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PLANNING AND TESTING OF A BALSA WOOD TRUSS BRIDGE USING THE VARIABLE OF TRUSS WEIGHT AGAINST MAXIMUM LOAD WEIGHT

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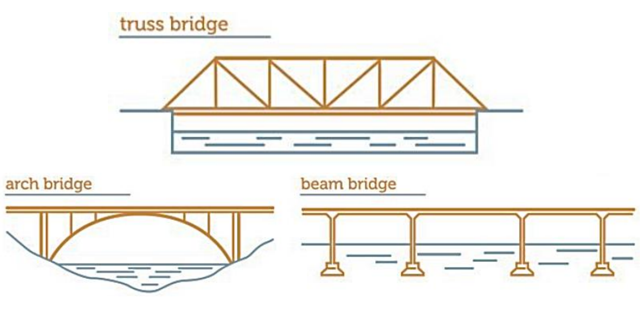
ABSTRACT

The use of lightweight materials like balsa wood in prototype bridge construction has become a fascinating topic in civil engineering, especially in laboratory-scale experimental studies. This research aims to evaluate the structural performance of a prototype balsa wood truss bridge under concentrated loading. The bridge is designed with a symmetrical truss system and a main joint at the central connection, which acts as the center for force distribution. The design process was conducted using a numerical approach through structural software to analyze the axial force and bending moment under various load scenarios, namely 10 kg, 20 kg, and 30 kg. The analysis results show that the compressive and tensile axial forces, as well as the bending moments that occur, are still within safe limits based on the specifications of balsa wood's modulus of elasticity and strength. Additionally, experimental testing was also carried out on this balsa bridge prototype. Structurally, this bridge has a total weight of 25,91 grams. The test results show that the bridge can withstand a load of 30.90 kg. When compared to the weight of its structure, the bridge demonstrates good material efficiency as it can support 1,161.327 times its own weight.

Keywords: balsa wood, lightweight material, load**,** truss bridge.

Introduction

A bridge is a transportation facility that plays a very important role in human life. [1] A truss bridge is a type of structure made of interconnected members forming a triangular pattern, which provides high stability and the ability to distribute loads efficiently. The construction materials can vary, such as wood or metal. A truss structure is composed of components arranged into triangular units — the most stable geometric shape known in construction. [2]



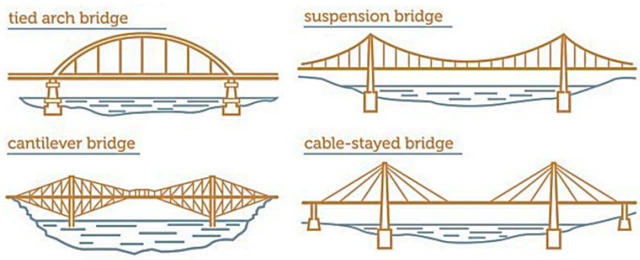


Figure 1. Kinds of bridge truss shapes

A Wood structure is a type of structure whose components are made of wood materials. As construction technology develops, wood is increasingly used as an alternative option in various civil engineering projects. Its uses include roof trusses, bridge frames and girders, scaffolding structures, and building elements such as columns and floor beams.[3] Wood has the advantage of being a renewable material. So far, it has been more commonly used in industries such as plywood and furniture manufacturing, while its application in bridge construction remains relatively limited.[4] The use of wood as the main material for bridges has been around for a long time because wood is known as a suitable material for connecting areas separated by rivers or ravines. Although many bridges now use materials such as steel and concrete, wooden bridges still have their place in civil engineering. However, the use of wood also has its own challenges.[5]

The quality of wood as a construction material is crucial in ensuring the strength and durability of bridge structures. A lack of quality control can lead to various problems, such as structural damage or a reduction in the material's service life.[6] In general, the wood used must be in good condition, provided that its characteristics and any defects do not damage or reduce the quality and strength of the building's construction.[7] Nonetheless, wood continues to offer a number of advantages, such as ease of cutting and processing, as well as its environmentally friendly properties, making it a promising alternative for future bridge construction.[8]

Figure 2. Balsa wood

Balsa wood has unique characteristics that set it apart from other types of wood, namely its very lightweight. It also has good flexibility and a high strength-to-weight ratio, making it a very valuable material for various purposes such as making miniature bridges, carved crafts, surfboards, model airplanes, and other creative applications.[9] Balsa (Ochroma pyramidale) is a type of wood known for its low density. The elastic properties of balsa wood are very important when it is used as a core material.[10] Balsa is a type of natural wood used in composite materials and is also considered an environmentally friendly material. It is known as one of the lightest commercial woods, with a low density (60–380 kg/m³) and good mechanical properties and performance.[11] Moreover, one of the important things that must be considered in a wooden structure is its joints. The joints must be calculated in such a way that the safety of the wooden structure is guaranteed.[12]

Method

The steps of this research are shown in the following image. This research began with the design of a truss bridge model using balsa wood with a cross-section of 3 mm × 3 mm and a rod length of 1000 mm.

