Structural Capacity of Columns Using Bamboo Culms from Species in Thailand

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Abstract

Bamboo has played more and more significant role in modern day architecture because of its sustainable contribution, and also simply respond to the UN's Sustainable Development Goals. To promote more uses, bamboo still is uncertain for architects and designers on structural capacity. Bamboo architecture have been created by playing safe using over-structure or making a rough estimate. It should be important to design structure more precisely and properly. This research is the experimentation of using bamboo in column application. It is distinctive that bamboo architecture is quite different from typical structure using post and beams. Bamboo structure can be unclear on whether it is post or beam, rather they are truss frame. Then column design will become a critical factor. This research then looks into the column capacity of 5 Thai bamboo species. They are all species that mostly use for structural applications in Thailand. They were measured for physical properties, and tested for structural capacity in compression loads. The result show that they have various sizes that affect the structural capacity directly. Interestingly, most of them have relatively similar thickness. The test obviously confirms the bigger culm can receive more load. It showed that D.Giganteus can receive the most load, due to its sizes, and B.multiplex offered the least load. However, when formulating test result into per unit of section area and diameter, D.sericeus can received the most compression. In overall per unit section area, Dendrocalamus family perform better than Bambusa family. Moreover, when calculating compression load in unit diameter, it is also interesting that all species can relatively receive similar load per centimeter of culm diameter. In conclusion, it is confirmed that sizes of culms are proportioned to compression capacity, and if size is not the factor, Dendrocalamus family is doing better than Bambusa family. The research still uses computer model to calculate the applicability of bamboo column strength, and four species are working, except B.Multiplex. In that case, bundling with more culm can be further investigated. The benefit to this research is to promote more proper uses of bamboo species in column application, and as well promote to have more sustainable architecture.

Keywords: bamboo architecture, column, species, sustainability

1. Introduction

Following UN's 2030 SDGs, it has become a global trend for many community around the world to lead the direction as same as the Sustainable development goals, which there are 17 of them. In field of Built Environment, designers and architects are searching for many ways to comply with SDGs, especially goal number 11: Sustainable Cities and Communities. The inventions of new sustainable products for Built environment can fall under Goal number 9: Industry, Innovation and Infrastructure. Natural materials, especially fast growing and quickly renewable, have been the frame that designers are looking at.

Bamboo, the giant and fast growing grass, has become the focus material to answer the SDGs. Though bamboo has been used for hundreds of years for everything, from everyday product to building structure. The first record use of bamboo is the Chinese book scrolls, and many food containers. In Southeast Asia, bamboo has been used for many structures, because it is strong and easy to find anywhere. For many evidences of bamboo uses in the past, we easily see that bamboo can answer many factors to respond to SDGs. Bamboo are abundant in local areas. Bamboo are renewable, due to its fast growing. It can grow back much quicker when comparing to timber. Bamboo are light-weight, so simple tools and manpower can work with it without lots of power or energy used. The only question remains, though it has been used for hundreds of year, that how strong it is. There are also many species to choose from, while some are big and small. The further investigation of bamboo in structural application then become the critical information to find out.

2. Bamboo in Column application

Architecture using Bamboo as major structure has very much different language, when comparing with other typical structure like timber, concrete, or steel. Since the sketch of Domino House by Le Corbusier, the house resembled the mass production of structure using post, beams, slab, and stairs. Late after, the world is influenced by the idea of posts and beams, and have become the most practical way in structural design.

On the other hand, bamboo architecture initially are created from applying this simple rule of using post and beams. Though bamboo is the sustainable material, and with limited technology and knowledge of local people, the development of right designs and construction do not go beyond a simple hut or pavilion. Bamboo architecture then is constructed in practical way of using posts and beams. Referring to Figure 1(left), typical bamboo projects are mostly seen in local villages by local people, using local technology, and that may be limited. While new trend of creating bamboo architecture, due to its strength and benefit of being a sustainable material, the design has been created in many interesting ways to bring out the most of its capacity and beauty. Good project example is shown in Figure 1(right). Bamboo can bend, split, bundle, splice, and connect in many different ways. Bamboo architecture then are seen in variety of organic geometrical forms. Moreover, bamboo architecture does not have clear cut on what are posts, or what are beams. So, it will crucial to understand how bamboo will behave and able in the column application of bamboo structure.

