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Design of bamboo ladder as traditional construction equipment based on static loading analysis

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ABSTRACT

The bamboo ladder is a traditional construction equipment that still survives on the market and is in demand, especially in rural communities such as Kedalingan village. However, bamboo stairs still do not consider the standard of stairs design. In addition, there are concerns that users of the ladder may experience injury due to falls because the ladder cannot withstand the load (unbalanced). This study aims to obtain the maximum load that can be held by bamboo ladders and the angle of the position of the safe ladder by considering the Indonesian people's anthropometric weight. Calculation results based on the principle of equilibrium show that with a maximum user weight of 89.25 kg, the ladder must be positioned with a minimum slope of 53,26º but less than 65.43º. In addition, a static loading simulation was carried out using SolidWorks 2019 on a bamboo ladder frame structure that was made referring to SNI 19 - 1956 – 1990. Simulation results show that the design of a bamboo ladder can withstand a maximum body weight of 89.25 kg with the maximum load value of bamboo holding is 98.93 kg.

1. INTRODUCTION

The ladder is a construction tool used to reach a taller building and can be moved around [1]. Ladders are used not only during construction projects but also to perform specific needs such as changing lights, painting walls, etc. Ladders are made of wood, bamboo, or aluminium based on the material. The amboo is lighter than wood and aluminium because it has the smallest specific gravity value but has a reasonably high strength ratio [2]. It is not surprising that people, especially in rural areas, still use bamboo because it is considered strong and more economical.

The bamboo ladder is one of the few traditional construction equipment that still survives the competition with aluminium work ladders. Bamboo is also traditionally used as a structural member in low-rise houses, bridges, roofs, and construction slabs in countries with abundant bamboo resources. In addition, bamboo structures are environmentally friendly and aligned with the goal of green and sustainable development with reasonably good mechanical properties [3]. This ladder is still often used, especially by rural communities, one of which is in Kedalingan Village, Tambakromo District, Pati. The use of bamboo ladders was chosen because it is considered more economical than the price of aluminium ladders on the market. Often the villagers make their ladders that will be used because they are easy to make and the bamboo material is easy to find. Specifically, the bamboo type suitable for making

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Augmented reality-based application design with rapid prototyping method to support practicum during the covid-19 pandemic

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A B S T R A C T

The COVID-19 pandemic that has occurred throughout the world has hampered the world of education in carrying out the learning process. It requires the world of education to make rapid changes to the concept of learning so that the results of the learning process remain following the curriculum. However, during a pandemic, students are forced to study from home. Of course, this limits the essence of the practicum, which has to be done in the laboratory because students need interaction activities with machines. Augmented reality (A.R.) is a technology that allows users to interact with virtual objects. In this study, the application design is carried out using the rapid prototyping method, which can quickly accommodate the application development process. This study proves that AR-based applications can increase the understanding of 58% of students about the use of lathe, milling and 3D printing machines.

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1. INTRODUCTION

Covid-19 is an infectious disease that can interfere with a person's breathing, originating in the city of Wuhan and has spread throughout the continent [1]. On March 2, 2020, the first case of Covid-19 was detected in Indonesia. Until September 2020, COVID-19 cases continued to increase to 177,571 cases, and 7,505 people died.

COVID-19 containment measures in their respective regions are one of the most preferred ways to reduce the impact of the crisis due to the pandemic [2]. Lockdown is an emergency implemented by the government to prohibit residents from leaving their homes. It has resulted in the closure of schools and colleges for an undetermined time as a preventive measure against the increasing number of COVID-19 cases. In mid-March, up to 75 countries announced the closure of educational institutions [3]. The closure of the educational institution caused around 73.8% of registered students to be affected [4].

The closure of the University caused a shift in the teaching and learning process from offline to online. There needs to be a change in the Education system to adapt to conditions during an unprecedented pandemic. One of the teaching and learning activities that need to be redesigned is practicum activities, which require interaction between students and the tools available in the laboratory.

In pandemic conditions, students cannot carry out their regular practice. Therefore, it is feared that

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Linkages analysis risk factors of the return process in logistics fast moving consumer goods

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A B S T R A C T

This study analyzed the linkage of risk factors in the return process of fast-moving consumer good (FMCG) logistics systems. The risk of returning products due to expired, near expiration, order errors and bad stock (damaged) haunts sustainable supply chains in the industry. In four business processes, warehousing, transport/distribution, production/supply and order processing identified twenty-two risk factors that cause the return process. The decision-making and trial evaluation laboratory (DEMATEL) method helps decision-makers simplify causal relationships between twenty-two complex risk factors. Through the depiction of the matrix and the network relationship map, twelve risk factors entered the dispatcher group, namely risk factors that can affect other risk factors that impact the return process on the FMCG logistics system. The result becomes a reference for decision makers to prioritize risk factors management that have a relationship with other risk factors, because the impact obtained will be maximal.