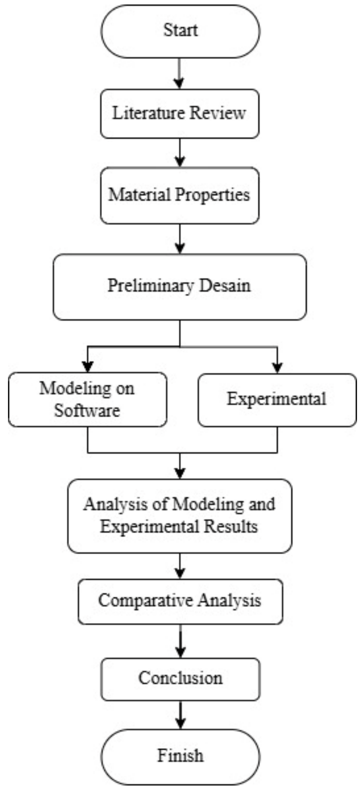


Figure 3. Flowchart

The bridge has a span of 320 mm, a height of 100 mm, and a width of 68 mm. The following are the specifications of the balsa wood as the primary material for the bridge:

Table 1. Specifications of balsa wood

Details	Spesifications
Name	Balsa
Tree size	*Ochrama Pyramidale*
Dry wight	150 kg/m3
Spesific gravity	0,12 ; 0,15
Tensile splitting strength	19,6 Mpa
Elasticity	3,71 Mpa
Compressive strength	11,6 Mpa

Using the Indonesian Forest team's balsa wood identification as a reference, the minimum air-dry density of 150 kg/m^3 is used. Density is defined as weight per volume divided by the weight of an equal volume of water.[13] Therefore, its modulus of elasticity (E) can be calculated using the following equation:

$$E = 16000 \text{ x } G^{0.17} \tag{1}$$

Where:
E = Modulus of Elasticity (Mpa)
G = Specific Garvity (t/m^3)

Based on the equation above, the flexural modulus of elasticity (E) can be calculated as follows:
E = 16000 x 0.15 $^{0.17}$
E = 4160.49 Mpa

The material specifications used for structural analysis modeling are as follows:

Material	: Balsa wood
Dimension	: 3 mm x 3 mm x 1000 mm
G	: 150 kg/m^3
E	: 4160,49 Mpa

The modulus of elasticity (E) for balsa wood is 4160.49 MPa. The reference modulus of elasticity for stability (E_{min}) can be determined using the equation from SNI 7973:2013, C4.2.4-1 [14], as follows:

$$E_{min} = \frac{E.[\,1-1{,}645\,.COV_E].(1{,}03)}{1{,}66} \quad (2)$$

Where:
E = Modulus of Elasticity
1,03 = Correction factor to correct the value of E
1,66 = Safety factor
COV = Variation coefficient of E

We can see the coefficient of variation for the modulus of elasticity (COV_E) in SNI 7973:2013 [14] as follows:

Table 2. Coefficient of variation (COV_E)

Variation	COV_E
Visually graded sawn timber	0,25
Mechanically evaluated wood	0,15
Mechanically stress-graded timber	0,11
Structural glued laminated timber	0,1

The value of the modulus of elasticity (Emin) can be calculated from equation 2.

$$E_{min} = \frac{E.[\,1-1{,}645\,.COV_E].(1{,}03)}{1{,}66} \quad (1)$$

$$E_{min} = \frac{4160{,}49.[\,1-1{,}645\,.0{,}25].(1{,}03)}{1{,}66} \quad (2)$$

E_{min} = 1519,86 MPa (3)

The balsa wood used has a modulus of elasticity for stability (E_{min}) of 1519.86 MPa.