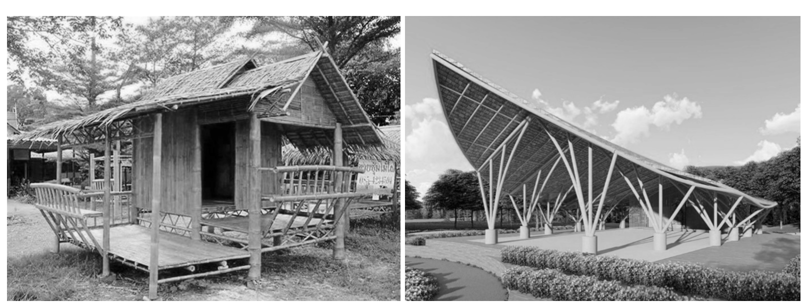


Figure 1: (Left) Bamboo architecture using conventional post and beams methods. The typical hut in Thailand designed by Local villagers ; **(Right)** Trend of innovative bamboo architecture in organic geometry rather using bamboo truss frame as main structure. The meditation center is designed by Bamboosaurus studio, Thailand.

It is obvious that structural members of bamboo architecture are made into a form of frames. Frame can be columns and turned to receive lateral forces. Columns in bamboo structural applications are serving various stress and forces. In order to design bamboo architecture to be more properly, it is important for architects and designers to understand the capacity and behavior of bamboo when using in column applications. Columns in this sense means the member of structures that receive gravity loads as majority.

Figure 2. Bamboo column was being tested at the Laboratory using Universal Testing Machine

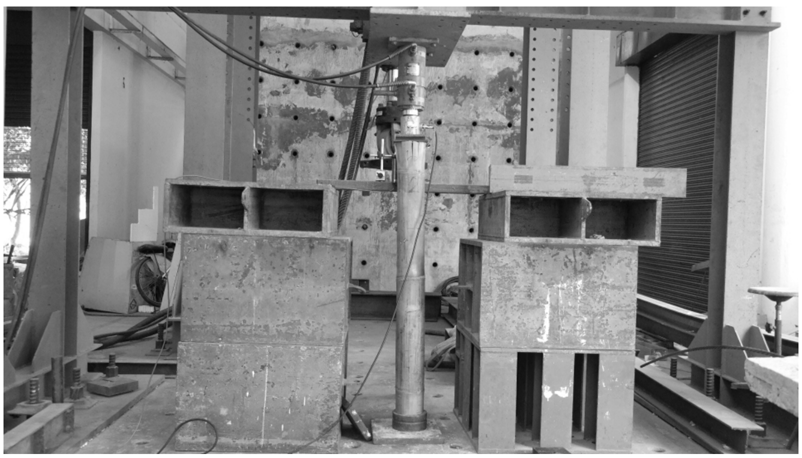
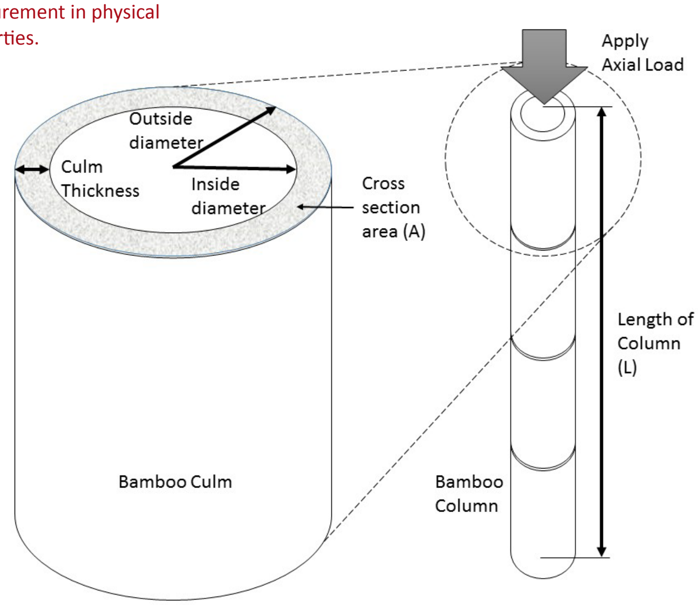


