Determination Of Some Hydraulic Characteristics Of Bamboo (*Bambusa vulgaris* (Schrad)) Pipe

Kola' Ogedengbe[1]*
[1]Department of Civil and Environmental Engineering
Faculty of Engineering and Information Technology, University of Namibia
Ongwediva Campus, P.O. Box 3624, Ongwediva, Namibia

Received: 10th February, 2014. Accepted: 4th April, 2014.

Abstract

The hydraulic characteristics (HCs) of any pipe are important in determining its acceptability for water conveyance. Bamboo culms made into pipes by drilling through their septa at the nodes have been in use for many years but very few documented researches have been reported on their HCs. The HCs of *Bambusa vulgaris* (Schrad) pipe were therefore investigated to contribute to knowledge of its potential usage in irrigation of agricultural land. Three drilling bits namely hole saw drilling bit (HSDB), Ethiopian drilling bit (EDB) and Tanzanian drilling bit (TDB) were studied and compared, in the removal of the septa at the nodes to make bamboo pipes (BPs) from the *Bambusa vulgaris* culms. Experimental set-ups were made using 9 m length of the BPs to determine hydraulic parameters such as the head loss due to the nodes and the internodes; friction factors and flow types. The data obtained were analyzed using one-way analysis of variance which were further tested using Duncan post-hoc test. The HSDB performed significantly better ($p < 0.05$) than the TDB and EDB in the smoothness of septa removal at the nodes with the average percentage head loss value of 0.36%, 0.42% and 0.46% respectively. Average friction factor obtained were 0.037, 0 047 and 0.049 for HSDB, TDB and EDB prepared BPs respectively. All these values are within the acceptable limits for a good hydraulic pipe. The flow type through the BPs was turbulent like for most manufactured pipes presently in use for water conveyance. Based on the determined values of its hydraulic characteristics, *B.vulgaris* pipe is suitable for usage in irrigation and drainage practices.

Keywords: Hydraulic characteristics, Bamboo pipe, drilling bits, friction factor, head loss, turbulent flow

ISTJN 2014; 3(1):82-99.

*Corresponding author - E-mail: kogedengbe@unam.na

1 Introduction

Bamboo is a monocotyledon and a perennial grass which contains two main parts, the cylindrical stem or culm that stands tall above the ground, bearing thin branches and leaves and the underground stem called the rhizome on which the culm grows (Higuchi, 1989; Scurlock et al., 2000; Gib, 2005).The culm is hollow in the inner area with some horizontal partitions called diaphragms or septa while on the outside these partitions are denoted by ring around the culm which is referred to as the node and the area between two nodes are called internodes (Gaur, 1990; Banik and Rao, 1995; Janssen, 2000) with diameter ranging from 5mm to 30cm and height from 10cm and 40m (Liese,2004; Armstrong, 2006)

Perdue (2005) noted a great interest in increased use of bamboo because of its acceptable chemical properties, rapid growth, ease of propagation, relatively short time required for new plantings to reach full production and apparent high yield. Verma (1998) reported on the use of bamboo pipes as water conveyance structure in Meghalaya a state in the north east of India where it has been working for over 200 years. Although bamboo has been used as water conduit in many parts of the world, scientific information regarding its behavior as water pipe is scanty. However, Lipangile (1989) revealed that the values of Mannings coefficient for *Arundinaria alpina* lie between 0.013 and 0.016, the lower value indicating good node removal. To enhance its utilization for water conveyance, the septum that causes discontinuity is removed using drilling bits to make way for a hollow length of bamboo for water conveyance (Lipangile, 1987).

Various drilling bits have been used in different parts of the world to effect septa removals from the bamboo culm (Kirchof, 1988). The removal of the septa notwithstanding, the hydraulic effectiveness of bamboo for water conveyance is affected by the rough edges left behind by the drilling bits employed in the removal of the septa in the bamboo culm (Sanghvi, 1985). These rough edges introduce friction resistance to water flow.The pressure drops result from friction, change in cross- sectional area of flow, change in direction of flow, enlargement and contraction of cross sectional area et cetera (Douglas et al., 1996). The total pressure at any point in the pipe is the sum of static pressure and velocity pressure. When flow in pipe is forced to change its direction of flow, total pressure losses are a combination of equivalent length measured in diameter for round pipe and in width for rectangular pipes (Jonas, 1992). Head losses in pipe network due to abrupt changes in flow geometry resulting from bends, branches, expansion, contractions, partial obstacles, valves and fittings of all types are generally known as form or minor losses (FAO, 1990). Very little and limited research works have been published on the hydraulic properties of bamboos. It is therefore imperative that the properties which will assist in the proper utilization of bamboos in irrigation and drainage practices are determined.