Figure 3. Bridge illustration

This bridge truss design was inspired by an open book, where each page resembles the truss structure of a bridge. The book's structure has sharp angles and clean lines, providing a strong visual representation of how elements can connect to form a harmonious whole.

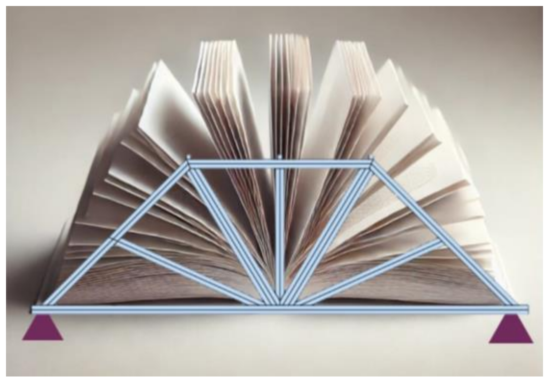


Figure 4. Truss bridge design

Each open page is like a bridge truss, connecting the ideas, knowledge, and creativity into one complete whole. Here are the basic data points for planning a balsa bridge structure.

Type of brige: Truss

Width of the bridge	: 68 mm
Bridge span	: 320 mm
Truss height	: 100 mm
Support	: Pin - pin
Material	: Balsa wood 3 x 3 x 1000 (mm)
Connection	: Glue

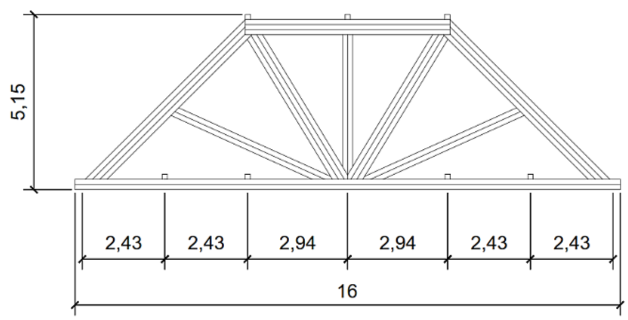


Figure 5. Side view of the truss bridge

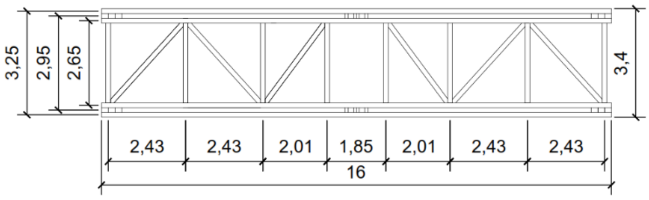


Figure 6. Bottom view of the truss bridge

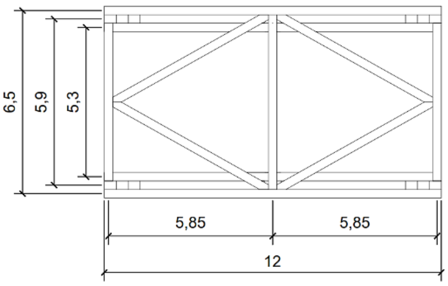


Figure 7. Top Side view of the truss bridge

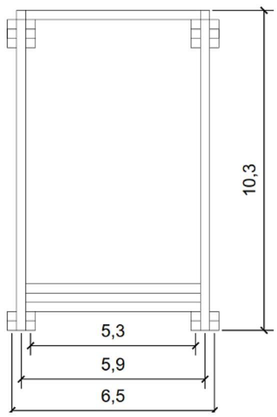


Figure 8 Front view of the truss bridge

The entire truss of this bridge is centered on a main joint in the middle. This innovation makes the bridge more sturdy and stable because the forces from each member are distributed evenly to a single central point. This central joint not only functions as a truss binder but also as a load distribution center, allowing the bridge to withstand larger loads with maximum efficiency.

Results

Modeling

This bridge structure modeling uses structural analysis software. The modeling aims to model the planned structure and loads, with the output being axial forces and moments used to design the dimensions of the trusses.[15]

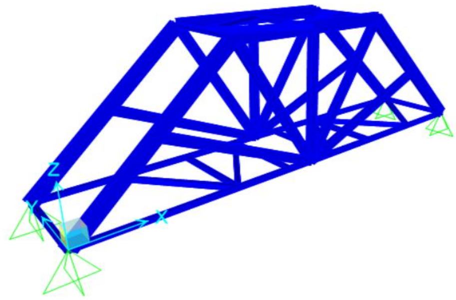


Figure 9. 3D bridge design using structural software

The planning of three load trials (10, 20, and 30 kg) were conducted as follows:

Load 10 kg: Here is a discussion of the internal forces that occur due to a 10 kg load.