Figure 3. Diagram of Bamboo specimen explains technical measurement in physical properties.



3. Research Hypothesis

Bamboo architecture has distinctive language that is different from other material structure. Though there are many research testing in mechanical properties of bamboo. However, it is the nature of bamboo that they are irregular and offered different properties of bamboo in different parts of the world. In Thailand, there are still limited research in bamboo's structural capacity, especially column subject. It is also to understand that when designing structure of bamboo projects in Thailand, the loading capacity will depend on columns significantly. Particularly sizes of columns are the concern. Bamboo comes in different sizes from different species. In practicality, constructor will use large-culm columns to receive more loads. However, different species of bamboo in Thailand can offer capacity variably. The same size column from different species can perform differently. It is important to search for factors in different physical properties and different species can have effect of column capacity performance.

4. Research Methodology

This research is the experimental research. Bamboo specimen were collected from many provinces in Thailand. All selected Thai bamboo are species that are used as a construction material in structural applications in Thailand. Most Thai bamboo are from Prachinburi province, except D.Gianteus (Pai Yak Nan) bamboo is from Nan province. Prachinburi province as part of the central plain of Thailand is one of the areas that grow good quality bamboo. The research testing facility is the Laboratory of Faculty of Engineering, Thammasat University Rangsit Center. The test setup is shown in Figure 2. Variables are determined as follow:

4.1 Independent variables: There are five species of structural Thai bamboo to be used for testing specimen.

1. Dendrocalamus Asper (Pai Tong)
2. Dendrocalamus Sericeus (Pai Sangmon)
3. Bambusa Blumeana (Pai Seesuk)
4. Bambusa Multiplex (Pai Liang)
5. Dendrocalamus Giganteus (Pai Yaknan)

4.2 Dependent variables

1. Physical properties: Moisture Content, Outside and Inside Diameter, and Culm thickness. Explanation of physical parameter is shown in Figure 3.
2. Mechanical Properties: Axial Compression loads and failure behavior

4.3 Testing Methods

The mechanical properties are used the Universal Testing Machine (UT) to do hydraulic pressure test on specimen, following the ISO 22157-1 method, “Determination of physical and mechanical properties of bamboo”. Displacement Transducer and Data logger is used to collect numeric data.

5. Research Findings

Each species are tested using 5 specimen to guarantee the accuracy of the results. Firstly, all specimen were measured to find the physical properties; outside and inside diameters, wall thickness, section areas. Then, specimen are set at UTM to test the loading capacity of compression forces. The test result of all five species are shown in table 1 to 5:

Bamboo Column - D.Asper		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Outside diameter (D)	mm.	84.95	90.50	84.03	85.90	90.53
Inside Diameter (d)	mm.	67.65	72.65	64.43	69.95	69.93
Culm thickness (t)	mm.	8.65	8.93	9.80	7.98	10.30
Cross section area (A)	cm.	20.73	22.87	22.85	19.52	25.96
Column height (L)	cm.	150.00	150.50	150.30	149.60	150.50
Moisture Content (MC)	Percent	53.45	67.74	68.57	39.53	43.18
Compression force (Fult)	Kg.	8,750.00	7,280.00	2,120.00	8,120.00	11,560.00
Compression stress (σult)	Kg/cm^2	422.00	318.29	92.77	415.91	445.31
Mode of Failure		Splits	Splits	Splits	Splits	Splits
Average σult	Kg/cm^2	338.86				

