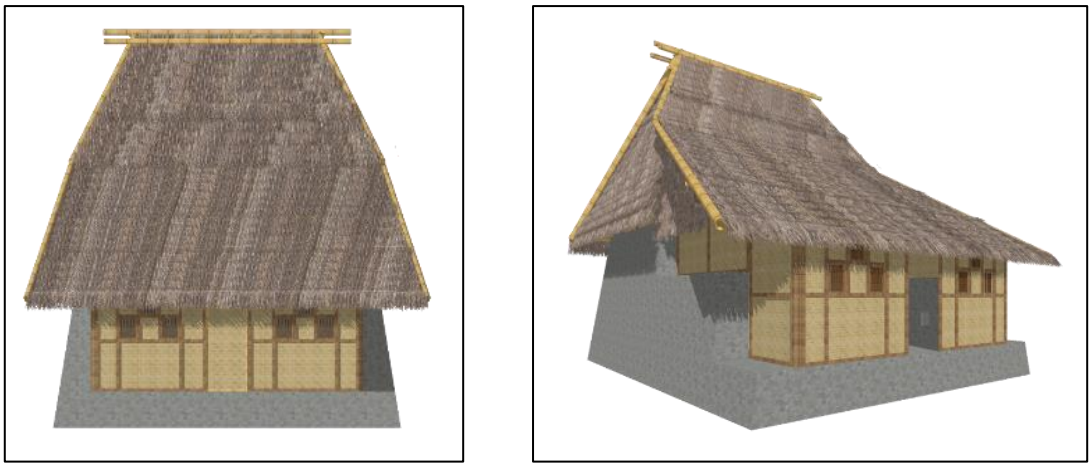
Source: Fathurrahman, L.

Figure 1. Bale Tan*i* before transformation

However, the current conditions have changed following cultural and technological developments. Apart from being a place to live, it is also a house with aesthetic value and philosophy. It utilizes natural resources as a livelihood and a source of building materials for its house [9][19]. To more clearly seen in Figure 2. The roof no longer reaches the ground but is already a wall boundary between a room and outside.

Source: Author. 2022

Figure 2. Bale Tani after transformation



Left Side View Perspective View

Source: Author, 2022

Figure 3. Building View

The typology of *Bale Tani* buildings can be seen in Figure 3. Bale Tani architecture symbolizes the microcosm of the small world—namely, the microcosm of the relationship between God, ancestors, and fellow human beings. One is on the Bale Tani roof, rising at the back, then going down in the middle and flat at the bottom. It symbolizes the relationship between God and humans that humans must submit to God, and God will give affection to their creatures equally and fairly [12]. Technically, the shape of the roof with a pretty steep roof responds to nature. When the rainy season arrives, this steep shape makes it easier for water to flow directly to the ground [20].

On the plan, the *Bale Tani* room is divided into a *sesangkok* (the middle room), and on the inside, it is divided into *Bale Dalem* (inner room). People entering the house will face a *sesangkok* (living room). You must climb three steps from *Sesangkok* to the inside (*Bale Dalem*). These steps mean life goes through three processes: birth, life, and death. Alternatively, it is called WetuTelu. Entering *Bale Dalem* is divided into a kitchen on the left and the right; it is called *Dalem Bale*. *Bale Dalem* is to store family assets. *Bale Dalem* is private, only for women. So, this shows the role of highly valued and protected family members. The boys are outside. If a man sleeps enough, he will sleep in the *berugaq* (name of the building that use as a sitting place) (not in the bale) [21].

Building materials for *Bale Tani* are materials taken from around the environment. The clay floor is covered with buffalo dung which provides warmth, especially at night (because the air is quite cold). The walls use bamboo in the form of woven, which functions for air circulation so that the room temperature inside the building is quite comfortable. The roof uses reeds with a reasonably thick arrangement. The thickness of the thatch roof is approximately 15 – 20 cm so that it can reduce the sun's heat during the day. This wall is reinforced with columns from local wood, namely tinus wood. So these building materials certainly support earthquake-resistant construction because the materials are obtained from the surrounding nature, are lightweight, and use techniques learned from nature. This building has beauty and rational values that can be proven scientifically by analyzing earthquake-resistant structures.

From the explanation above, this earthquake-resistant building is fascinating to study. Remember that construction in this modern era is an earthquake-resistant construction model, not earthquake-friendly. Earthquake-friendly is a knockdown connection system that is flexible/not rigid when it receives earthquake forces [16].

The study was limited to an earthquake-friendly wood connection system, the *Bale Tani* (residential). In *Dusun Sade*, *Bale Tani* is the primary residence with an interesting structure to study.

