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Structural Analysis of Bamboo Trusses Structure in Greenhouse

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Abstract— **The objective of this paper is to analyze the shape and cross-section of bamboo structure for a single greenhouse in Thailand. The green house is designed to open on the roof for ventilation, and under geometrical constrains for minimize deflection. We calculate the cross-section, self weight and displacement values of bamboo structure to determine the truss shape design problem in the greenhouse. The truss shape has designed in eight different types: Double Howe, Modified Fan, Modified Queen, Pratt, Fan, Double W, M shape and W shape. The displacement value in each truss shape is determined by using standard load (Dead Load, Live Load, and Wind Load) to calculate axial force in each truss shape member. The results of eight type displacement values show that the minimum displacement is Modified Fan truss shape and the minimum weight of the trusses structure in greenhouse is Double Howe truss shape.**

Keywords-optimum, bamboo, truss structure

I. INTRODUCTION

A greenhouse is a structure providing the suitable place for protecting plants from changing in weather, seasonal, environmental, pollutions, and etc. It can be build with different types of covering materials, like glass, plastic roof, frequently glass or plastic walls. Inside green house, the temperature is relatively high because plants, soil, and other things inside the greenhouse absorbed the incoming visible solar radiation.

Greenhouses can be separated to two kinds: glass greenhouse and plastic greenhouse. Since 1960s, polyethylene film had been widely used to construct the greenhouse. After that [1] the aluminum extrusions, special galvanized steel tubing, and PVC water pipe were developed and used to reduce the construction cost.

Regarding to the high construction cost of normally greenhouse using steel structure, the greenhouse in small farms and private gardens cannot be obtained. Thus, bamboo is introduced as the low cost material for constructing greenhouse. Bamboo is a useful material that is simpler and cost lower in greenhouse construction than steel. We also found that bamboo has a high capability to compose share tension rather than capability on compression.

Several publication studies on bamboo and bamboo building. [2] In tropical countries, bamboo is use as a material for fundamental structure in house construction. It also use as a bamboo sheets for structural element in prefabricated construction [3]. Bamboo is confirmed that it has an economical advantage as it reaches maximum yield in a few months and as it has a high mechanical resistance in few years [4].

Bamboo also determined as a composite material consisting of long and parallel cellulose fibers embedded in a ligneous matrix. The more thickness of bamboo gives the more density of the fibers in the cross-section. Bamboo has been used for many purposes for a long time. Due to it is a fast growing plant and versatile usage, bamboo is one of materials that we consider to use for building and framing. Using bamboo to replace steel and wood framing in the construction of the greenhouses, has many advantages such as, reduce a high cost of imported material, reduce the impact on the natural environment, easily work with simple tools, easy to build and readily to repair in the event of damage.

Regarding bamboo is a natural plant that has variety in trunk, using bamboo has some limitation. We cannot standardize bamboo as a unique material like steel. The shape and cross-section of each bamboo trunk are required to categorize the bamboo for using in greenhouse. The users can easily select the correct bamboo shape and cross-section to the right framing. Thus, the objective of this study is to analyze the shape and cross-section of bamboo structure for a single greenhouse by evaluating the weight and the displacement values to define the best suitable bamboo trunk for each structure.

II. METHODOLOGY

A. Criterias for Basic Characteristics of Bamboo

In this analysis, we used physical and mechanical properties of wood from sweet bamboo culms (Dendrocalamus asper Backer) in Thailand as follow [5];

- The ages of bamboo for this study are 3 years old.
- The moisture content in bamboo is less than 15% by weight.

- Modulus of rupture is 135 MPa
- Modulus of elastic is 13,115 MPa
- Toughness is 676 kPa
- Tensile strength parallel with grain is 314 MPa
- Compressive strength parallel with grain is 72 MPa
- Shear strength is 14 MPa
- Bending strength is 1,399 kg/cm^2

B. Bamboo truss design parameters

We are many parameters for analysis of bamboo truss need to be considered.

Firstly, the shape of single span greenhouse (Fig. 1) has been selected for the study. The dimension of greenhouse model, length, width, and height are 8.0 m, 6.0 m, and 3.0 m respectively. The cover material is clear polyvinyl chloride (PVC), which thickness 1 mm.

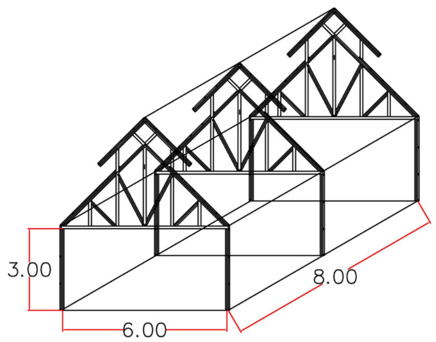


Figure 1 Geometrical of bamboo greenhouse.

