Full paper

EVALUATION OF THE PIPE BURST STRENGTH OF THREE SPECIES OF BAMBOO

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ABSTRACT

The pipe burst strength (P.B.S) of three species of monopodial bamboo namely *Phyllostachys viridis*, *Phyllostachys boryana* and *Phyllostachys mazelli* were investigated to determine their suitability for water conveyance. Matured samples of the three species were obtained from the same farm in Anduze, Le Gard in France. Thirty selected samples each of the species, free of drying defects such as splits and cracks, were tested for the P.B.S evaluation.

The highest pressures (P.B.S) sustained before bursting were $5.45x10^5$ N/m^2, 8.05 x 10^5N/m^2 and > 9.20 x 10^5 N/m^2 for *P. viridis*, *P. boryana* and *P. mazelli* respectively. Samples with nodes were observed generally to give higher values of P.B.S than those without nodes. Also samples from the bottom section of the culm give highest value when compared to those from the middle and top sections of the culm.

Statistical analysis of the P.B.S. for the three species showed that there were significant differences (at $P<0.05$).The values of the P.B.S. are low when compared to that of Aluminium pipe (13.8-32.4 x 10^5N/m^2) However, the value of P.B.S for *P. mazelli* is comparable to that of the PVC (8.75-17.9 x10^5N/m^2) and *Arundinaria alpina* (6 x 10^5 N/m^2) used in Tanzania for rural water supply.

In conclusion, by comparison, *P. mazelli* is potentially more suitable for water conveyance based on its pipe burst strength than the other two species studied.

KEYWORDS: Bamboo pipe, Burst strength, Monopodial bamboo

1. INTRODUCTION

Bamboos are tree-like woody grasses growing naturally in the tropics and temperate region of Asia, Africa and America within 40°N and 40°S (Ralambondrainy, 1983). Of all the continents only Europe does not have indigenous species (Liese, 2004). About 1575 species belonging to 75 genera are reported worldwide (Bystriakova *et al*., 2002, Gielis, 2002). Half of the bamboo species grow in Asia while other continents account for the rest (Ahmad, 2000). Bamboo is renewable and grows rapidly. Some species grow at the rate of 100 cm/day reaching up to 40 m in height and some expand to 30 cm in diameter (Sattar, 1995; Armstrong, 2006). Bamboos generally reach their maximum height within 2-3 months of their growth, making them the fastest growing plant (Granaharan and Janssen 1993).

Like grasses bamboo have underground rooting system called rhizome, aerial stem called culms, branches and leaves (Gib,2005). However, unlike grasses, bamboo culm is an extremely useful material in a number of engineering works (Janssen 2000, Varmah and Bahadir, 1980). More than 4000 traditional and modern uses have been estimated for bamboo (Kumar, 1995; Ahmad, 2000) and about 2.5 billion people all over the world depend on or use bamboo materials (Salleh, 1995).

One of the old but technologically improving uses of bamboo is in the area of water conveyance, where bamboo pipes are used in water supply, irrigation and drainage. Bamboo pipes were utilized by the Japanese during the Second World War to supply water to some of their cities when there was shortage of raw materials to manufacture pipes from metals. (Lamb, 1979). The Tanzanian Government also adopted the use of bamboo pipe to supply potable water to more than 100,000 inhabitants in 19 villages of the country (Lipangile, 1984). Also in Bangladesh split bamboo was used in water harvesting to provide drinking water in communities to avoid long distances of travel to fetch water (Verma, 1998). In a number of places in Taiwan bamboo piping was used to replace iron pipe in the construction of well casing attaining a depth of up to 150 m (Hugier and Martin, 1982).

Despite the seemingly large scale usage of bamboo for water piping, there is a dearth of information on a number of parameters that are useful to the engineer to properly design bamboo piping system. Bamboo pipes in service for water supply, irrigation and drainage are subjected to water pressures. Reliable estimates of the maximum hydrostatic pressure which the pipe can hold before bursting are needed in pressurized water system. This study therefore has a specific objective of evaluating the burst strength of three species of bamboo *Phyllostachys viridis Phyllostachys boryana* and *Phyllostachys mazelli*. This is an important parameter which has to be considered in using bamboo culms as water conveyance structure. Other important parameters of relevance include durability and movement characteristics (shrinkage characteristics); these are to be separately studied as part of an ongoing research on utilization of bamboo in irrigation and drainage engineering.