2 Materials and Methods

2.1 Fabrication of the Drilling Tools to Remove the Septa

In this study, three drilling tools were used namely Ethiopian drilling bit (EDB), Tanzania drilling bit (TDB) and Hole saw drilling bit (HSDB), for comparison. The first two-EDB and TDB were fabricated locally similar to the procedures used in Ethiopia and Tanzania respectively (Heuvel, 1981) and the third one (HSDB) was purchased off the shelf (Figures 1, 2, 3).

The fabrication of the EDB involves the heating, beating and forming of a 25mm diameter metal rod to the desired shape. The end to be formed about 100mm in length was placed in the furnace. The forming involved repeated heating and beating of the red hot metal in an anvil by a sledge hammer until it flattened and was shaped to the required dimension (Figure 1). The edges of the flattened end were cut to size with hacksaw tapering at about an angle of 60° from the tip. The edges were then machined to sharpness with a grinding machine such that the tools can drill in either direction. The other part of the drilling tool a solid cylindrical metal part 120mm in length bore two holes 8mm diameter, for coupling with the handle bar.

For the TDB a 120×50mm metal sheet of thickness 5mm was cut to intricate shape using hacksaw. The sheet was then heated in a furnace, twisted to the desired shape and allowed to cool. Upon cooling, a drilling bit of length 120mm, diameter 8mm and a hollow pipe length 100mm diameter 50mm with two bores 8mm holes were welded to opposite ends of the twisted sheet. The cutting edges were later machined to required sharpness (Figure 2). The other part of the drilling tool for coupling with the handle bar was made similar to that of the EDB.

For the HSDB (obtained off-shelf from the market) a 45mm diameter hollow steel pipe length 19mm was used as the seat. Three 8mm diameter holes were bored into the pipe with one of the holes threaded so that a bolt of corresponding dimension was screwed in to provide a firm attachment of the drilling tool to the handle (Figure 3).

The handle bar was made to be a shaft for easy rotation. It was made from a hard wood (*Terminalia superba*) because of its availability, lightness and cheapness compared to metal shaft. The handle was 1373 mm long and turned on the lathe to a shaft of 32mm diameter. A wooden grip 305mm in length and 35mm in width was nailed to the top of the wooden shaft for ease of turning during drilling.

2.2 The Preparation of the Bamboo Pipes Using the Drilling Tools

Each bamboo culm used for the study on hydraulic characteristics was cut to 3 metres length. This was drilled through, to remove the diaphragms (septa) at the nodes (Figure 4), from both ends to a distance of 1.5m, maximum length of the drilling shaft from each end. Each of the