1. INTRODUCTION

In recent years, risk management and sustainable supply chains (SSCs) have caught the attention of researchers [1]–[3]. Today, with the globalization of business operations, logistics systems are threatened by all sorts of uncertainties and disruptions. Almost every month, serious transportation accidents and natural disasters worldwide are reported in the media. As a result, effective and efficient risk management schemes are a top priority. The Covid-19 pandemic in 2020 impacted economic activity in almost all industrial sectors. The retail industry sector, especially fast-moving consumer good (FMCG), is said to have experienced the worst contraction in the last 20 years. The year 2021 is considered a challenging time, although the government has started to run a vaccination program that is considered the key to national economic recovery.

FMCG characteristics can be seen from two perspectives, the perspective of consumers and producers. From a consumer perspective, FMCG characteristics are demonstrated by high product purchase frequency, low attachment, and low price. From a producer's perspective, its characteristics are high sales volume, extensive use of distribution channels, and high inventory turnover. These characteristics often lead to problems on the

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Website-based final project management system design at Trisakti university industrial engineering

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ABSTRACT

Preparing the final project is one of the requirements for graduation from a college student. The right Final Project management system will affect the quality of education. Industrial Engineering Trisakti University is one of the leading universities in Indonesia that continues to develop its education system. Managing the final project at Trisakti University Industrial Engineering is still manual and has not been integrated. As a result, the risk of errors in entering and saving Final Project data is still high. Therefore, this research was conducted to design a final project management system at Trisakti University Industrial Engineering. It begins with analyzing the existing management system. It is described with swim lane diagrams and PIECES to determine the process flow in the system and the actors who play a role in the system. After analyzing the system, proceed with designing information systems with Object-Oriented Modeling and evaluate it with black box testing and ERRC. This research results in website-based final project management at Trisakti University Industrial Engineering.

1. INTRODUCTION

Education is a necessary sector of a country because the quality of education will affect the future of a country [1]. Pandemic in Indonesia since 2020 has been one of the drivers of accelerating the development of information technology, including in the education sector. All educational activities must be online. The lecture process, which used to be held on campus, has now become online from home. Not only that, but the restrictions on people's movement imposed by the government at the beginning of the pandemic also caused management and administration activities to be flexible so that distance was no longer a barrier to all activities in the education sector.

Designing an information system to support academic activities at a university is one solution to accelerate development in the world of education [2]. Academics is one form of the service industry that, if managed using an information management system, can optimize performance systems [3]. The management system in the world of education is divided into various processes, one of which is the final project management system. The process of completing the final project is one of the important requirements for prospective undergraduates at the level

Design of Bamboo Ladder as Traditional Construction Equipment based on Static Loading Analysis

by Novie Susanto

Design of Bamboo Ladder as Traditional Construction Equipment based on Static Loading Analysis

ABSTRACT

Bamboo ladder is one of the traditional construction equipment that still survives on the market and is in demand, especially by rural communities such as in Kedalingan village. However, bamboo stairs still do not consider the standard of the stairs design. In addition, there are concerns that users of the ladder may experience injury due to falls because the ladder is unable to withstand the load (unbalanced). This study aims to obtain the maximum load that can be held by bamboo ladders and the angle of the position of the ladder that is safe by considering the anthropometric weight of the Indonesian people. Calculation results based on the principle of equilibrium show that with a maximum user weight of 89.25 kg, the ladder must be positioned with a minimum slope of 53,26° but less than 65.43°. In addition, a static loading simulation was carried out using SolidWorks 2019 on a bamboo ladder frame structure that was made referring to SNI 19 - 1956 – 1990. Simulation results show that the design of a bamboo ladder is able to withstand a maximum body weight of 89.25 kg with the maximum load value of bamboo holding is 98.93 kg.

Keywords:
Static loading
Bamboo
Ladder
Traditional
Construction

INTRODUCTION

Ladder is a construction tool used to reach a taller building and can be moved around [1]. Ladders are not only used during construction projects, but are also needed to perform certain needs such as changing lights, painting walls, and others. Based on the material, there are ladders made of wood, bamboo, or aluminum. [2] stated that bamboo is lighter than wood and aluminum because it has the smallest specific gravity value but has a fairly high strength ratio. It is not surprising that people, especially in rural areas, still use bamboo because it is considered strong and more economical.

The bamboo ladder is one of the few traditional construction equipment that still survives the competition with aluminum work ladders. Bamboo is also traditionally used as a structural member in low-rise houses, bridges, roofs, and construction slabs in countries with abundant bamboo resources. In addition, bamboo structures are environmentally friendly and aligned with the goal of green and sustainable development with fairly good mechanical properties [3]. This ladder is still often used, especially by rural communities, one of which is in Kedalingan Village, Tambakromo District, Pati. The use of bamboo ladders was chosen because it is considered more economical than the price of aluminum ladders on the market. In fact, often the villagers make their own ladders that will be used because they are easy to make and the bamboo material is easy to find. Specifically, the type of bamboo that is suitable for making household appliances and light construction is apus bamboo (*Gigantochloa apus)*[4]. Several studies related to the use of bamboo were carried out by Chung and Yu (2002) which examined variations in the compressive strength of various physical properties along the bamboo stem for the two species of bamboo used as scaffolding materials used in construction projects. In addition, [5] discussed improvising the optimal angular position for the extension ladder, while [1] evaluated the effect of a designed "walk-through" extension ladder based on the kinetic behavior and externally induced destabilizing forces on the ladder during the transition to elevation. In general, the use of ladders as a work equipment in the construction sector certainly has advantages and disadvantages that need to be considered [6-21].