2. MATERIALS AND METHODS

The three species namely *P. viridis*, *P. boryana* and *P. mazelli* were obtained from a bamboo merchant's farm situated in the Prafrance near Anduze, Le Gard in the southern part of France. The bamboo samples were all 5 years old. Several smaller samples from the culms of these species were obtained by dividing a whole culm into three portions as follows:

(a) The bottom portion: consisting of the base of the culm to 2 metres above it.
(b) The top portion consisting of the top of the culm to 2 metres below it.
(c) The middle portion consisting of the remaining part between the bottom portion and top portion.

Each smaller sample was again subdivided into smaller units: - samples with nodes and samples without nodes(non-nodal). The diaphragms at the nodes of each of these smaller units were drilled using hole saw which was powered by an electric drilling machine (plate 1). These were kept under cover to allow for gradual drying. At the time of testing each sample (free of drying defects such as splits and cracks) for burst strength, the moisture content of each sample was determined in accordance with International Standard Organization standard (ISO DIS 22157 (2000)). Also determined were the thicknesses, internal diameters using calipers, as well as the length of the sample using metre rule.

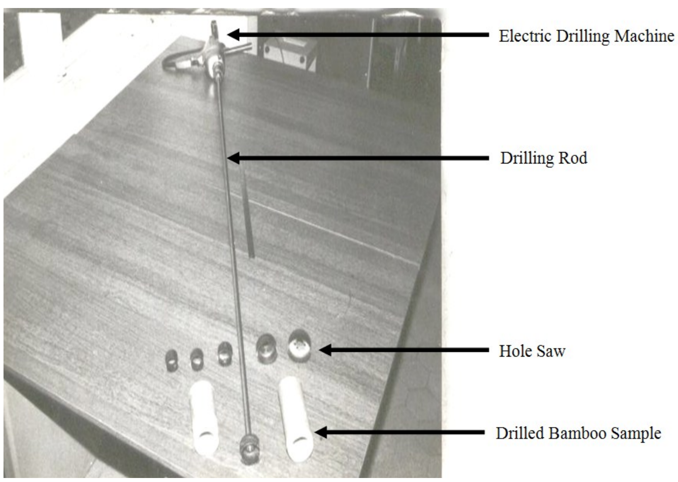

Plate 1: The Equipment used to remove the diaphragm at the Nodes

The equipment used in carrying out the pipe burst strength were designed and fabricated. The principles used are based on that of the equipment for determining the pipe burst strength of asbestos cement pipe in France (Eternit Industries, 1984). Essentially the equipment has to satisfy the following criteria.

(i) It must be able to hold the pipe in proper position such that the filling of the pipe with water will take place without leakage.
(ii) It must be provided with water control valve through which water is allowed to fill the pipe
(iii) It must also be air tight so that it retains air while the water filled pipe is being pressurized.
(iv) It must be provided with a non-returning valve and air channel through which air is pumped under pressure into the pipe.
(v) In addition it must be easy to operate and cheap to fabricate.

Details of the equipment showing stages in the fabrication process are shown in Fig. 1 and Plate 2.

In carrying out the test, the bamboo pipe was filled up with water through the Quick Closing Gate Valve at end B (Fig.1). The water-filled pipe was thereafter pressurized through the Quick Closing Gate Valve at end A, using the air supply from the compressor. The pressure was monitored by reading it up on the on-line pressure gauge of the compressor (Plate 2). A distinct bursting sound signified the end of the test

3. RESULTS AND DISCUSSIONS

The average green moisture contents of the three species (*P. viridis*, *P. boryana* and *P. mazelli)* of bamboo were quite high ranging from 103% to 110% (oven dry basis) (Tables 1, 2 and 3). High values of moisture content are known for timbers and bamboos. Some timbers species found in Nigeria such as *Ceiba penthranda* and *Mitraagyna cihata* have green moisture levels of about 170% and 105% (oven dry basis) respectively (Armstrong, 1960; Wendorff and Okigbo, 1972). Also green samples of bamboo (*Bambusa vulgaris*, Schrad) found in Nigeria were known to have moisture contents ranging from 108.6%to 151.8% (Lucas and Ogedengbe, 1987)