Secondary, the type of truss is a triangle that has slope of truss is 45 degree and the number of intermediate members (diagonals and verticals) that show in Fig. 2.

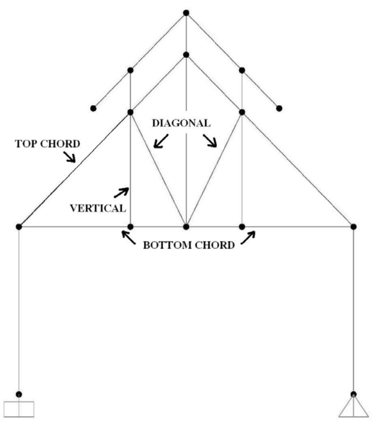
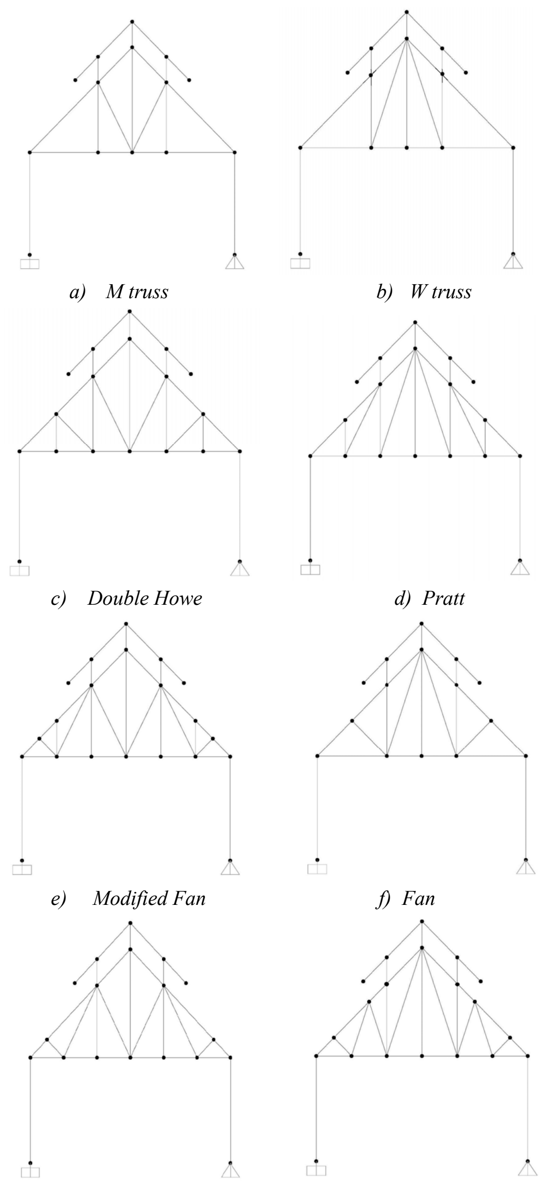


Figure 2 shown the intermediate members (diagonal and vertical), top chord and bottom chord

For this study, we select the types of truss from the truss structure analysis by considered the load or force in member of diagonal and vertical members so we can separate in to 2 groups; M shape (Fig. 3a) and W shape (Fig. 3b). After that, we select 6 types of truss for more analysis by separate in to 2 groups; in M shape are shown in Fig. 3c, 3e and 3g and W shape shown in Fig. 3d, 3f and 3h.



a) M truss *b) W truss*

c) Double Howe *d) Pratt*

e) Modified Fan *f) Fan*

g) Modified Queen *h) Double W*

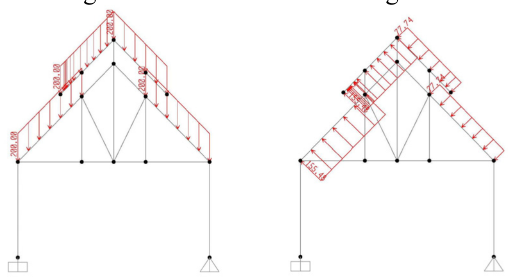
Figure 3 A plane trusses with six difference types

The third parameters that consider are the combination load form the constant uniform load (dead load, live load and wind load).