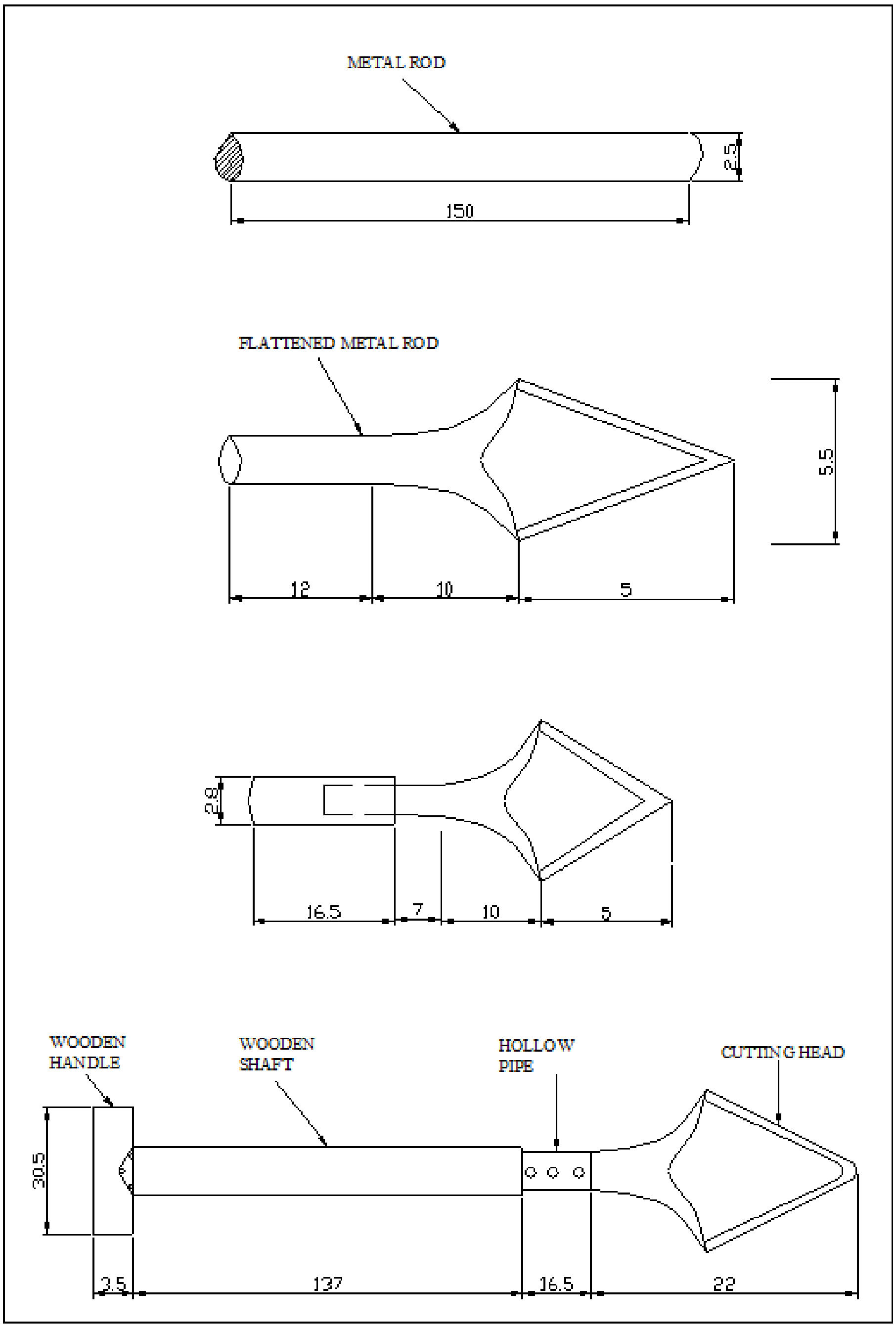

Figure 1: Details of Ethiopian Drilling Bit Fabrication Showing the Various Stages Involved (All dimensions are in cm).