2. Research Method

The aims of this study are: (1) to study an earthquake-friendly wooden connection system in traditional *Sade* buildings in particular *bale* which must be maintained, bearing in mind that Lombok Island is an earthquake-prone area; (2) to find out the connection system model as part of local wisdom values that must be maintained; and (3) to enrich knowledge in the scientific field of architectural culture and to increase understanding and understanding for writers and readers [21]. (4) To emphasize the importance of connection systems that have existed since ancient times, namely pegs and *purus* in simple buildings, especially in earthquake-prone areas in the world in general and in Indonesia in particular; (5) As a material for studying simple building structures for earthquake resistant buildings in the future with technological engineering.

The method used in this study is a descriptive qualitative and structural analysis test method to determine the

resistance of buildings to earthquakes. The data collection technique used in this study was a primary survey: direct observation in the field was carried out to obtain data directly on the existing physical conditions. Interviews were conducted with informants (residents of Sade Hamlet) to find data that still needed to be revealed. Secondary survey: literature.

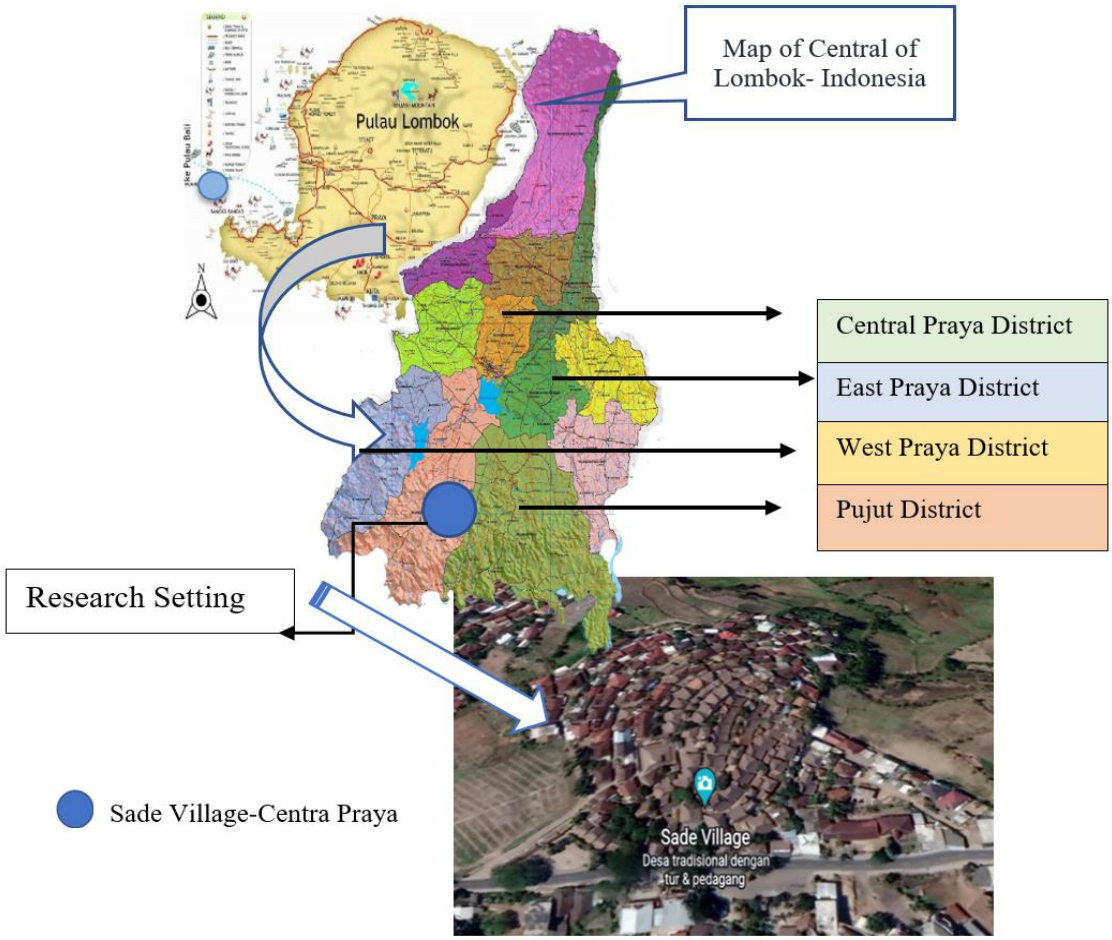
3. Results and Discussion

3.1. Research Setting

The traditional settlement of *Sade* is one of the hamlets of Rembitan Village, Pujut District, Central Lombok Regency. The settlements were built in hilly areas and surrounding natural conditions from those built on the mainland [22]. The location of the population in Dusun Sade is concentrated, but there has been a spread in its development (see Figure 4).