In practice, the ladder design used by the Kedalingan village community does not meet the existing laddercase design standards (BSN, 2019) due to a lack of knowledge about safe laddercase design standards. In addition, from the results of a preliminary study conducted on twenty workers, it is known that users of bamboo ladders experience several difficulties as shown in table 1 below.

Table 1. Difficulties using Bamboo Ladders

Difficulty Type	Amount
How to place the ladders to balance	37%
Position the ladder so it doesn't slip	18%
Falling because the ladders are not comfortable to use	18%
Don't know the maximum load the ladder can withstand	27%

This shows that bamboo ladders must withstand loads that vary depending on the user's weight. Load analysis on bamboo material needs to be carried out to find out whether the bamboo frame used is strong enough to withstand variations in the user's load so it is safe to use. In addition, to get the optimal ladder position angle seen from the user's weight. In identifying the forces involved, including the reaction force caused by the support and weight, a diagrammatic sketch of the Free Body Diagram is taken into account. Furthermore, because a stable object such as a bamboo ladder will remain in balance, the forces acting on it will satisfy the static equilibrium equation, while the analysis of the bamboo ladder frame is carried out using SolidWorks software because it can be used to analyze the static load on the frame.
Based on this background, it is a need to research design bamboo ladders as traditional construction equipment to result a safe and reliable tools.

This study aims to calculate the compression force that occurs in the body segments of workers who use bamboo ladders based on the Free Body Diagram, to get the optimal ladder position angle based on body weight and to determine the critical point on the bamboo ladder frame when loading based on the worker's weight using SolidWorks software simulation.

RESEARCH METHODS

The study was conducted on villagers who work as construction workers in Kedalingan Village, Tambakromo District, Pati Regency with a sample of twenty people. The respondents divided into ten respondents as construction workers and ten respondents who use ladders only for household purposes. The data needed in this study are data on specifications of bamboo ladders used by rural communities, data on the respondent's height, weight, and the angle of inclination of each body segment to the horizontal plane. In addition, interview methods and distributing questionnaires to find out the difficulties experienced by ladders users, especially construction workers were also carried out. The bamboo ladder specification data was obtained through direct measurements carried out in the field. The equipment used during the data collection process includes:

1. The ladder used is a three-meter-high bamboo ladder which is often used by construction workers during work.
2. The hammer is used by respondents to see how the ladder user's posture is when he has to carry an equipment in one hand.
3. The meter is used to measure the height of each respondent.
4. Weight scales were used to calculate the weight of each respondent.
5. Goniometer is used to measure the angle of the respondent's body when he is on the ladders.

The making of a work ladder model is based on two sources, namely based on the results of measuring ladder specifications that have been carried out in the field and based on existing ladder design standards. The standards used refer to ANSI A14.1-1990: Ladders Wood-Safety Requirements and SNI 19-1956-1990: Occupational Safety in the Manufacture and Use of Work Ladders. The use of this standard is a proposed configuration for improving the ladder case design which is often used by villagers. Some of the limitations used in the design of the ladders are:

1. The type of bamboo material used is apus bamboo with a diameter of 60 to 80 mm and the age of bamboo when it is cut is about 3-5 years
2. The diameter and thickness of the bamboo are adjusted to the type of bamboo used and the age at which it is cut
3. The shape of the bamboo which is close to round with holes in it has non-uniform dimensions, both outside diameter, wall thickness and the distance between books.
4. The conceptual design of the ladders refers to the *American National Standards Institute* (ANSI A14.1-1990): *Ladders Wood-Safety Requirements* and the Indonesian National Standard (SNI 19-1956-1990): Occupational Safety in the Manufacture and Use of Work Ladders

The standards used in the design of work ladders are declared safe and suitable for use, including [22]:

1. The distance of all steps of ladders must be given the same distance and a minimum of 22 cm or more by 27 cm.
2. The width of the banisters between one another should not be less than 27 cm or not more than 36 cm.
3. The length and width of the ladders shall not be less than the details as shown in table 2.