- The dead load is self-weight of the truss members and purlin equal to 140 kg/m (Fig. 4a).
- The live load is standard in Thailand construction such as load from water pipe, load

form user, light, pump and others equal to 200 kg/m (Fig. 4a).

- The wind loads calculate from the Thai standard wind-building [12] that not unbalance like dead load and lived load (Fig. 4b). The value of wind load in the pressure side is 78 kg/m and suction side is 156 kg/m.



a) *Dead Load and Live Load* b) *Wind Load*

Figure 4 Example of uniform load

Next, parameters are joint connections. The creating connections with round profiles are leading to difficult. So in this case study, we considered only the drilling connection.

C. Steps of structural analysis

The first step of analyses the bamboo truss structure were check the tensile or compress load in 4 main members (top chord, bottom chord, diagonal and vertical member). After that, we check the limited of tension and compression forces by considered strength that under allowable stress [6] by assume the cross-section area of bamboo. And after check all of step we can get the suitable cross-section area from the bamboo truss structure.

In case of tension was considered the axial force in member by following expression:

$$f_t = \frac{P}{A_n} \leq F_t \qquad (1)$$

where f_t is the design tensile strength parallel the grain (ksc), P is the axial force in member (kg), A_n is the net cross-section area (cm^2) that calculate from $A_g - \sum A_h$ where A_g is gross cross-section area at tension force (cm^2), $\sum A_h$ is sum of projected area of hole area at critical section (cm^2) and F_t is reference tension design value parallel to grain (ksc).

Next step of tension member, we check the bending and tension. So the equation that checking and designing for member that supported the bending and tension as:[7]

$$\frac{f_t}{F_t} + \frac{f_{bx}}{F_{bx}} + \frac{f_{by}}{F_{by}} \leq 1.0 \qquad (2)$$

where f_t, f_{bx}, f_{by} are actual tension and bending stress (ksc) in x-axis and y-axis, F_{bx}, F_{by} are references bending design value (ksc) in x-axis and y-axis.

The compressed members are checked for compressive strength as well as for buckling criteria:

$$f_c = \frac{P}{A} \leq F_c \qquad (3)$$

where f_c actual compressive stress parallel to grain (ksc), P is axial compressive force in member (kg), A is cross-section area (cm^2) and F_c is reference compressive design value parallel to grain (kg).

In addition to being a compression member, a column or compression member is sufficiently long that the possibility of bucking needs to be considered that for checking in three terms; short, medium or long column uses the formula: Fourth Power Parabolic Formula

Short $$\frac{L_e}{d} \leq 11 \;;\; F_a = F_c \qquad (4)$$

Medium $$11 \leq \frac{L_e}{d} \leq K \;;\; F_a = F_c\left[1 - \frac{1}{3}\left(\frac{L_e/d}{K}\right)^4\right] \qquad (5)$$

Long $$K \leq \frac{L_e}{d} \leq 50 \;;\; F_a = \frac{0.3E}{\left(L_e/d\right)^2} \qquad (6)$$

where $K = 0.671\sqrt{E/F_c}$, L_e is effective unbraced length of column (cm), d is cross-section dimension of rectangular column associated with axis of column bucking (cm) so L_e/d is slenderness ratio of column and E is modulus of elasticity (ksc).

Next step of compression member, we check the bending and compression. So the equation that checking and designing for member that supported the bending and compression as:

$$\frac{f_a}{F_a} + \frac{1}{1 - J_x \frac{f_a}{F_{bx}}}\frac{f_{bx}}{F_{bx}} + \frac{1}{1 - J_y \frac{f_a}{F_{by}}}\frac{f_{by}}{F_{by}} \leq 1.0 \qquad (7)$$

where f_a, f_b are actual compressive and bending stress (ksc), F_a is adjust compressive design (ksc), F_{bx}, F_{by} are references bending design value (ksc) in x-axis and y-axis and J_x, J_y is adjust of slenderness ration equal to zero when short column and long column is 1.0. And the last check is deflection in truss as follow:

$$\Delta = \frac{5}{384}\frac{wL}{EI} \quad (8)$$

where w is uniform load (kg/m), L is beam span length (m) and I is moment of inertia (cm^4). The limiting value of the instantaneous deflection for the simply supported beam is recommended to be in a range from $L/300$ to $L/500$. If the deflection is more than the limiting, we have to change the cross-section area again.

III. RESULTS AND DISCUSSION

The results from analysis the bamboo truss structure in 8 types by check the tension and compression force in 4 main members (top chord, bottom chord, diagonal and vertical member) are show in Fig. 5.