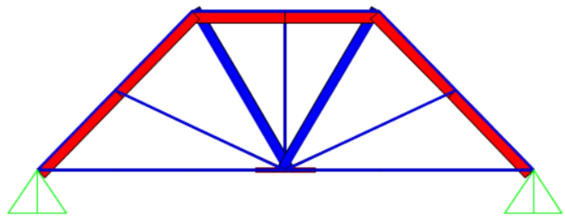
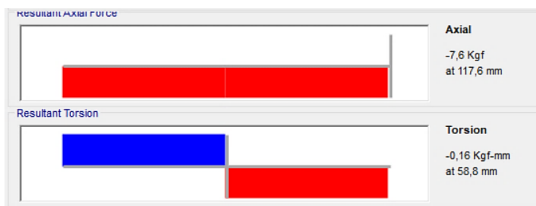
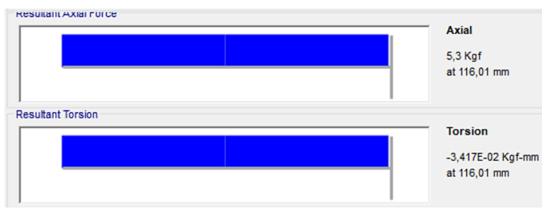


Figure 10. Normal force (axial) diagram due to load 10 kg

The beam with a maximum axial force due to a 10 kg load, along with details, is shown in Fig. 11 below.



(a)



(b)

Figure 11. (a) Compression (b) Tension due to load 10 kg

Based on Fig. 11, the results show a maximum compressive axial force of -7.6 Kgf at a position of 117.6 mm and a maximum tensile axial force of 5.3 Kgf at a position of 116.01 mm. This indicates a small but significant compressive force on the axial axis, where the structure is experiencing a compressive force that needs to be considered for further calculations.

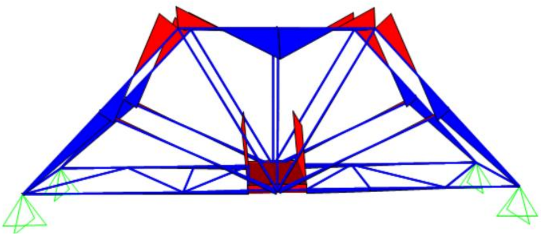


Figure 12. Moment diagram due to load 10 kg

Beam with maximum moment due to a 10 kg load with details is shown in Fig. 13 below.

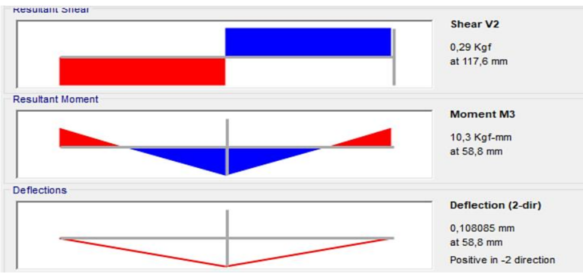


Figure 13. Maximum moment due to load 10 kg

Based on Fig. 13, the structure experiences a maximum bending moment of 10.3 Kgf-mm at the 58.8 mm position. Overall, the structure is able to withstand these forces well and remains within safe limits for balsa wood.

Load 20 kg: Here is a discussion of the internal forces that occur due to a 20 kg load.

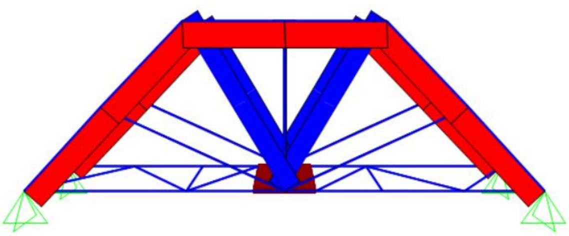
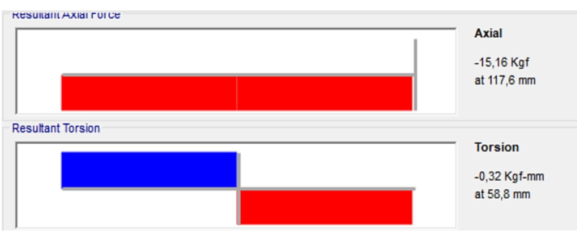
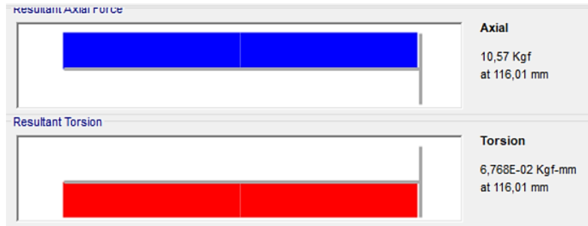