Table 2. Single Ladder Size [22]

Ladder length (m)	Smallest size banister
4 to 0 (the smallest)	6,50 cm x 3,50 cm
4 to 7 meters	7,20 cm x 3,50 cm
7 to 10 meters	9,50 cm x 4,50 cm

According to ANSI A14.1-1990: Ladders Wood-Safety Requirements, ladder case design requirements include [23]:

1. The single ladder as determined further consists of three types, namely type IA and type I not more than 30 ft, type II not more than 20 ft and type III not more than 14 ft.
2. The width between the side rails at the base must be at least $11 - \frac{1}{2}1$ inch for all ladders up to 10 ft long. The minimum width must be increased by at least 1/4 inch for each additional 2 feet of ladder length.
3. The minimum dimensions of single ladder side rails are not less than those specified in [23]

In making this ladder model, SolidWorks 2019 software was used. After the ladder model was created, the next step was to perform a simulation to analyze the model framework. The specifications for the improvement of the ladder case design based on the standards used include:

1. Configuration 1 with a ladder height of 4 meters, a footing length of 6.5 cm, a distance between steps of 27 cm, a ladder diameter of 80 mm, and a footing diameter of 40 mm.
2. Configuration 2 with a ladder height of 4 meters, a footing length of 4.5 cm, a distance between steps of 28 cm, a ladder diameter of 80 mm and a footing diameter of 40 mm.

After running the Solidworks simulation, the calculation results will include:

- Displacement is a movement that occurs due to the load on the ladder frame. The high and low value of the movement depends on the high and low *Force Load* applied to each part of the ladder frame.
- Von mises stress is the surface of an object that is stressed due to the application of a load on the ladder frame.
- Safety factor is a factor used to evaluate the safety of a structure.

Manual calculations are carried out by making a Free Body Diagram by describing the forces that exist in the worker's body segments when climbing ladders. From the FBD calculation, the force and moment values of each body segment will be obtained. Then, for the calculation of the angle of the ladder position using the equilibrium equation between the load force borne by the ladder and the friction force generated between the ladder and the surface.

The research was conducted by calculating the force and moment values of each body segment based on the Free Body Diagram (FBD) diagram. to get the compression value in the L5-S1 (back) bone. Free Body Diagram (FBD) is a sketch that depicts and measures the forces and moments acting on a person's body as an indicator of potential injury. The equation to calculate the forces and moments in each body segment based on the FBD sketch [24].

$$W_H = weight\ segment\ value\ for\ each\ body\ x\ W_{body} \quad (1)$$

$$W_o = m_{object}\ x\ g \quad (2)$$

$$F_{yw} = \frac{W_0}{2} + W_H \quad (3)$$

$$M_w = F_{yw} x \, SL_1 x \cos\theta \quad (4)$$

After getting the value of the force of each body segment, the value of the compression force or compression force can be calculated with the equation:

$$F_C = \left| W_{tot} \, x \cos\theta_H - F_A + F_M \right| \quad (5)$$

$$W_{tot} = W_o + 2W_H + 2W_{LA} + 2W_{UA} + W_T \quad (6)$$

$$F_M = \frac{M_{L5/S1} - (F_A \, x \, D)}{E} \quad (7)$$

$$F_A = PA \, x \, AA \quad (8)$$

$$P_A = \frac{10^{-4} \left| 43 - 0{,}36(\theta_H + \theta_T) \right| \left| M_{L5/S1} \right|^{1{,}8}}{0{,}0075} \quad (9)$$

Information:

P_A= abdominal pressure (N/m^2)
F_A= Abdominal force (N)
θ_H= angle of abdominal inclination
θ_T= angle of inclination of the thigh
AA = diaphragm area (465 cm ^{2})
F_M= muscle force on *spinal erector* (N)
spinal erector muscle moment from L5/S1 (5 cm)
D = distance from abdominal force to L5/S1 (11 cm)
F_C= compression force L5-S1 (N/m ^{2})
W_{tot}= total weight (N)
F_M= muscle force on *spinal erector* (N)

Equilibrium is a characteristic of a state where there is a balance of force and torque (moment of force) on the human body. Three conditions must be met to achieve static equilibrium conditions, namely:

$$\Sigma F_x = 0 \quad (10)$$

$$\Sigma F_y = 0 \quad (11)$$

$$\Sigma M = 0 \quad (12)$$

Safety Factor is a factor used to evaluate the safety of a structure [25]. The calculation of the safety factor is formulated as follows:

$$SF = \frac{S_y}{\sigma_e} \quad (13)$$

Information :

SF= safety factor
S_y= *Yield Strength* (N/m ^{2})
σ_e= maximum *Von Mises* voltage (N/m ^{2})

RESULTS AND DISCUSSION

Respondent profiles

The profiles of the respondents in this work simulation are:

1. Gender is male
2. Age 27-50 years ($\bar{X}$=43 $\pm$7.17 years old)
3. For respondents who work as construction workers, they have at least 3 years of experience
4. Respondents as research objects are in good physical and psychological health.
5. The average Height was X=164.5$\pm$ 5.07 cm.
6. The average body weight was X 61.45$\pm$2.11 kg.

Actual Ladder Dimension Measurement

Based on the survey conducted, the laddercase design commonly used by construction workers does not meet the design standards so that they do not pay attention to the safety of their users. Fig. 1 shows an illustration of a ladder commonly used by construction workers.