The population's livelihoods include farmers, ranchers, tour guides, weavers (for women), and accessories sellers. From the beginning until now, this hamlet has entered its 15th generation. The population is around 700 people, comprising 152 households (KK) and divided into seven household pillars (RT). Therefore, the remaining 152 houses were retained, and new buildings were not permitted in the hamlet. Even though they are traditional people, with the influx of technology and the development of the times, they also accept and use technology, such as motorbikes, television, and cell phones [13].

From the tourism sector, Dusun Sade is one of six supporting villages for the Super Priority Tourism Destination (DPSP) area – KEK *Mandalika*, Central Lombok. The research location was set in Sade Hamlet, Central Lombok Regency because this location was considered to represent the traditional settlement of the *Sasak* tribe on Lombok Island. He considers that there is a phenomenon of Dusun Sade as a hamlet with strong local wisdom values. Another supporting factor is that this hamlet is a buffer for KEK *Mandalika* (a super priority tourism destination in Indonesia that has started going global), so the government has made many program policies in Sade Hamlet to advance tourism.



Source: Google Earth, 2021

Figure 4. Location of Research Area

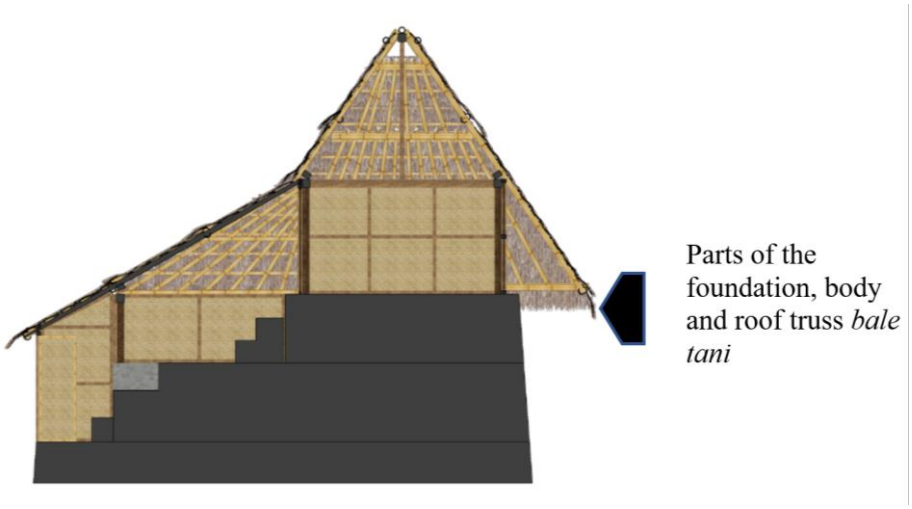
3.2. Construction per Section and Structure at *Bale Tani*

Bale Tani is a residential building with a simple structure but complete with its parts, legs, body, and head. The legs are the stepped foundation. Where is the wood for the function of the columns and bamboo as a wall ? The wall is not a barrier but does not function as a bearer but as a filling element [23]. The upper part is the roof with a bamboo frame to support the roof. The roofing material is reed material which is helpful so that during the day, it feels fantastic, and at night it gives warmth [24][30]. More details from the legs to the head are in Figure 5.

The study results showed that in the construction of *Bale Tani*, the foundation used pedestal foundations planted in the ground. This foundation is raised as high as 40 cm from the ground.