Figure 14. Normal force (axial) diagram due to load 20 kg

Beam with maximum axial force due to a 20 kg load with details is shown in Fig. 10 below.



(a)



(b)

Figure 14. (a) Compresion (b) Tension due to load 20 kg

Based on Fig. 14, the results show a maximum compressive axial force of -15.16 Kgf at a position of 117.6 mm and a maximum tensile axial force of 10.57 Kgf at a position of 116.01 mm. This indicates a small but significant compressive force on the axial axis, where the structure is experiencing a compressive force that needs to be considered for further calculations.

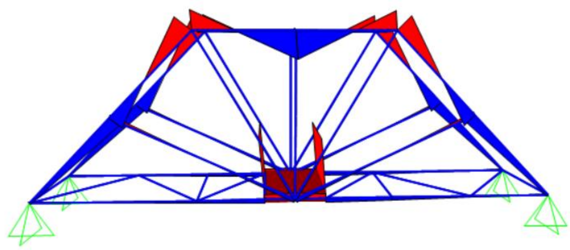


Figure 15. Moment diagram due to load 20 kg

Beam with maximum moment due to a 20 kg load with details is shown in fig. 16 below.

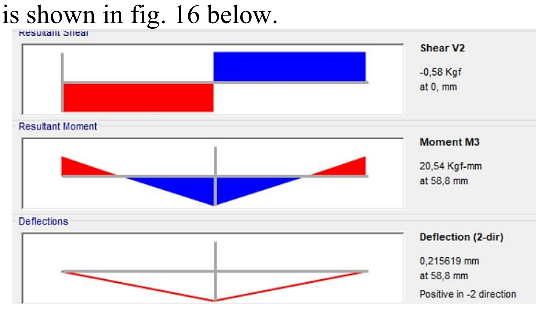


Figure 16. Maximum moment due to load 10 kg

Based on fig. 16, the structure experiences a maximum bending moment of 20.54 Kgf-mm at the 58.8 mm position. Overall, the structure is able to withstand these forces well and remains within safe limits for balsa wood.

Load 30 kg: Here is a discussion of the internal forces that occur due to a 30 kg load.

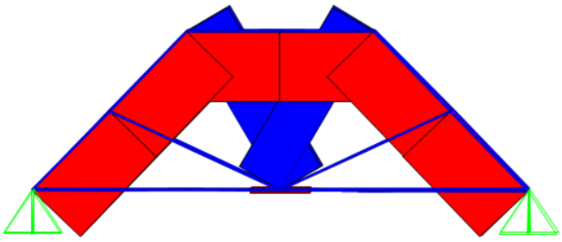
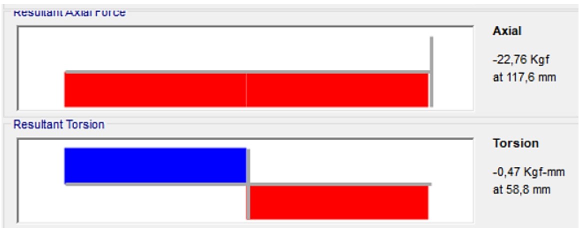
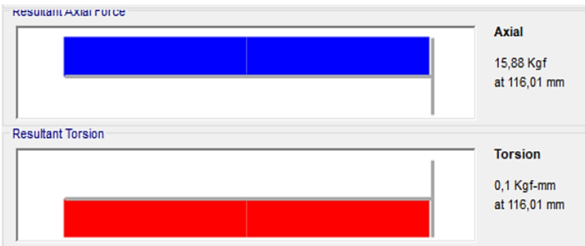


Figure 17. Normal force (axial) diagram due to load 30 kg

Beam with maximum axial force due to a 30 kg load with details is shown in Fig. 18 below.