Table 1. Test result of five specimen of Dendrocalamus Asper (Pai Tong), physical properties, compression stress, and failure behavior

Bamboo Column - D.Sericeus		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Outside diameter (D)	mm.	70.95	66.30	75.50	75.45	75.13
Inside Diameter (d)	mm.	7.23	5.30	10.90	9.60	6.25
Culm thickness (t)	mm.	56.50	55.70	53.70	56.25	62.63
Cross section area (A)	cm.	149.40	149.90	149.90	419.90	150.20
Column height (L)	cm.	14.46	10.16	22.12	19.86	13.52
Moisture Content (MC)	Percent	5,600.00	3,880.00	6,980.00	10,110.00	3,280.00
Compression force (Fult)	Kg.	387.16	382.01	315.53	509.07	242.54
Compression stress (σult)	Kg/cm^2	9.09%	12.50%	16.67%	20.31%	22.03%
Mode of Failure		Buckling	Buckling	Buckling	Buckling	Buckling
Average σult	Kg/cm^2	367.26				

Table 2. Test result of five specimen of Dendrocalamus Sericeus (Pai Sangmon), physical properties, compression stress, and failure behavior

Table 3. Test result of five specimen of Bambusa Multiplex (Pai Liang), physical properties, compression stress, and failure behavior

Bamboo Column – B.Multiplex		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Outside diameter (D)	mm.	41.25	41.00	44.95	43.98	45.50
Inside Diameter (d)	mm.	31.25	36.50	30.05	20.20	20.45
Culm thickness (t)	mm.	5.00	4.75	7.80	10.73	12.80
Cross section area (A)	cm.	5.69	5.41	9.10	11.20	13.15
Column height (L)	cm.	150.00	150.10	150.10	150.10	149.75
Moisture Content (MC)	Percent	14.29%	12.77%	15.79%	13.85%	11.11%
Compression force (Fult)	Kg.	1,470.00	1,380.00	2,380.00	3,380.00	3,130.00
Compression stress (σult)	Kg/cm^2	258.16	255.11	261.44	301.70	238.03
Mode of Failure		Buckling	Splits & Buckling	Buckling	Buckling	Buckling
Average σult	Kg/cm^2	262.89				

Table 4. Test result of five specimen of Bambusa Blumana (Pai Seesuk), physical properties, compression stress, and failure behavior

Bamboo Column – B.Blumeana		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Outside diameter (D)	mm.	79.68	80.60	78.40	76.38	88.95
Inside Diameter (d)	mm.	59.08	54.05	60.75	41.38	67.55
Culm thickness (t)	mm.	10.30	13.28	8.83	17.50	10.70
Cross section area (A)	cm.	22.45	28.08	19.29	32.37	26.30
Column height (L)	cm.	150.00	150.30	150.50	149.50	150.40
Moisture Content (MC)	Percent	29.63%	21.43%	38.24%	31.88%	32.65%
Compression force (Fult)	Kg.	4,400.00	7,180.00	3,980.00	9,560.00	5,900.00
Compression stress (σult)	Kg/cm^2	196.00	255.72	206.33	295.35	224.30
Mode of Failure		Buckling	Splits	Splits	Buckling	Buckling
Average σult	Kg/cm^2	235.54				

Table 5. Test result of five specimen of Dendrocalamus Giganteus (Pai Yuknan), physical properties, compression stress, and failure behavior