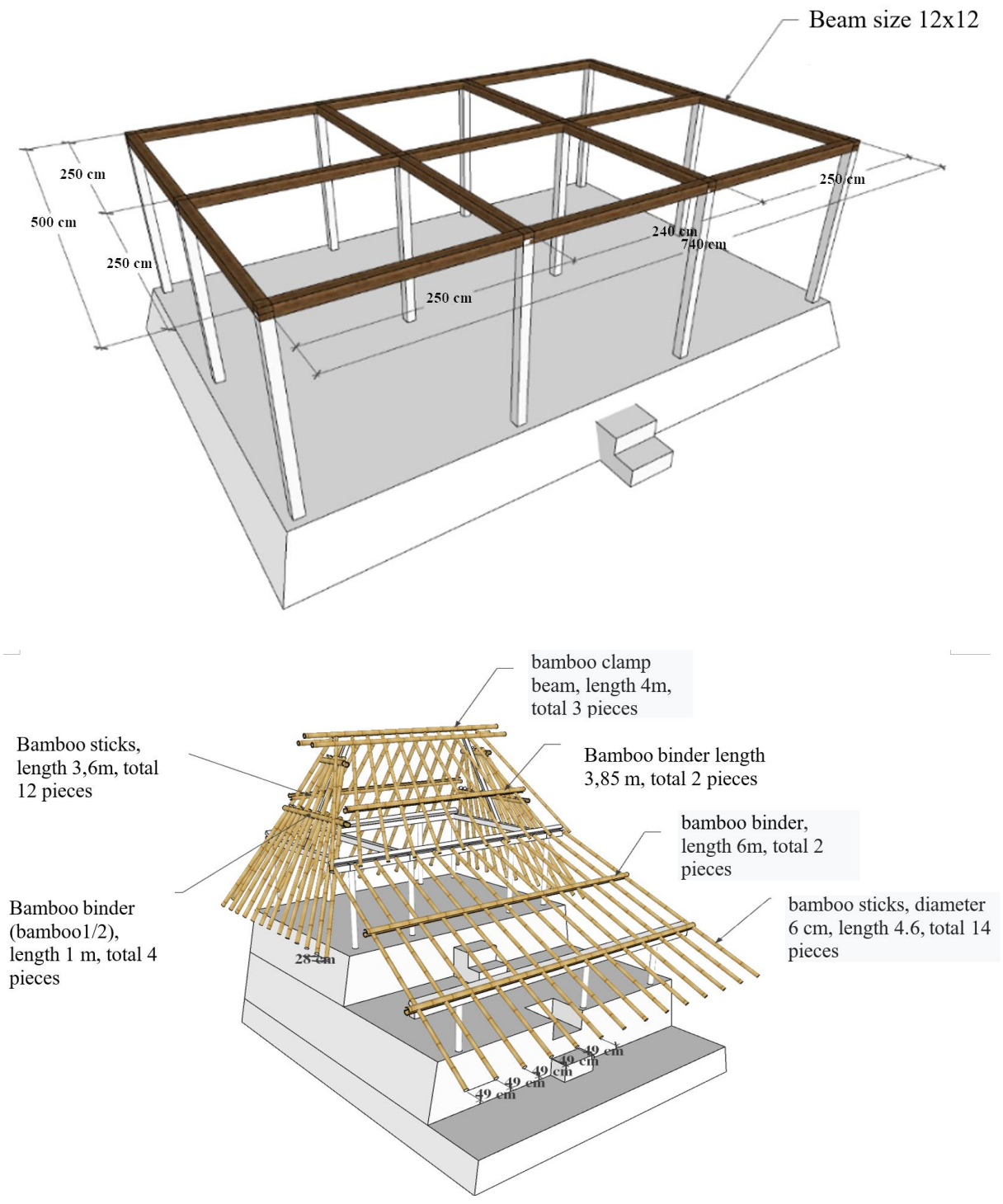
For columns, the shape is in the form of logs with a diameter of 10 cm with a total of 11 pieces, 155 cm high. In comparison, the terrace column height is 100 cm. The wood used for this column comes from local wood, namely Tinus wood. Furthermore, the roof frame uses rafters with bamboo material.

Ring beams generally function as a binder between columns and transfer roof loads through rafters. Using a 12/12 size wooden block, then connected to the column using the tenon and mortise. The connection of the column has also reinforced a bracket (bracing). They strengthen the rigidity of the column and beam connection. The connection of the beams is continued with the construction of the trusses in the form of 8/8 truss beams, 8/8 truss legs, and 12/12 truss beams (in Figure 6).



Source: Gazalba & Author. 2022

Figure 5. Parts of a *Bale Tani*



Source: Gazalba & Author. 2022

Figure 6. *Bale Tani* Construction

Generally, bamboo ropes with a diameter of 6-8 cm are used for rafters placed in a vertical row. The number of ribs on each side is generally odd, but in some cases, an even number is found. A block of bamboo clamps is used to bind the distance between the ribs, used which is halved. Whereas on the roof, the bond is made of reeds as a roofing material, as one of the unique features found is the existence of three bamboo beams specifically used to clamp the reeds [25][31][32].

3.3. Earthquake- Resistant Rules on Buildings

In general, all parts of Indonesia are earthquake-prone areas. It is because, geographically, Indonesia is among the world's three major plates that are actively moving. Where the source of earthquakes in Indonesia comes from subduction zones and active faults on land, this zone stretches from Sumatra to West Nusa Tenggara, then turns to Maluku.