The pipe burst strength (P.B.S.) of samples from two of the three species tested to burst point (viz. *P. viridis* and *P. boryana)* increased with increase in the moisture content (Tables 1 and 2). However, the limitation in the maximum pressure available at the compressor used did not permit the determination of changes in burst strength of the third species (*P. mazelli)* as none of the samples burst at the available maximum pressure ($\approx 9.2 \times 10^5 N/m^2$)

It was observed that values of the P.B.S. for the tested samples with node are higher than those without nodes (Non-nodal) at comparable moisture content for all the species for which the P.B.S. were determined. It seems the node reinforces the culm in resisting bursting pressure. Also, it was observed that samples of species with shorter internodal distance such as *P. mazelli* have higher values of P.B.S. than those with longer internodal distance; for *P. mazelli* average internodal values (33.6 - 34.6 cm) were smaller than those of P. boryana and P. viridis having average internodal lengths of approximately (39.0 - 42.2 cm) and (37.4 - 41.0 cm) (viz.Tables 1, 2, 3) respectively. Species with shorter internodal length has higher number of nodes, these nodes as observed, reinforced the culm thus making it more resistant to bursting pressure. This perhaps may explain why *P. mazelli* is more resistant in this respect than others.

It was also observed that for the same species of bamboo, the P.B.S. increased with increase in the culm wall thickness for samples having comparable moisture content (Tables 1 and 2). Thus samples from the bottom portions of the culms with thicker culm wall thickness generally show higher P.B.S. than those from the middle and top portions at comparable moisture content. This trend in P.B.S. with increase in culm wall thickness was also observed by Lipangile (1984).

In general, the values of the P.B.S. of bamboo species tested are much lower than those of Aluminum pipe (viz. Table 4) and slightly lower than that of PVC pipes (viz. Table 4) – these are some of the other types of pipes that are being extensively used in irrigation and drainage practices. The values of burst strength for *P. viridis* range from 4.5 to 5.45 x 105 N/m2, for *P. boryana* the values range from 4.6 to 8.05 x 105 N/m^2 and for *P mazelli* ≈9.2 x 105 N/m^2 . Statistical analysis of these values using Paired T-test showed that there were significant differences ($P<0.05$) in the Top, Middle and Bottom Portions (Table 5).

These low values of P.B.S. of the three species of Bamboo were also recorded by Lipangile (1988) for *Arundinaria alpina* one of the species found and used in water supply to villages in Tanzania. It seems therefore that Bamboo pipes based on their P.B.S. cannot compete with Aluminum pipe as irrigation pipe especially for those systems requiring higher pressure but they can readily compete with Plastic Pipes (PVC) for low pressure water supply and drainage in small community.

4. CONCLUSION

The study showed that bamboo samples with smaller internal diameter(i.e. thicker culm wall) can withstand pipe bursting pressure better than species with bigger internal diameter. The