Bamboo Column - D.Giganteus		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Outside diameter (D)	mm.	158.38	143.10	141.43	146.58	149.28
Inside Diameter (d)	mm.	134.33	128.20	124.73	129.93	127.13
Culm thickness (t)	mm.	12.03	7.45	8.35	8.33	11.08
Cross section area (A)	cm.	55.29	31.75	34.91	36.16	48.08
Column height (L)	cm.	114.50	139.50	119.50	114.40	115.60
Moisture Content (MC)	Percent	20.00%	10.00%	9.68%	26.67%	12.20%
Compression force (Fult)	Kg.	15,960.00	9,200.00	10,410.00	8,380.00	11,500.00
Compression stress (σult)	Kg/cm^2	288.67	289.78	298.21	231.76	239.16
Mode of Failure		Bearing & Buckling	Splits	Splits	Bearing	Splits & Bearing
Average σult	Kg/cm^2	269.52				

Table 6. Comparison of Test result of five species in physical properties, compression stress, and failure behavior

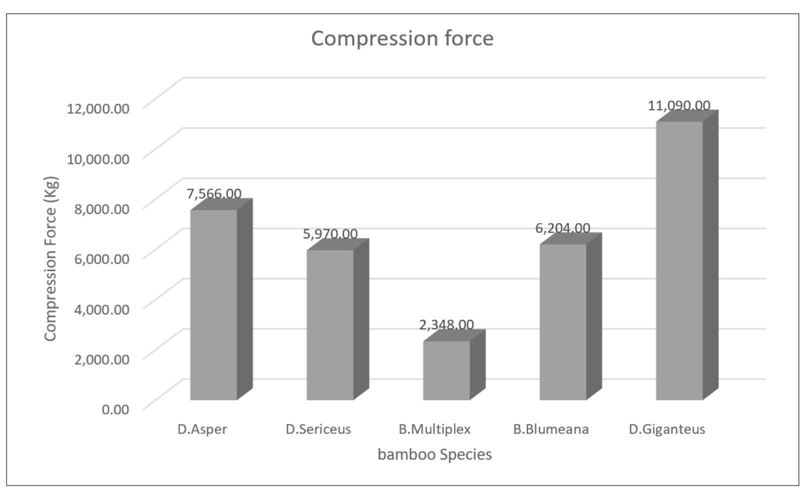
Description		Unit	D.Asper	D.Sericeus	B.Multiplex	B.Blumeana	D.Giganteus
Moisture Content (MC)		%	54.50%	16.12%	13.56%	30.77%	15.71%
1. Specimen dimension	Outside Dia. (D)	mm.	87.18	72.67	43.34	80.80	147.75
	Inside Dia. (d)	mm.	68.92	56.96	26.91	56.56	128.86
	thickness (t)	mm.	9.13	7.86	8.22	12.12	9.45
	Height (L)	cm.	150.18	203.86	150.01	150.14	120.70
	Radius of Gyration	mm.	39.29	32.64	18.03	34.87	69.31
2. Area (A) A= π/4 (D^2- (D-2t)^2)		cm^2	22.39	16.03	8.91	25.70	41.24
3. Max. Compression force (Fult)		Kg	7,566.00	5,970.00	2,348.00	6,204.00	11,090.00
4. Max. Compression stress (σult) σult = Fult/A		Kg/cm^2	338.86	367.26	262.89	235.54	269.52
5. Mode of Failure			Splits	Buckling	Buckling	Buckling or Splits	Splits & Bearing
6. Slenderness ratio			1:38	1:62	1:83	1:43	1:17

6. Experiment Conclusion

The experiment has shown that all bamboo species have different culm sizes, while D.Giganteus is the biggest and B.Multiplex is the smallest. However, interestingly they have relatively similar sizes in wall thickness, ranged from 7.8 to 12.1 mm., and average at 9.3 mm. Moisture content are controlled at 14-16%. While D.Asper and B.Blumena may have higher than others because of their thicknesses, so they can retain more moisture. Areas of column then are varied due to the differences in culm sizes that may affect how the compression load is applied.