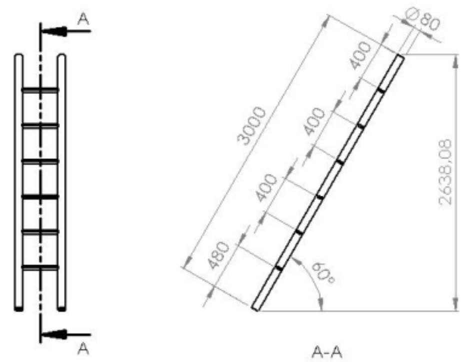

Fig. 1. Actual Bamboo Ladder Design

For the actual laddercase design, construction workers used two types of materials, namely bamboo to make the ladders and wood to make the steps for the ladders. The actual ladder specifications commonly used by construction workers are as follows :

Ladder length : 3 meters
Footing width : 2 cm
Footing length : 5 cm
Distance between steps : 40 cm
Ladder diameter : 70 mm

Configure Ladder Design Improvement Based on Standard

Repair ladders are needed to overcome the deficiencies in the actual ladder design. Fig. 2.

shows the laddercase design that follows the SNI 19-1956-1990 standard [22].

Ladder length : 4 meters
Ladder diameter : 80 mm
Footing length : 6.5 cm
Footing diameter : 40 mm
Distance between steps : 27 cm

Next, Fig. 3. shows the laddercase design that follows ANSI A14.1-1990: *Ladders Wood-Safety Requirements* [23].

Ladder length : 4 meters
Ladder diameter : 80 mm
Footing length : 4.5 cm
Footing diameter : 40 mm
Distance between steps : 28 cm

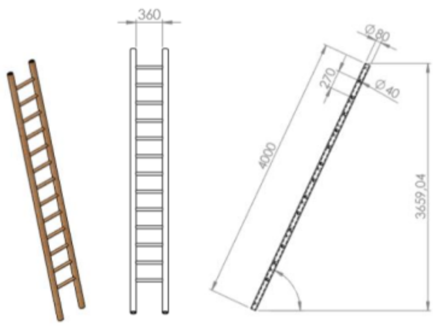

Fig. 2. Design Improvements 1

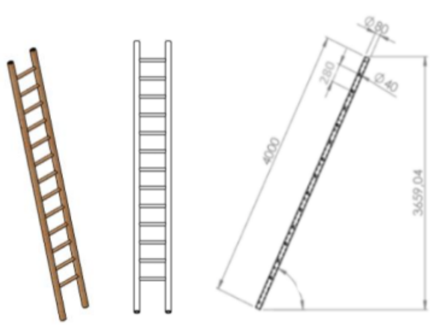

Fig. 3. Design Improvements 2

The difference in the specifications for the improvement of the ladder case design is in the length of the steps and the distance between the steps, where the length of the footing for SNI is wider than for ANSI.

Body Model

The body posture of each respondent when climbing the ladders varies. The work posture to be studied is shown in Fig. 4.

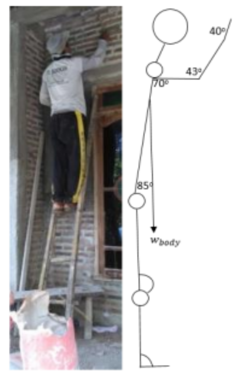

Fig. 4. Work Attitude on the Ladders

This work posture is carried out by the respondent when standing in the middle of the ladders with both feet on the same step. The respondent stands straight with his right hand raised up. The choice of footing in the middle of the ladders because this position is a position that is often used by respondents so that from this work position the angle of inclination of the body to the horizontal plane can be measured. From this working posture, a Free Body Diagram sketch is made for each body segment and the magnitude of the force and the moment of the force is calculated. [26] explains the value of the length and weight of body segments and the angle formed in each body segment (Attachment 1).

The following is a description of the calculation assuming the user's weight is 89.25 kg and height is 183 cm [28], namely:

The mass of the ladder = 2 kg

$w_o = m \, x \, g = 2 \, x \, 9{,}81 = 19{,}62 \, N$

Body mass = 89.25 kg

$w_{badan} = m \, x \, g = 89{,}25 \, x \, 9{,}81 = 875{,}5 \, N$

Free Body Diagram sketch of each body segment, including palm, forearm, upper arm, back, thigh, calf and foot [24] as seen attachment 2.