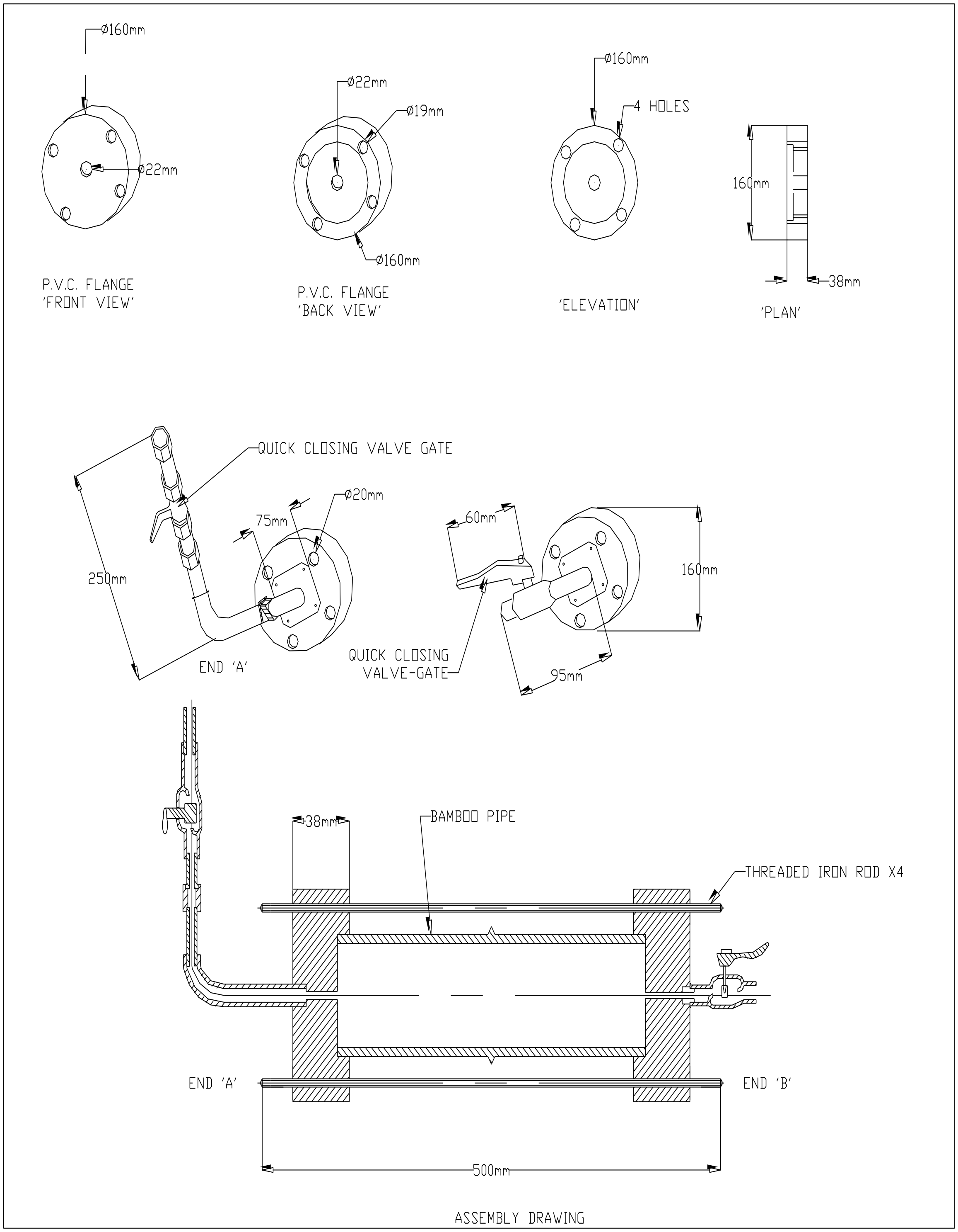

Figure 1: Details of the Fabricated Equipment used for the Pipe Burst Strength Test