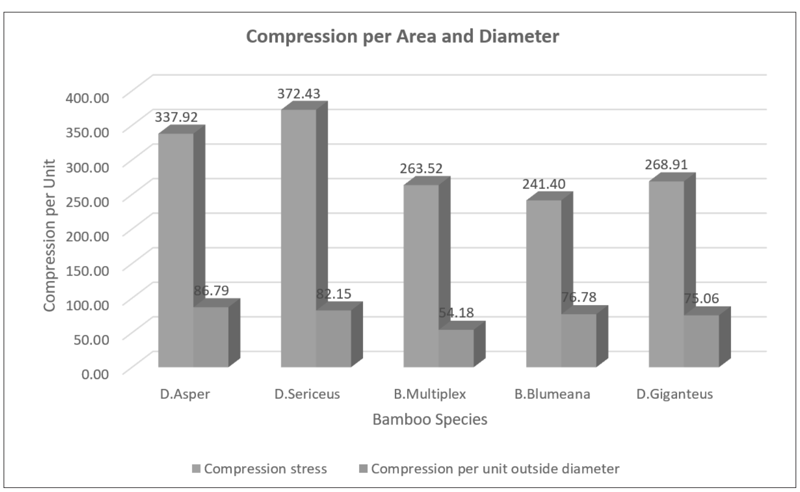
The relative similar height of columns were all being test for compression axial load. It is shown that D.Giganteus can receive at the highest load of 11 tons, and D.Asper, B.Blumena, and D.Sericeus at 7.5, 6.2, and 5.9 tons respectively shown in Figure 4. The smallest-culm specie, B.Multiplex, can receive the least load as expected at 2.3 tons. The mode of failure indicated that some species split, while others buckled. This can be explained in the slenderness ratio. All species were collected in relatively similar height, while there are different in diameters, due to nature of species. Small specie, like B.Multiplex, will fail by buckling, while big species, like D.Asper and D.Giganteus will split instead. This also lead to explanation that big bamboo tends to receive better loads, and will not buckle, so they will be better columns.

Figure 4. Graph diagram shows maximum compression load in Kilogram that each species can averagely receive. D.Giganteus can receive the most and B.Multiplex can receive the least. It is quite obvious that maximum compression load varies due to culm sizes.



The experiment also shows the interesting finding shown in Figure 5 that when calculating the compression load based on unit section area and unit diameter, the result has changed. When considered at Unit section area of column per square centimeter, D.Sericeus has the highest capacity to receive compression load, 372 Kg/cm^2. D.Asper and D.Gianteus are second and third high capacity, at 337 and 268 Kg/cm^2. B.Mulitplex and B.Blumena are in the last two at 263 and 241 Kg/cm^2. It is interesting to observe that Dendrocalamus family show the great performance of receiving compression axial load per unit section area, while Bambusa family is also good, but not as good as those of Dendrocalamus. Moreover, when calculating compression axial load in unit diameter, it is also interesting that all species can relatively receive similar load per centimeter of culm diameter. Therefore, it can be concluded that all five Thai structural species of bamboo can perform the compression, based on the sizes of culm. Larger culm can receive more load, and can be a better column. However, for the same size of culm but in different species, Dendrocalamus Bamboo species can receive more compression load than Bambusa species. Top performance is B.Sericeus or Pai Sangmon, follows by D.Asper and D.Gianateus.

Figure 5. Graph on left side shows maximum compression load per unit section area. Three Dendrocalamus family can receive better load than Bambusa family. While Graph on right side shows maximum compression load per unit diameter, it is interestingly that all species do not show much different in capacity.



In column applications, we can conclude that architects and designer can use as big as possible for the strongest column. More culm thickness or more section area will help the performance of column as well. The selection will depend on the aspect of the design and availability of bamboo in construction area as well. It does not mean the bigger is always better. It has to adjust according to the workability of structural member as well. In order to see the real applicability of uses, the simulated computer model is designed and construction to see the performed result.