Earthquakes generate waves and impact vibrations on the earth's surface. There are three vibrations, namely primary, secondary, and large waves. The primary wave vibrations are adjacent to the direction of propagation (coincide). While secondary waves move perpendicular to the direction of propagation that runs on the ground [26][27]. This vibration will affect the building through the emergence of inertial forces. Another consequence will be overturning, which causes the building to bend at the bottom and torsion forces to arise (caused by differences in the location of the center of mass stiffness and the epicenter). It causes the building to rotate about the x-axis. If there is an earthquake, the reaction of the wood is in the form of flexibility (stiffness and plasticity), damping, and stability. Stability itself is the absorption of vibrations to counter inertial forces. Elasticity and ductility are the ability of a building to undergo plastic deformation without collapsing. As well as the presence of hyperstatic formed from beam elements with the presence of plastic hinges.

Based on the SNI 03-1726-2019 Public Works Service guidelines and Indonesian Timber Construction Planning Procedures. The main principles in earthquake-resistant construction are (a) Simple and symmetrical building plans; (b) Building materials should be as light as possible, adequate construction system. It means that the forces acting on the load-bearing construction can be channeled from each element to the foundation, then to the ground.

3.4. Knockdown System in the *Bale Tani* Building

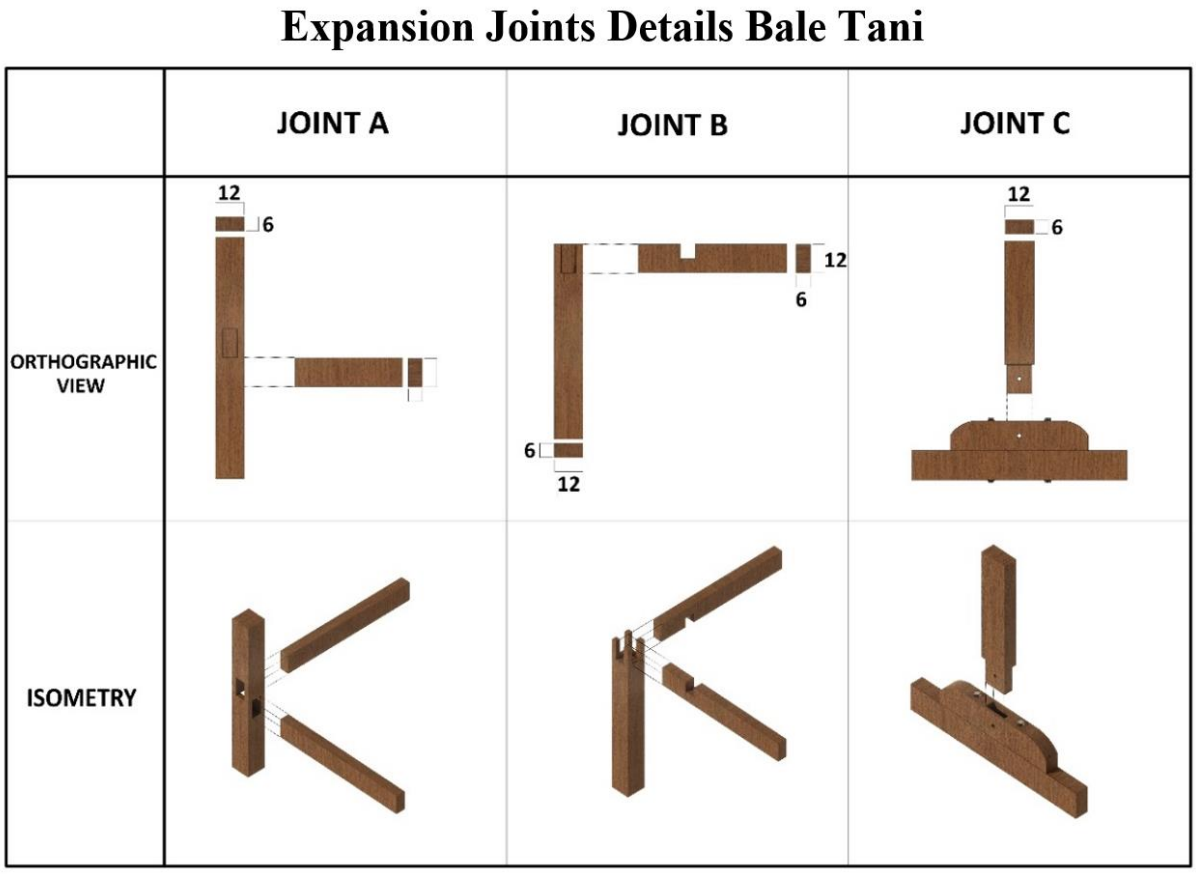
a) Foundation

The *Bale Tani* construction is divided into the lower part, namely the pedestal foundation. The pedestal foundation has become an earthquake-resistant foundation. It has taken into account the behavior of the building and events from the past [27]-[29]. Pillars will be placed to support the roof construction. The pedestal foundation will be covered with soil according to the planned height. The function of the pedestal foundation is the place for the pillars to stand firm/not collapse.