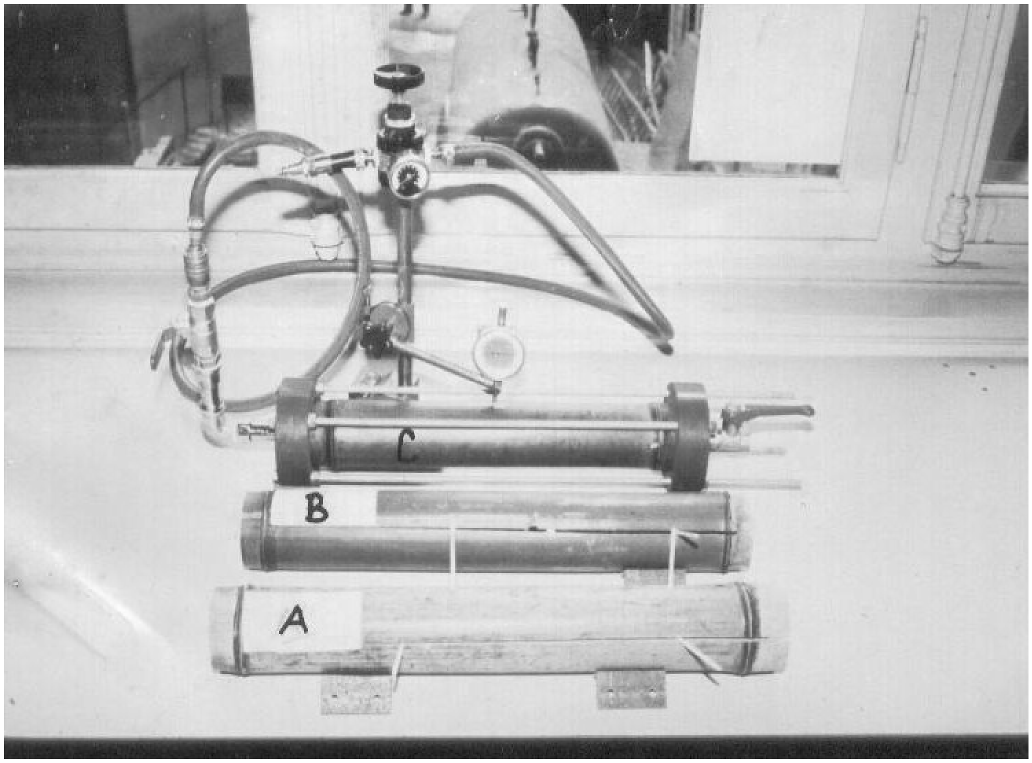

Plate 2: The Experimental set up for the Pipe Burst Strength Determination
A: - The Burst pipe of *P. viridis*
B: - The Burst pipe of *P. boryana*
C: - Unburst pipe of *P. mazelli* attached to the fabricated equipment

Table 1: Burst Strength for Different Portions of Phyllostachys viridis

Sample No	Portion along the culm	Length/Internodal length (cm)	Average thickness (mm)	Average Internal Diameter (mm)	Moisture content (%)	Description of sample	Burst strength ($x10^5N/m^2$)
1T*	Top	45.0	5.5	52.0	108	With node	5.15
2T	-do -	45.0	5.4	51.0	72	- do -	5.10
3T	- do -	45.0	5.4	50.0	66	- do -	5.05
4T	- do -	45.0	5.3	52.0	58	- do -	5.00
5T	- do -	45.0	5.3	51.0	49	- do -	5.00
Average	**-do-**	**45.0**	**5.4**	**51.2**	**71.8**	**-do-**	**5.06**
6T	- do -	41.0	5.3	52.0	108	Non-nodal	5.05
7T	- do -	42.0	5.4	51.0	71	- do -	5.00
8T	- do -	41.0	5.4	50.0	67	- do -	4.80
9T	- do -	40.0	5.3	52.0	59	- do -	4.50
10T	- do -	43.0	6.3	51.0	49	- do -	4.50
Average	**-do-**	**41.0**	**5.5**	**51.2**	**71.8**	**-do-**	**4.77**
1M**	Middle	45.0	6.3	56.0	107	With node	5.35
2M	- do -	45.0	6.2	56.0	70	- do -	5.20
3M	- do -	45.0	6.1	55.0	64	- do -	5.15
4M	- do -	45.0	6.1	56.0	56	- do -	5.10
5M	- do -	45.0	6.1	55.0	45	- do -	5.10
Average	**-do-**	**45.0**	**6.4**	**55.6**	**66.4**	**-do-**	**5.18**
6M	- do -	39.0	6.3	56.0	106	Non-nodal	5.15
7M	- do -	40.0	6.2	56.0	70	- do -	5.00
8M	- do -	40.0	6.1	55.0	63	- do -	5.00
9M	- do -	39.0	6.1	56.0	55	- do -	4.90

Table 1: Burst Strength for Different Portions of Phyllostachys viridis (contd.)

10M	- do -	40.0	6.1	55.0	44	- do -	4.85
Average	**-do-**	**39.6**	**6.2**	**55.6**	**67.6**	**-do-**	**4.98**
1B***	Bottom	45.0	6.5	52.0	103	With node	5.45
2B	- do -	45.0	6.4	52.0	68	- do -	5.35
3B	- do -	45.0	6.3	51.0	57	- do -	5.30
4B	- do -	45.0	6.3	51.0	50	- do -	5.30
5B	- do -	45.0	6.3	51.0	39	- do -	5.20
Average	**-do-**	**45.0**	**6.4**	**51.6**	**63.4**	**-do-**	**5.32**
6B	- do -	38.0	6.4	52.0	103	Non-nodal	5.30
7B	- do -	37.0	6.3	52.0	66	- do -	5.15
8B	- do -	38.0	6.3	51.0	55	- do -	5.15
9B	- do -	37.0	6.3	52.0	50	- do -	5.10
10B	- do -	37.0	6.3	51.0	39	- do -	5.05
Average	**-do-**	**37.4**	**6.3**	**51.6**	**62.6**	**-do-**	**5.15**