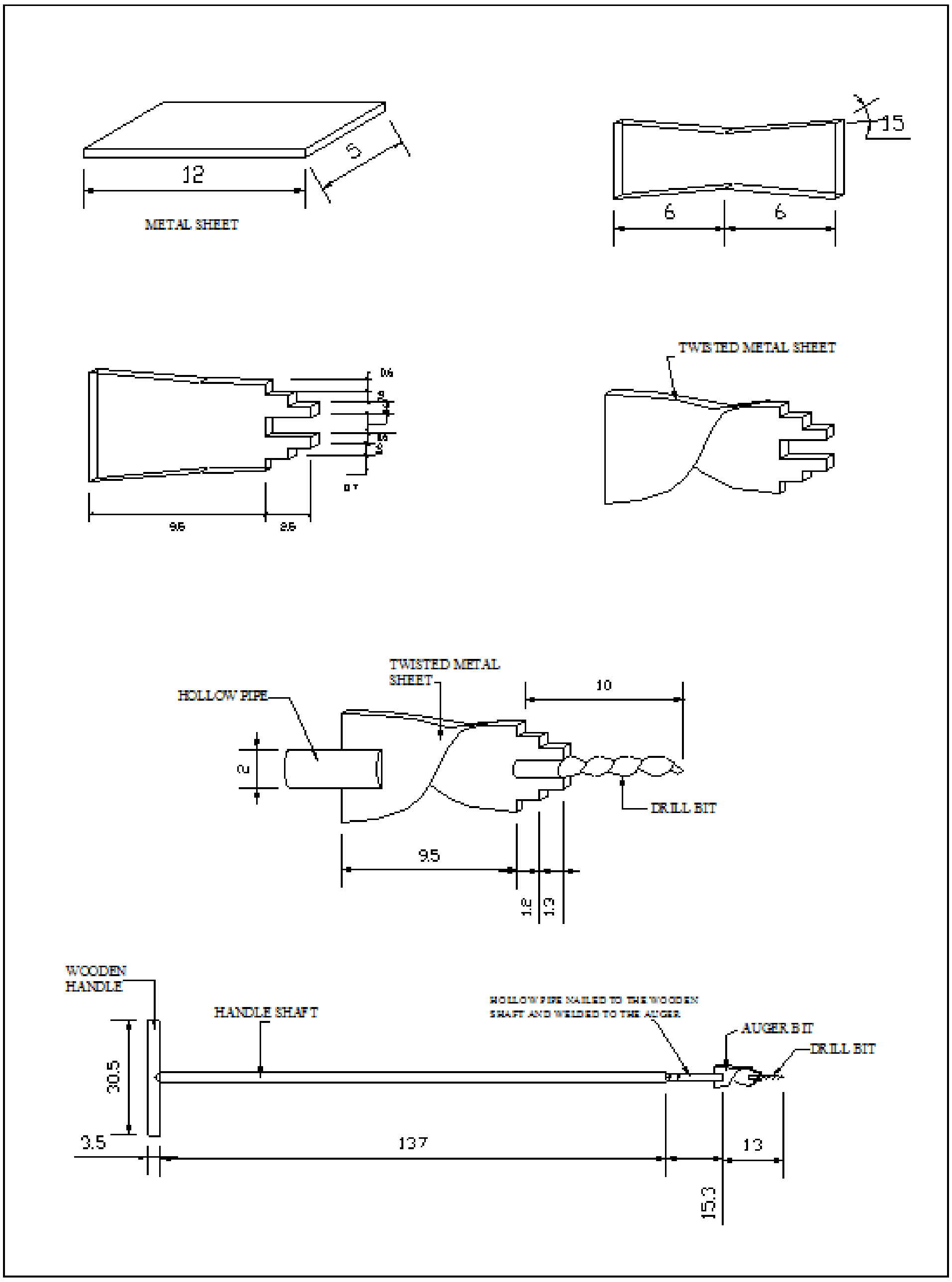

Figure 2: Details of Tanzanian Drilling Bit Fabrication Showing the Various Stages Involved (All dimensions are in cm).