Lastly, it is also important to mention that there is the limitation of the experiment. The research use the result of five specimen of each specie. It may not seems to be many, but the test results has shown the data were resulted in the same direction. The variation can naturally occur due to the typical irregularity of the bamboo itself.

7. Application to Architecture Model

It is interesting to see the result of experiment to apply the calculation on a typical bamboo architecture design. The research created the computer model as shown as Figure 6, and can be explained as follow:

- A single-story residential building, area 30 m^2
- Span not more than 3 meters
- Maximum column height 4 meters
- Bamboo as main and roof structure, columns and beams
- Live load at 30 Kg/m^2, Dead load for roof at 8 kg/m^2 and 10 at 10 Kg/m^2
- Safety factor at 3 (based on building code for single-story wood structure, 2.93-7.6)

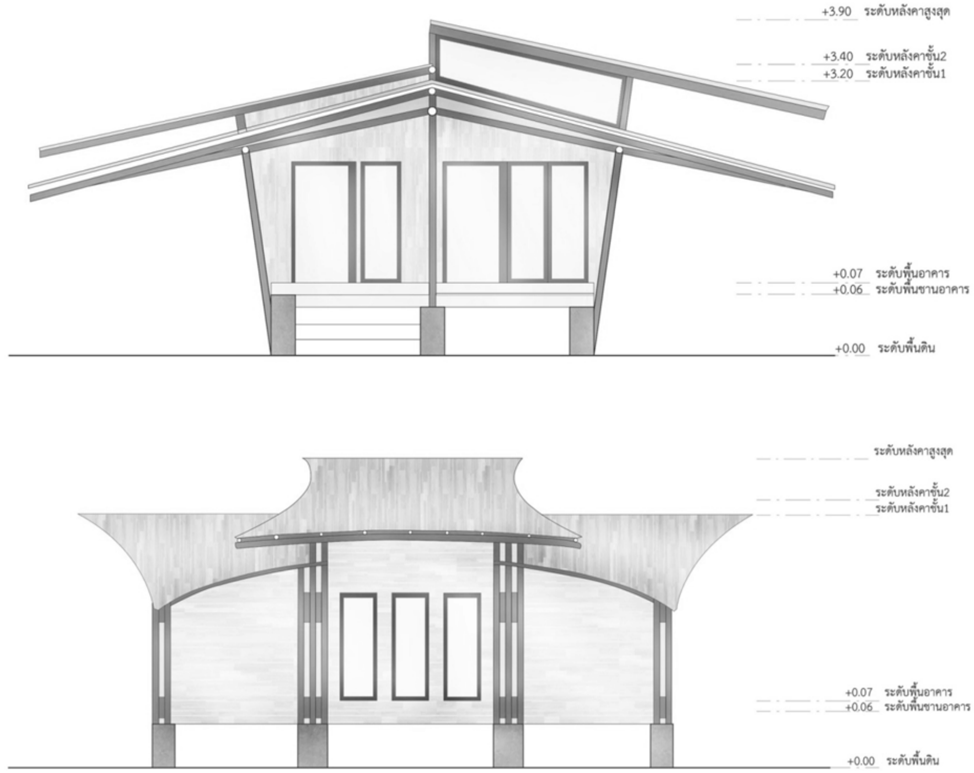


Figure 6. Elevations of computer model of Bamboo architecture

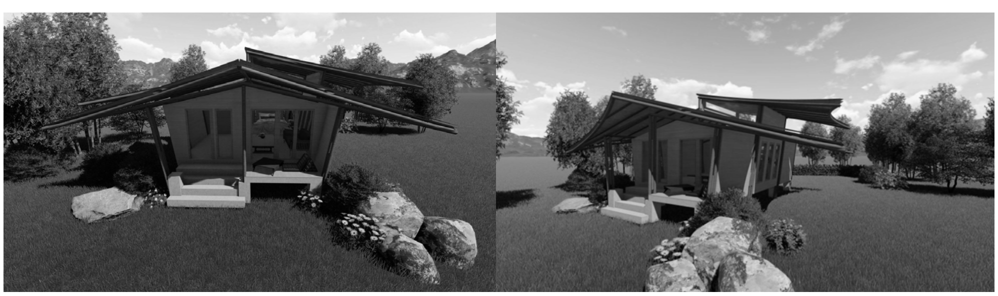


Figure 7. Perspective renderings of computer model of Bamboo architecture

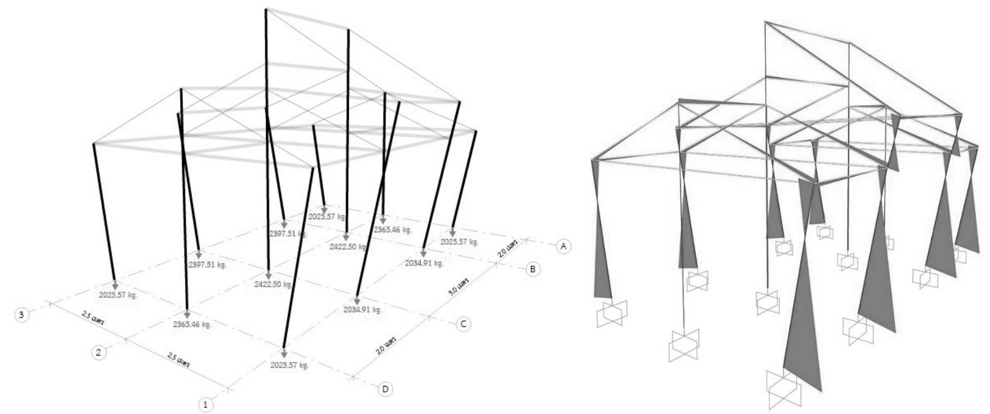


Figure 8. Both diagrams show the Computer model of bamboo building using SAP 2000 is to calculate the receive loads at columns. **(Left)** the Compression axial load at columns; **(Right)** Moment diagram occurred in columns.

After running the computer model to do theAfter running the computer model to do the loading simulation in SA P 2000 as seen in Figure 8, software to test the structural performance, the result show that all columns receive the compression axial loads at 2,025 – 2,422 Kilogram. This actual load is very much less 2 to 5 times of 4 species, except Bambusa Multiplex. This experiment is only calculated for a single story. To receive more 2-5 times, structural can surely have more stories, such as minimum of 3 or more. Moreover, the single column is used for