* The T stands for Top Portion
** The M stands for middle portion
*** The B stands for Bottom portion

Note (Non-nodal samples have internodal length Samples with nodes were selected to have the same length=45.0 cm with node at the middle)

Table 2: Burst Strength for Different Portions of Phyllostachys boryana

Sample No	Position along the culm	Length/ Internodal length (cm)	Average thickness (mm)	Average Internal Diameter (mm)	Moisture content (%)	Description of sample	Burst strength ($x10^5 N/m^2$)
1T*	Top portion	45.0	4.5	51.0	110	With node	7.00
2T	- do -	45.0	4.4	51.0	75	- do -	6.90
3T	- do -	45.0	4.3	50.0	68	- do -	6.85
4T	- do -	45.0	4.3	50.0	59	- do -	6.80
5T	- do -	45.0	4.2	51.0	49	- do -	6.80
Average	**-do-**	**45.0**	**4.3**	**50.6**	**72.2**	**-do-**	**6.87**
6T	- do -	43.0	4.5	51.0	110	Non-nodal	4.80
7T	- do -	41.0	4.4	50.0	74	- do -	4.70
8T	- do -	42.0	4.3	50.0	68	- do -	4.65
9T	- do -	43.0	4.2	50.0	58	- do -	4.60
10T	- do -	42.0	4.2	51.0	49	- do -	4.60
Average	**-do-**	**42.2**	**4.3**	**50.4**	**71.8**	**-do-**	**4.67**
1M**	Middle	45.0	4.8	55.0	108	With node	7.55
2M	- do -	45.0	4.7	54.0	72	- do -	7.35
3M	- do -	45.0	4.6	55.0	66	- do -	7.30
4M	- do -	45.0	4.5	54.0	56	- do -	7.10
5M	- do -	45.0	4.5	55.0	46	- do -	7.10
Average	**-do-**	**45.0**	**4.6**	**54.6**	**68.4**	**-do-**	**7.30**
6M	- do -	41.0	4.8	55.0	108	Non-nodal	5.00
7M	- do -	42.0	4.7	55.0	73	- do -	4.90
8M	- do -	40.0	4.6	54.0	65	- do -	4.80
9M	- do -	42.0	4.6	55.0	56	- do -	4.75
10M	- do -	40.0	4.5	54.0	46	- do -	4.75
Average	**-do-**	**41.0**	**4.6**	**54.6**	**69.6**	**-do-**	**4,84**
1B***	Bottom	45.0	5.0	51.0	105	With node	8.05
2B	- do -	45.0	4.8	52.0	68	- do -	7.70
3B	- do -	45.0	4.8	51.0	56	- do -	7.55
4B	- do -	45.0	4.7	52.0	50	- do -	7.50
5B	- do -	45.0	4.7	51.0	40	- do -	7.50
Average	**-do-**	**45.0**	**4.8**	**51.4**	**63.8**	**-do-**	**7.66**
6B	- do -	39.0	5.0	51.0	105	Non-nodal	5.20
7B	- do -	40.0	4.8	50.0	68	- do -	5.10
8B	- do -	40.0	4.7	51.0	55	- do -	5.05
9B	- do -	38.0	4.7	51.0	49	- do -	4.95
10B	- do -	38.0	4.7	51.0	40	- do -	4.95
Average	**-do-**	**39.0**	**4.8**	**50.8**	**63.4**	**-do-**	**5.01**

* The T stands for Top Portion
** The M stands for middle portion
*** The B stands for Bottom portion

Note (Non-nodal samples have internodal length Samples with nodes were selected to have the same length=45.0 cm with node at the middle)