(a)



(b)

Figure 18. (a) Compresion (b) Tension Due to Load 30 Kg

Based on Fig. 18, the results show a maximum compressive axial force of -22.76 Kgf at a position of 117.6 mm and a maximum tensile axial force of 15.88 Kgf at a position of 116.01 mm. This indicates a small but significant compressive force on the axial axis, where the structure is experiencing a compressive force that needs to be considered for further calculations.

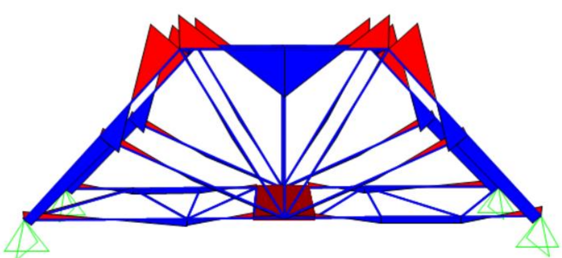


Figure 19. Moment diagram due to load 30 kg

Beam with maximum moment due to a 30 kg load with details is shown in Fig. 20 below.

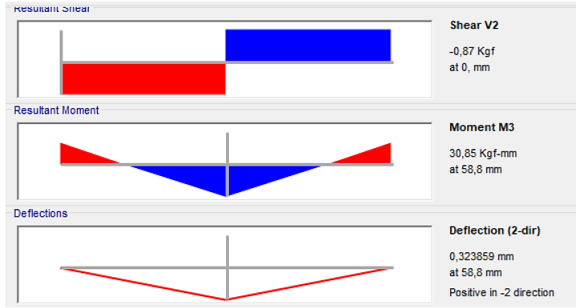


Figure 20. Maximum Moment Due to Load 10 Kg

Based on Fig. 20, the structure experiences a maximum bending moment of 30.85 Kgf-mm at the 58.8 mm position. Overall, the structure is able to withstand these forces well and remains within safe limits for balsa wood.

Experimental

Constructing a balsa wood bridge is not an easy task. It is quite time-consuming and requires a complex process, thus it demands meticulous planning, careful execution, and periodic evaluation. The stages begin with assembly, checking the frame's specifications and weight, and end with testing.

Figure 21. Prototype of the bridge

The bridge's weight was measured, which will be used as a parameter for the strength-to-maximum load ratio it can bear.

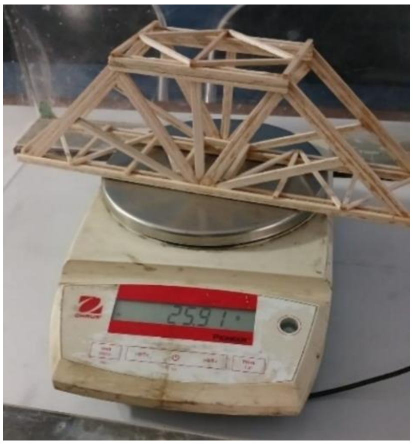


Figure 22. Weight of the bridge

Based on Fig. 22, the bridge's weight was 25.91 gr. The bridge's dimensions were then checked by measuring it with a ruler, and the bridge could be passed through by a wooden block measuring 80 mm x 40 mm with a length of 300 mm.

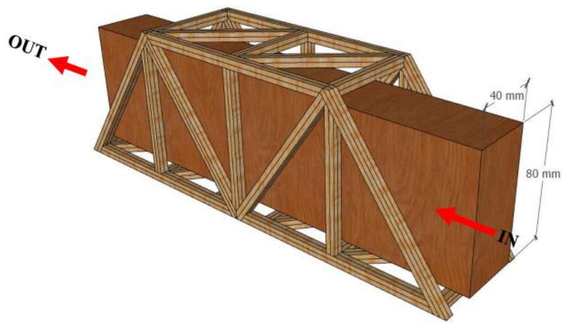


Figure 23. Bridge dimension checking

Based on Fig. 23, the bridge dimensions obtained are a span of 320 mm, a height of 100 mm, and a width of 68 mm, which meet the specifications. After this, a load test can be performed on the bridge.

The Load Testing stage is conducted to determine the maximum load capacity of the bridge. This process is carried out by suddenly attaching a hooking mechanism, consisting of a plate and a bucket (initial weight of ±1 kg). Subsequently, the load is added gradually (500 grams per measure) into the bucket every 5 seconds. The test ends when the bridge collapses.