calculation, in receiving more loads, the bundles of columns can be used to maximize the section area. However, more research has to be done to confirm. Another analysis is performed to investigate the moment occurred in columns. It is found that moment tends to be significant at column-foundation location, which is much less than columns connected to upper frames. Though the simulation do not show damage at columns. It is the next step to study further in bamboo's bending capacity and connection design. In conclusion, it is confirmed that physical properties of section area can affect the compression load capacity of columns, and in further, different species in the same size can affect the capacity as well.

8. Research Summary

Bamboo Architecture in Thailand are commonly used these five structural species. Due to nature of different sizes of bamboo species, it is confirmed that sizes of culms are proportioned to compression capacity. It showed that D.Giganteus can receive the most load, due to its sizes, and B.multiplex offered the least load. However, when formulating test result into per unit of section area and diameter, D.sericeus can received the most compression, followed by D.Asper, D.Gianateus, B.Multiplex, and B.Blumena respectively. However interestingly if size of culm is not the factor, Dendrocalamus family is doing better than Bambusa family. After the research still uses computer model to calculate the applicability of bamboo column strength, and four species are working well, except B.Multiplex. In that case to make B.Multiplex works, bundling with more culms in a column can be further investigated to add more receiving load capacity.

This research finding can be useful for designers to design sizes and species of columns more precisely. At the end, it is promote more uses to this wonderful sustainable material for the future, and to fulfill the SDGs in sustainable cities and community.

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