b) Knockdown System

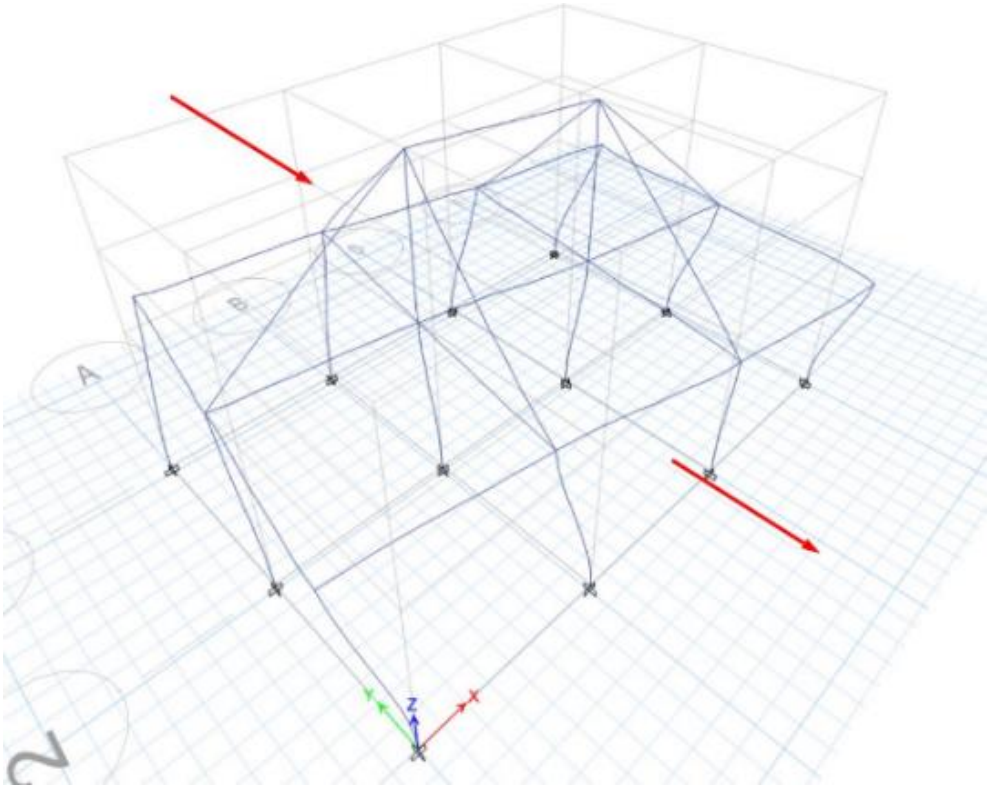
The knockdown system can be seen in the joints between the pedestal foundations and the piles using a clamp system. In comparison, the connection between the pile and the ring beam uses a joint system, namely the tenon and mortise connection model. This system is called a knockdown system which has a locking system (can be seen in Figure 7). This hinge and clamp system is a type of earthquake-friendly structure. It means that if there is a wobble in the building due to the earthquake, the clamp system on the foundation will bind the building/stabilize the building during the earthquake, and the movement due to the earthquake will be accompanied by the rhythm of the movement in the building due to the joint system. So if the shaking stops, the building will also stop in its original position.

The above information can be seen from the test results using the SAP (Structural Analysis Program) for building earthquake responses. In the science of earthquake-resistant building structures, the critical point is the connection, located at the joints of the wooden columns-beams. The nature of this joint serves as an effort to reduce earthquake vibrations that reach the foundation while the foundation is clamped, stabilizing the building when it receives an earthquake. These two properties cause friction, a damper for vibrations during an earthquake (Figure 8).