Furthermore, from the calculation of the moment of this force, the value of the compression force will then be calculated to find out whether the user is on the ladder in that position. Description of the calculation of the compression force on L5-S1:

- Abdominal inclination angle = 98.5 °
- Thigh inclination angle = 86.5 °
- The value of the moment of force at $M_{L5/S1}$ = 40.07 Nm

Then, to calculate the abdominal force (F_A) (equation (8)) it is necessary to find the abdominal pressure (P_A) with the equation (9). The value of PA is 241,5 N/m^2 and F_A = 11.23N. Next, the value of the muscle force on the *spinal erector* with the equation (7) and it is obtained F_M = 776.69N. Then, calculate the total weight with the equation (6).

$$W_{tot} = 546.65\ N$$

Furthermore, the compression force at L5/S1 can be calculated by the equation (5).

$$F_C = 868.72\ N$$

Then, calculations were made with variations in body weight and height to include the lower and average percentiles. Table 3 shows the recapitulation of calculations for the 5th percentile with a weight of 50 kg and height of 162 cm, the 50th percentile with a weight of 63 kg and height of 172 cm and the 95th percentile [27].

It can be seen that the total weight of the force increases depending on the body mass and height. The total value of this force is to calculate the value of the compression force or compressive force that occurs in L5-S1 produced by the body when climbing ladders because it is the most important part of the bone that supports body weight when doing activities such as standing. Thus, from the calculation of the compression force, it can be seen whether the respondent's weight is 89.25 kg and the body position as shown in Fig. 4. can still be held by the ladders. From the calculation results, the value of the compression force held by the ladders is 868.72N. This value is included in the safe category because it is still below the calculation of the maximum test load that can be held by bamboo, which is 970.56 N. In addition, the respondent's body posture tends to be perpendicular to the horizontal plane and forms an angle of 90° so that it produces a force that is not large enough and can still be held by the bamboo ladder.

Calculation of Ladder Position Angle

In calculating the angular position of the ladder, it is necessary to describe the force that occurs between the ladder and the surface. Figure 5 shows an illustration of the forces acting on the equilibrium ladder.

From the figure, calculations can be made with the following assumptions:

- The weight of the ladder is 19.62 N
- Weight centered on the feet is 684.11 N
- Normal force exerted by the wall (to the right)
- The normal force exerted by the surface (upwards)
- There is no friction between the ladder and the wall because the wall is assumed to be slippery so the ladder can slip easily
- There is a frictional force between the ladders and the surface with a coefficient of friction of 0.373.
- The direction of friction in the calculation is assumed to be to the left. If the result is positive, then the direction is correct. Meanwhile, if the results obtained are negative, the direction of the frictional force should be to the right.
- The axis of rotation takes the point where the ladder meets the surface because at that point there is the most unknown force value.

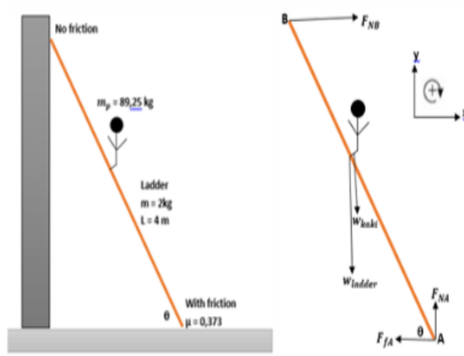

Fig. 5. Stylistic Decomposition Illustration

Table 3. Recapitulation of FBD Calculations by Percentile

Body Segment	5th percentile		50th percentile		95th percentile	
	Style (N)	Moment Style (Nm)	Style (N)	Moment Style (Nm)	Style (N)	Moment Style (Nm)
Palm	12.75	1.94	13.52	2.06	15.06	2.29
Forearm	21.09	4.76	24.03	5.37	29.94	6.48
Upper arm	34.82	7.53	41.33	8.8	54.45	11.18
Back	314.89	24.21	391.68	29.61	546.65	40.07
Thigh	363.94	12.11	453.48	14.81	634.2	20.04
Calf	385.03	12.11	480.06	14.81	671.85	20.04
Foot	391.9	109.32	488.71	143.53	684.11	211.82
Total weight value of each segment	314.89		391.68		546.65	
Compression Style	510.56		631.89		868,72	

For the axis of rotation, take the meeting point between the ladder and the surface because at that point there is the greatest unknown force value. Torque calculation assuming the user's weight is 89.25 kg is shown in Table 4.

Table 4. Force Moment Calculation

Forces	F_x	F_y	τ
Weight of the ladder	0	- 19.62 N	-39.24 Nm x sin (90° – θ)
tension	0	- 684.11 N	-1368.22 Nm x sin (90° – θ)
Normal force wall	F_{NB}	0	F_{NB}x 4 mx sin (θ)
Normal force ground	0	F_{NA}	0 Nm
Friction force ground	$-F_{fA}$	0	0 Nm