Table 3: Burst Strength for Different Portions of Phyllostachys mazelli

Sample No	Portion along the culm	Length/Internodal length (cm)	Average thickness (mm)	Average Internal Diameter (mm)	Moisture content (%)	Description of sample	Burst strength ($x10^5N/m^2$)
1T*	Top	45.0	4.8	49.0	110	With node	› 9.2®
2T	- do -	45.0	4.7	48.0	74	- do -	› 9.2
3T	- do -	45.0	4.6	47.0	66	- do -	› 9.2
4T	- do -	45.0	4.5	48.0	58	- do -	› 9.2
5T	- do -	45.0	4.5	47.0	48	- do -	› 9.2
Average	**-do-**	**45.0**	**4.6**	**47.8**	**71.2**	**-do-**	**› 9.2**
6T	- do -	36.0	4.8	49.0	110	Non-nodal	› 9.2
7T	- do -	35.0	4.7	47.0	74	- do -	› 9.2
8T	- do -	34.0	4.6	46.0	66	- do -	› 9.2
9T	- do -	35.0	4.6	47.0	59	- do -	› 9.2
10T	- do -	33.0	4.5	47.0	48	- do -	› 9.2
Average	**-do-**	**34.6**	**4.6**	**47.2**	**71.4**	**-do-**	**› 9.2**
1M**	Middle	45.0	5.6	56.0	106	With node	› 9.2
2M	- do -	45.0	5.5	56.0	70	- do -	› 9.2
3M	- do -	45.0	5.4	56.0	62	- do -	› 9.2
4M	- do -	45.0	5.4	55.0	55	- do -	› 9.2
5M	- do -	45.0	5.4	55.0	48	- do -	› 9.2
Average	**-do-**	**45.0.**	**5.5**	**55.6**	**68.2**	**-d9o-**	**› 9.2**
6M	- do -	35.0	5.6	56.0	106	Non-nodal	› 9.2
7M	- do -	35.0	5.5	55.0	70	- do -	› 9.2
8M	- do -	34.0	5.5	55.0	63	- do -	› 9.2
9M	- do -	34.0	5.4	56.0	56	- do -	› 9.2
10M	- do -	35.0	5.4	55.0	48	- do -	› 9.2
Average	**-do-**	**34.6**	**5.5**	**55.4**	**68.6**	**-do-**	**› 9.2**
1B***	Bottom	45.0	6.0	50.0	104	With node	› 9.2
2B	- do -	45.0	5.9	50.0	68	- do -	› 9.2
3B	- do -	45.0	5.8	50.0	63	- do -	› 9.2
4B	- do -	45.0	5.7	49.0	53	- do -	› 9.2
5B	- do -	45.0	5.6	49.0	48	- do -	› 9.2
Average	**-do-**	**45.0**	**5.8**	**49.4**	**67.2**	**-do-**	**› 9.2**
6B	- do -	34.0	6.0	50.0	104	Non-nodal	› 9.2
7B	- do -	33.0	5.9	49.0	68	- do -	› 9.2
8B	- do -	34.0	5.8	50.0	63	- do -	› 9.2
9B	- do -	34.0	5.7	49.0	53	- do -	› 9.2
10B	- do -	33.0	5.7	48.0	48	- do -	› 9.2
Average	**-do-**	**33.6**	**5.8**	**49.2**	**67.2**	**-do-**	**› 9.2**

* The T stands for Top Portion
** The M stands for middle portion
*** The B stands for Bottom portion
® Refers to the maximum pressure obtainable (from the compressor used)

Note (Non-nodal samples have internodal length. Samples with nodes were selected to have the same length=45.0 cm with node at the middle)

P.B.S. of *P mazelli* (≈9.2 $x10^5N/m^2$) with internal diameter of 49.2mm › P.B.S. of *P.boryana* (8.05 $x10^5N/m^2$) with internal diameter of 50.8mm ›P.B.S. of *P.viridis* (=5.45 $x10^5N/m^2$) with internal diameter of 51.6mm. The differences in the P. B.S. were found to be significant ($P<0.05$). The study also showed that nodal bamboo samples showed greater strength to withstand bursting pressure than non-nodal samples. The P.B.S for nodal samples of *P.viridis* with average value of 5.19 $x10^5N/m^2$ › that of non-nodal samples (from same species) with average value of 4.97 $x10^5N/m^2$). Thus samples with more nodes (i.e. shorter internodal length) like *P.mazelli* recorded the highest P.B.S. compared to *P.viridis* and *P.boryana.*

Based on P.B.S alone bamboo species of *P.mazelli* with higher values are more suitable as pipes, for irrigation water supply and drainage operating under low pressure than those of *P.viridis* and *P.boryana.*

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