Figure 24. Load testing phase

Based on Fig. 24, the bridge was able to withstand a load of 30.09 kg. This shows a trend that's similar to/consistent with the modeling analysis plan

Discussion

Comparison of modeling results

Modeling has been completed, followed by a comparative analysis of the results (model with a load of 10, 20, 30 kg). The purpose of the comparison is to determine the differences in the values of axial force and moment across three (3) modeling variations. The results of this comparative analysis are shown in the graph and table figures, including Table 3, Fig. 25, and Fig.26.

Table 3. Test output of bridge load testing using software.

No.	*Output*	Load (Kg)		
		10	20	30
1.	Max. Compression Force (Kgf)	-7.6	-15.16	-22.76
2.	Max. Tension Force (Kgf)	5.3	10.57	15.88
3.	Max. Moment (Kgf.mm)	10.3	20.54	30.85

Here is the graph based on the data in Table 3.

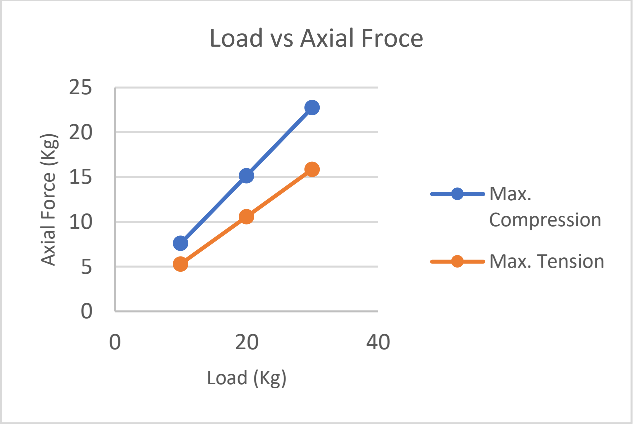


Figure 25. Comparison graph of load vs axial force

Based on Fig. 20, it can be seen that the axial force, both compressive and tensile, increases with the increasing load. This indicates a correlation between the axial force value and the load carried.

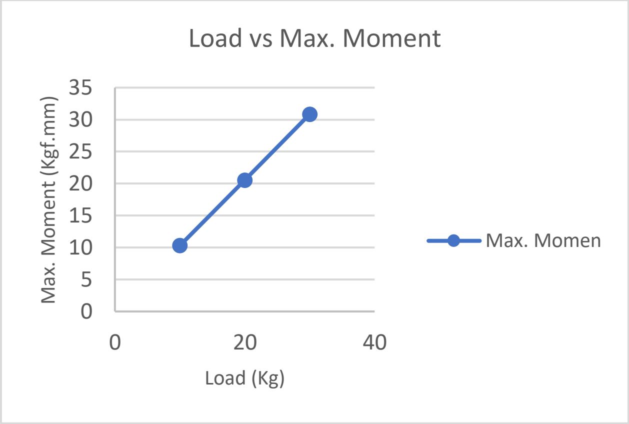


Figure 26. Comparison graph of load vs moment

Based on Fig. 21, it can be seen that the moment value increases with the increase in the applied load. This indicates a good correlation between the moment value and the load being carried.

Analysis of Experimental Result

Based on the results of the experimental test, the maximum weight that can be supported is 30.09 kg. This is in accordance with the design that was modeled in the structural software. Furthermore, from this test, the effectiveness value of the bridge truss can be calculated.

$$Effectiveness = \frac{Max.Load}{Bridge\ Weight} \tag{4}$$

$$Effectiveness = \frac{30090\ gram}{25.91\ gram} = 1161.327 \tag{5}$$

Based on the efficiency value calculation, it can be interpreted that the bridge is able to withstand 1161.327 times its own weight.

Conclusion

Based on research regarding bridge planning with balsa wood material, several important points about bridge planning were concluded. Among them is an innovative design where the entire framework of the bridge is centered on one main joint in the middle. This innovation makes the bridge more stable, as the forces from each frame are distributed evenly toward a single central point. This central joint not only serves to connect the frames but also acts as the main load distributor, allowing the bridge to withstand greater loads with maximum efficiency.

Based on the modeling of the three types of loads, it can be concluded that the greater the load carried, the greater the external forces that occur, both axial and moment. This means that the bridge truss will also experience greater deformation. Experimentally, the balsa bridge could withstand a load of 30.90 kg before it eventually collapsed.

If viewed from its efficiency value, it can be interpreted that the bridge is able to withstand 1161.327 times its own weight.

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