Then we can follow the equilibrium equation (10), (11) and (12) and find

$$F_{N1}.\tan\theta = 351{,}865\ N$$

To find the value of the angle (θ) ,the value F_{N1}first. Based on the sum of the forces from the x-axis component, the value of the normal force is F_{N1}equal to the value of the frictional force. So, the equation becomes:

$$F_f.\tan\theta = 351{,}865\ N$$

Static friction has a maximum value equal to $\mu.F_{N2}$, so the equation becomes:

$$F_f.\tan\theta \le \mu.F_{N2}\tan\theta$$

So, it can be calculated as:

$$351{,}865 \le \mu.F_{N2}\tan\theta$$

$$351{,}865 \le 0{,}373\ x\ 703{,}73N\ .\tan\theta$$

$$\tan\theta \ge 1.34$$

$$\theta \ge 53.26\,^{o}$$

Based on these calculation steps, the minimum value of the slope angle of the ladders is obtained so that there is no slip. Furthermore, interpolation is carried out to obtain the maximum angle of inclination of the ladders to keep it safe. By using weight based on the anthropometry of the Indonesian people, the calculation of the angle of inclination can be described as follows:

$$\frac{63-50}{89{,}25-50} = \frac{\theta - 53{,}26^o}{90^o - 53{,}26^o}$$

$$\frac{13}{39{,}25} = \frac{\theta - 53{,}26^o}{36{,}74^o}$$

$$\theta - 53{,}26^o = 12{,}17^o$$

$$\theta = 65{,}43^o$$

So, the calculation of the angle of the ladder position using the equilibrium equation shows that assuming the weight of the ladder user is 89.25 kg and the height is 183 cm, the slope angle of the ladder is between 53.26° to 65.43°. This calculation considers the user's body weight by assuming the coefficient of friction between the ladders and the surface is 0.373 [28]. The selection of body weight is based on the anthropometry of the Indonesian people with the 95th percentile which is 89.25 kg and height 183 cm because the highest body weight and height of respondents in Kedalingan village is still below the anthropometric value of the Indonesian people so it is expected that the results of this angle calculation can be applied.

Based on these calculations, in order to prevent falling ladder when in used, the ladder must be positioned with a minimum slope of 53.26°. However, to get a maximum of the most optimal angle is conducted by interpolation calculations. By assuming that the maximum angle of inclination of the ladder until it falls is 90°, it get the safest angle of inclination in positioning the ladder with the respondent 's body mass of 89.25 kg is 65.43°.

Previously, there was research on the angle of the ladder position with the extension ladder ladder type [5] using four methods, one of which was the anthropometric method. Based on this method, the value of the angle of the ladder position is generated with an interval of 64.6° – 79.2°. These results were obtained with a 95% confidence level. The results of this study are considering the user's weight are considered valid because they fall within the range of the angle of the ladder position and the calculation results are both based on the anthropometry of the user.

Calculation of Maximum Strength of Bamboo

The selected bamboo apus is 80 mm in diameter with a thickness of 20 mm and has a compressive stress value of 60.66 kg/cm ^{2} [4]. From this value it can be calculated the maximum test load that can be held by bamboo, namely:

$$\sigma_{tk} = \frac{P_{maks}}{b\ x\ h}$$

$$P_{maks} = \sigma_{tk}\ x\ b\ x\ h$$

$$P_{maks} = 60{,}66\ x\ 2\ x\ 8$$

$$P_{maks} = 970{,}56\ N$$

$$m = \frac{P_{maks}}{9{,}81}$$

$$m = \frac{970{,}56}{9{,}81}$$

$$m = 98{,}93\ kg$$

So, the value of the load that the apus bamboo material can withstand is 970.56 N or 98.93 kg. Thus, the value of the compression force generated is 868.72 Newton is still safe to be held by the ladders with the posture as shown in Figure 4. Compressive strength is the ability of objects to withstand external forces that are given in parallel directions which tend to shorten or compress parts of objects together [29]. The compressive strength for apus bamboo material can be calculated by providing a distributed test load on the bamboo truss structure. The force is accepted by the cross-sectional area of the cylindrical test object, so that stress will occur. From the results of calculations, the bamboo apus used is able to withstand a maximum test load of 970.56 N or when converted in mass it becomes 98.93 kg.

Previously there was research on the analysis of the effect of the arrangement and size of the blades on bamboo apus [30]. In this study, it was shown that the average maximum load on bamboo was 14,123.30 N which could be converted to 1439.68 kg. There is a significant difference because the apus bamboo used by the researcher is bamboo without prior preservation, while the apus bamboo used in the study by Manik, et al [30] is a laminated apus bamboo, namely bamboo that has been laminated with adhesive using *Polyvinyl Acetate (PVAc)* and it has higher strength.

Static Loading Simulation Results Using SolidWorks 2019

Strength analysis is done by calculating the stress based on static simulation. Materials used is apus bamboo. In the solidworks simulation, material properties regarding apus bamboo are not yet available, so it is necessary to input data regarding mechanical properties of apus bamboo including elastic modulus, poison's ratio, shear modulus, mass density, tensile strength, compressive strength, and yield strength [31]. The external loading inputted in the simulation is on all steps of the ladder. The load given on the steps of the ladders is 89.25 kg or 875.5 Newtons where the force exerted is directed downwards and the gravitational force is 9.81 m/s^2. The mesh process uses a size of 9 mm with many elements of 286,378 elements.