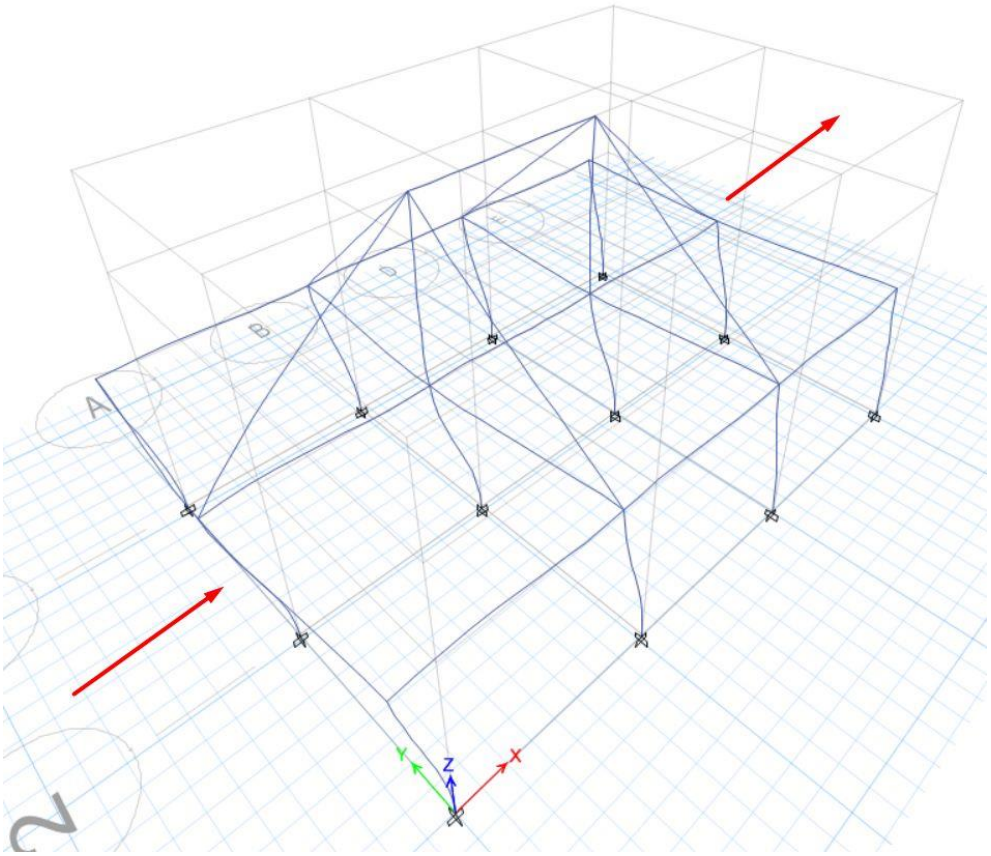


Source: Author, 2022

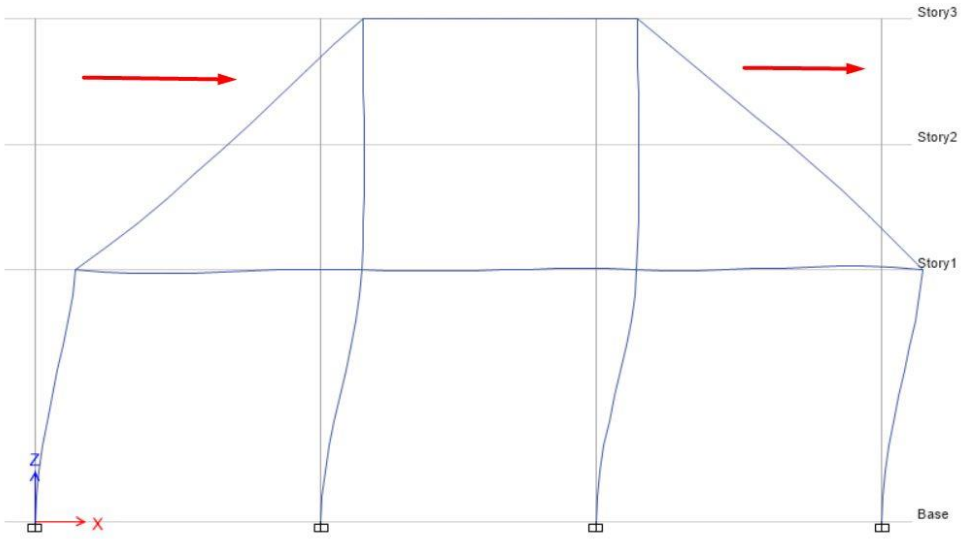
Figure 7. Timber connection system with tenon and mortise