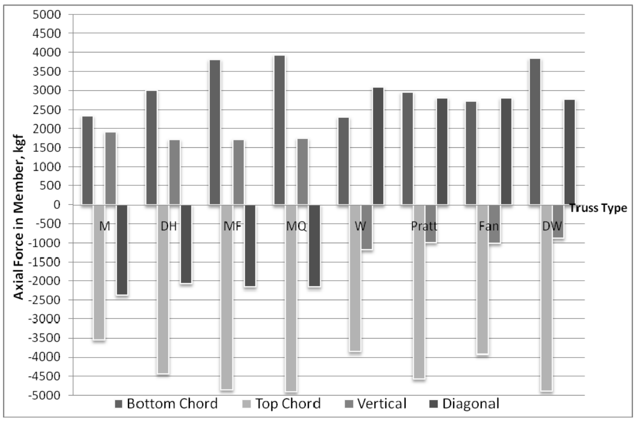


Figure 5 Axial force in truss member; top chord, bottom chord, vertical and diagonal

From the 8 truss types, axial force in the bottom chord members is tension force. The axial force of top chord members is compression force. The vertical member force in M shape group are supported the tension force but in the W shape group are supported the compression force. The diagonal member force in M shape group are supported the compression force but in the W shape group are supported the tension force.

After that, we assume the bamboo diameter for check the limiting the tension and compression force equal 10 cm and check value of bucking and bending follows the step of analysis. So, we were finding the appropriate the cross-section areas of the bamboo truss structure that shown in Table I.

TABLE I. BAMBOO CROSS-SECTION AREAS IN EACH MEMBERS

Type of Truss	M (cm^2)	DH (cm^2)	MF (cm^2)	MQ (cm^2)	W (cm^2)	P (cm^2)	DW (cm^2)	F (cm^2)
Top Chord	132.6	65.68	71.61	72.36	132.6	66.83	72.12	58.37
Bottom Chord	132.6	42.42	51.20	52.41	132.6	41.58	51.68	39.23
Diagonal	58.93	37.63	36.14	41.57	58.93	40.85	40.78	40.70
Vertical	58.93	28.85	28.49	29.00	58.93	53.60	43.30	46.85

The results from Table I are shown the cross-section areas of each member. The top chord and bottom chord member have cross-section areas between 50 cm^2 to 133 cm^2. The diagonal member and vertical members have cross-section areas between 28 cm^2 to 59 cm^2. After that, we will get the diameter for members in bamboo truss by select cross-section areas that more than calculated.

The diameters of bamboo truss are show in TABLE II. In part of top chord member are bigger than the other member because of weight from purlin.

TABLE II. DIAMETER OF BAMBOO

Type of Truss	M (cm)	DH (cm)	MF (cm)	MQ (cm)	W (cm)	P (cm)	DW (cm)	F (cm)
Top Chord	15	10x2	10x2	10x2	15	10x2	10x2	10
Bottom Chord	15	10	10	10	15	10	10	10
Diagonal	10	10	10	10	10	10	10	10
Vertical	10	10	10	10	10	10	10	10

TABLE III. RESULTS FOR TRUSS

Type of Truss	M	DH	MF	MQ	W	P	DW	F
No. of Member	10	14	16	14	10	14	16	12
Weight (kg)	209.8	201.4	216.2	206.5	218.8	218.5	288.8	180.1
No. of Joint	6	9	8	9	6	8	10	9
Deflection (cm)	4.25	4.64	4.64	4.64	4.25	4.64	4.64	10.76

From the result that shown in the Table III, the first case that we considered is weight of bamboo truss. We will consider the total weight of bamboo truss structure from the 8 types. The shape of truss structure that has the less total weight is Fan, Double Howe, Modified Queen, M, Modified Fan, Pratt, W and Double W respectively.

Next we check the deflection of the member in each truss shape that show in Table III. After that we considered the deflection. The deflections of other truss shape are under the limit. If we considered only the deflection, the M and W truss shape have the less value. The Fan shape has more deflection value than the others.

IV CONCLUSION

From the objective of the analysis, the bamboo truss structure that has minimum weight is Fan shape because it has 12 members. In case of deflection, the M shape and W shape have deflection less than the other shapes but the weight of truss is the third from minimum truss weight. So that the best shape for this study is Double Howe because it has minimum weight and the deflection is in the limit. In case of failed of all truss shapes are from the compression load and the deflection.

The members in truss that are increased are not necessary, because the columns and foundations of the weight must be increase unnecessarily. The connections of bamboo truss structure are very important that you should considered next came a sequence.

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