Static loading simulations were carried out using the SolidWorks 2019 software. Loading was carried out using the 95th percentile approach using a body weight of 89.25 kg. To get the unit of force, the value of the weight is multiplied by the acceleration due to gravity of the earth of 9.81

m/s^2, so that each loading point is assumed to receive a force of 875.5 Newtons and the angle of the ladder position is 65^o. From the simulation results, three outputs are obtained, namely *von Mises stress* and *displacement*. In the failure criteria, there are three types of theories that are often used, namely the theory of maximum normal stress, the theory of maximum shear stress and the theory of von Mises stress. Of the three types of theory, it was shown that the von Mises theory predicted failure with the highest accuracy. In addition, for design analysis it is recommended to use this theory because it is easier than the others.

The highest stress value is 5.097 x 10^6 N/m^2 while the lowest stress value is 1.721 x 10^2 N/m^2 and the yield strength value is 3.206 x 10^7 N/m ^{2} as shown in Fig. 6.

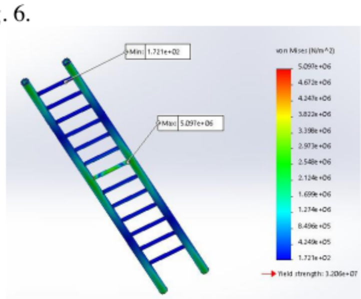

Fig. 6. *Von Mises* voltage results

Maximum stress indicates that at that position, the ladder experiences maximum strain or experiences the greatest or greater thinning or thickness reduction. The possibility of fracture usually starts from the area experiencing the maximum stress. From the simulation results show that the value of the resulting von Mises stress is still below the yield strength value of apus bamboo material. This means that with the loading position in the middle of the ladder and the ladder footing holding the given load, the ladder structure will only experience elastic deformation where the shape of the ladder will return to its original shape when the load is released and the structure is still able to withstand the given load.

Displacement value to see which frame works best to support the weight of the load as shown in Fig. 7.

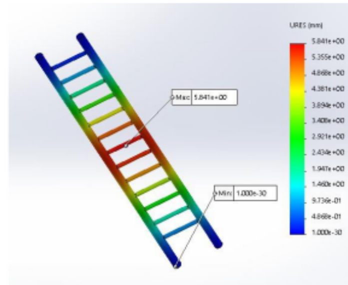

Fig. 7. *Displacement* Results

The maximum *displacement value* is 5.841 mm. From the simulation results, it is known that the ladder structure is able to support the given load.

The bamboo used to make the ladders in this study is bamboo with the name *Gigantochloa apus* or commonly known as bamboo apus with a cutting age of 3-5 years. This bamboo is taken from Kedalingan village, Tambakromo sub-district, Pati district, Central Java in fresh condition and without any preservative or other chemical process. The selected apus bamboo is 80 mm in diameter with a thickness of 20 mm and has a compressive stress value of 60.66 kg/cm^2 [4]. So, from this value it can be calculated the maximum test load that bamboo can withstand, namely:

$$\sigma_{tk} = \frac{P_{maks}}{b\ x\ h}$$
$$P_{maks} = \sigma_{tk}\ x\ b\ x\ h$$
$$P_{maks} = 60{,}66\ x\ 2\ x\ 8$$
$$P_{maks} = 970{,}56\ N$$
$$m = \frac{P_{maks}}{9{,}81}$$
$$m = \frac{970{,}56}{9{,}81}$$
$$m = 98{,}93\ kg$$

From the yield stress of the bamboo material and the maximum von Mises stress, the safety factor values can be calculated by equation (13). The safety factor value for the apus bamboo ladder structure is 6.28. The safety factor value parameter for this type of static load is at least 2.0 [32]. The result of the safety factor value of 6.28 indicates that the apus bamboo ladder structure is safe to use because it falls within the recommended minimum parameter value range.

CONCLUSION

From the results of data processing and analysis, it is obtained the greater the weight of the ladder user, the greater the compression force held by the ladder. Based on the body posture of workers with a body weight of 89.25kg and a height of 183 cm, the compression force value is 868.72 N. This value is still far below the maximum test load that can be held by bamboo apus of 970.56 Newton. The results of the calculation of the compression force can change depending on how the worker's body posture and the inclination angle of each body segment. The calculation of the angle of the ladder position using the equilibrium equation shows that the optimal slope angle of the ladder is between 53.26^o to 65.43^o. The optimal angle of the ladder can change depending on the interval of the user's weight value used and the assumption of the coefficient of friction between the ladder and the surface. Based on the results of the static loading simulation carried out using the SolidWorks 2019 software, it can be seen that the critical point when loading the ladder is at the step of the ladder because it withstands the greatest force, but there is no red color on the ladder so the ladder is considered to be able to withstand the given load of 875.5 N. In addition, the resulting stress value is still below the yield stress of the bamboo material.

Future research can focus on dynamic loading, overall loading in bamboo ladders and material or mechanical properties of other materials that may give better results.

Design of Bamboo Ladder as Traditional Construction Equipment based on Static Loading Analysis

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