Y- direction

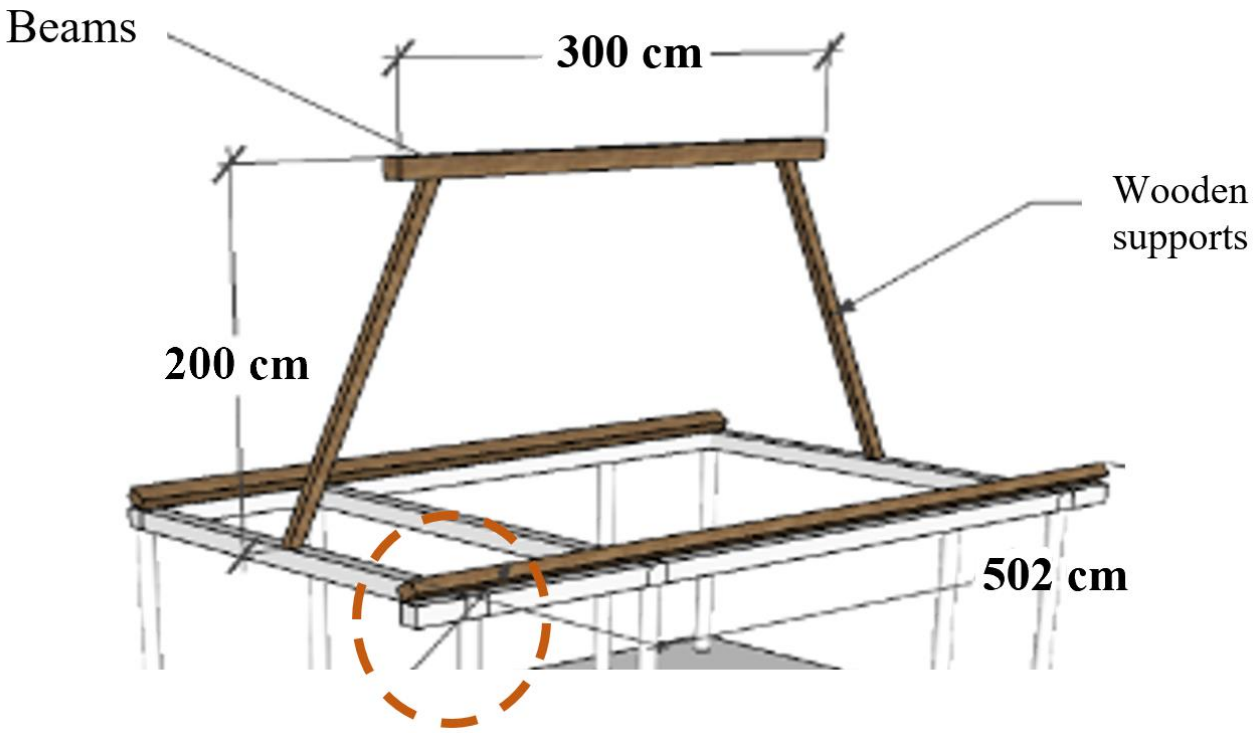


X- direction



Source: Author, 2023

Figure 8. AP test for *Bale Tani* against earthquakes



Source: Zaedar & Author, 2022

Figure 9. The building frame system on the *Bale Tani*

At the head, on the log as a function of the ring beam using a pen *purus* model connection system. The system is also a knockdown system that has a locking system. Then on top of it, on the front and back sides, as a support for the rafters supported wooden beams (Figure 9). The unique thing is that to support the roof covering, namely the truss, there is only one whose function is to hold the weight of the roof. Next, bamboo rafters will be arranged to support the roof with reed material (no battens). All knockdown locking systems are types of buildings responsive to earthquakes or, in other words, earthquake-resistant.

4. Conclusions and Recommendations

4.1. Conclusions

Bale Tani has an earthquake-resistant construction system. The connection system uses dowels and *purus*, which is a knockdown system. At the bottom/foundation, it uses a clamp system, and a wood connection system is a joint system so that if there is a wobble with this system, the building, after moving, will return to its original point (back to normal). All of this supports the building's responsiveness to earthquakes as an effort to mitigate natural disasters.

Environmentally friendly building materials and light in weight as one of the supports for earthquake resistance. In addition, this bale has a reasonable value that can be scientifically proven by analyzing earthquake-resistant structures.

4.2. Recommendations

The construction system with dowels-*purus* (knockdown) pattern is excellent to be applied to areas/areas with moderate to high potential for earthquakes, such as in Indonesia. It is not only applied to non-permanent buildings but also to permanent buildings with the application of technology but still referring to the knockdown system.

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