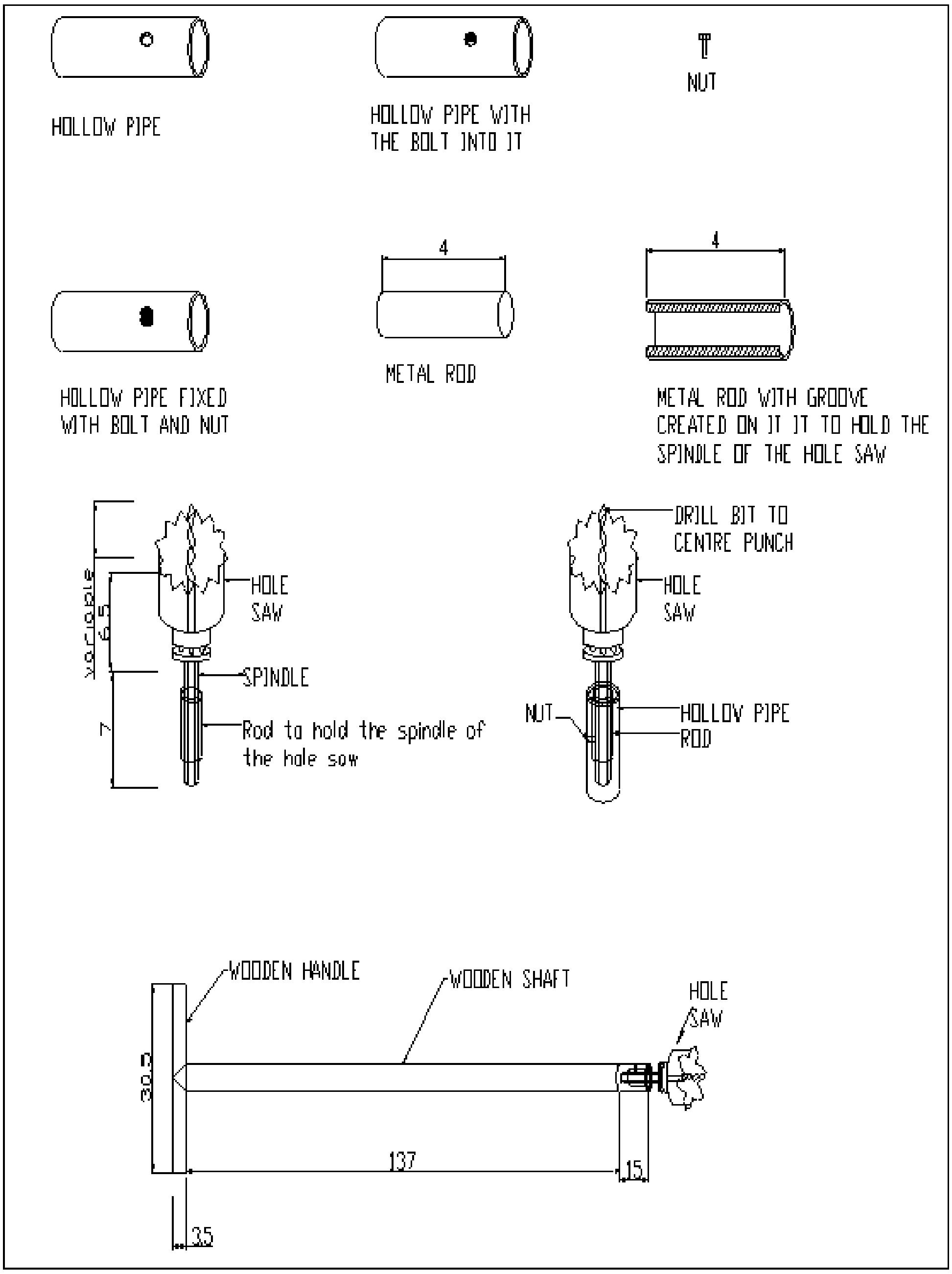

Figure 3: Details of the Hole Saw Drilling Bit Showing the Various Stages Involved (All dimensions are in cm).

three drilling tools was used to remove the septa at the nodes of the 3 metres long bamboo samples. After removal of the septa by the drilling tools, 7mm diameter holes were bored into the bamboo pipe surface at intervals (at nodes, between nodes and at point of joints) to be able to determine the head loss along the length of the pipe. The holes served as points for location of the piezometric tubes used to measure the head loss along the length of the pipe. While using the drilling tools; the time taken to drill through the same length of the bamboo sample was noted.

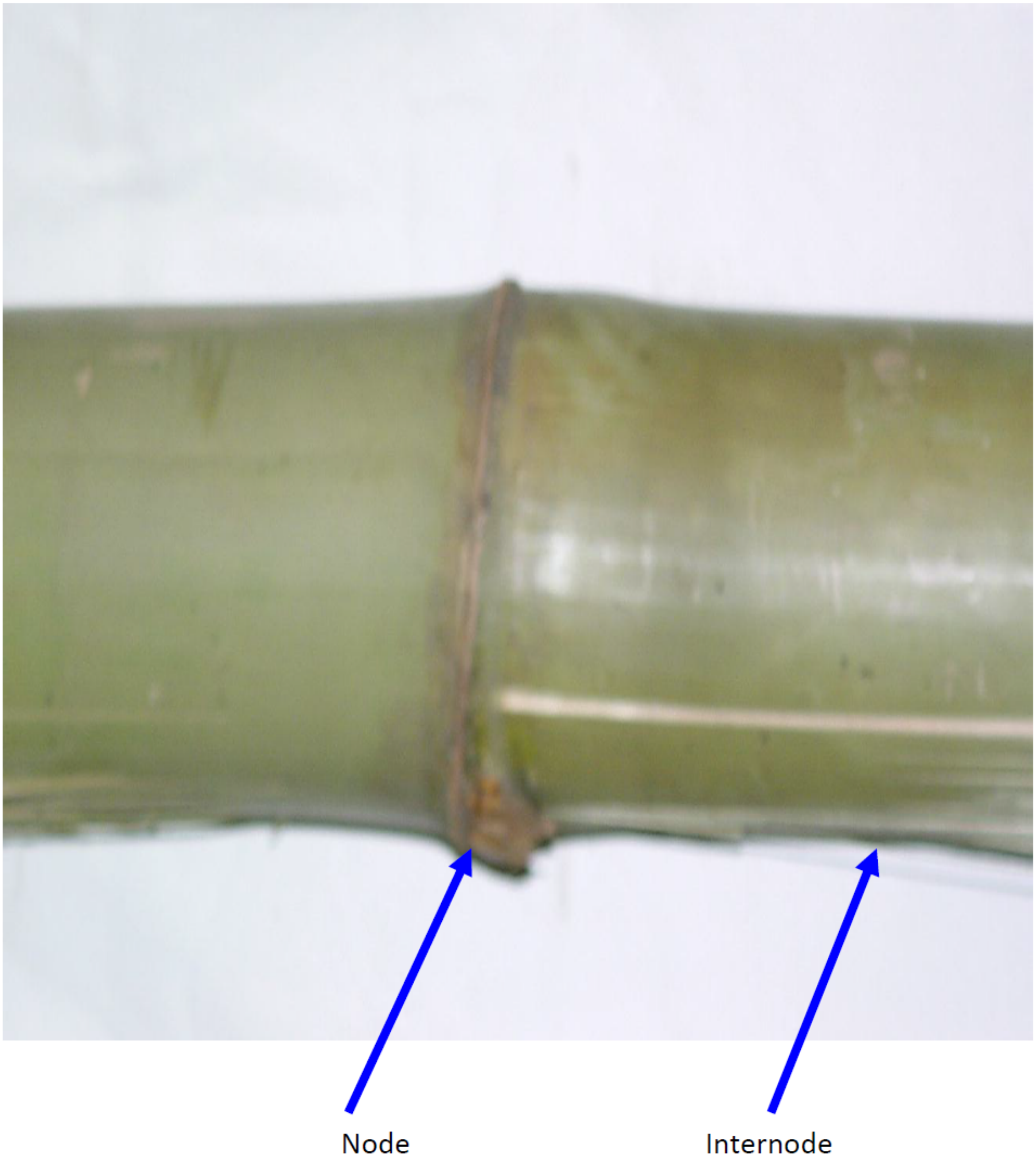

Figure 4: A sample of smaller portion of the Bamboo Clum (pipe) showing node and internode.

2.3 The Experimental Set Up for the Determination of the Hydraulic Characteristics

The experiment was set up such that three bamboo pipes were connected in series on bamboo stand. These three pipes were held together at their ends by means of rubber tubes (made from bicycle tire inner tube) held firmly to the pipes by jubilee clips. The length of the bamboo pipe was 9 metres comprising 3 lengths of bamboo each of 3 metres prepared using the three drilling tools under test for septa removal. Table 1 shows the sequence of combinations of the bamboo pipes for the experiment on the hydraulic characteristics.

Piezometric tubes were then carefully inserted to seat on the bored holes on the bamboo surface. The bamboo lines were free at one end to discharge water into a measuring container while water was pumped into the bamboo pipe line at the other end. Figure 5 shows the sketch of the experimental set-up for determining the hydraulic parameters.

Once the water level had stabilized, the level to which water has risen in each of the piezometric tubes was recorded. A 0.5hp Robin PTG (207) centrifugal pump with delivery rate of 9.97 litres/second to a total head of 25.91m was used. The experiment was repeated three times for each set-up, using the prepared bamboo pipes. The following hydraulic characteristics were determined for the experimental runs in each of the bamboo pipes.

The values for the friction factor (f) in pipes were determined using Darcy-Weisbach equation (FAO, 1990) of the form:

$$f = \frac{2gdh_f}{LV^2} \tag{1}$$

where:

f = friction factor (friction coefficient)

h_f = head loss between two points along the section of the pipe (at inlet and outlet of the section) in metres (m).

L = pipe length (m).

V = the mean flow velocity (m/s).

d = pipe internal diameter (m).

g = acceleration due to gravity (9.81ms^{-2}).

Other important hydraulic parameters of the bamboo that were considered:

1. Reynolds number given as

$$f = \frac{0.3164}{R_e^{0.25}} \tag{2}$$

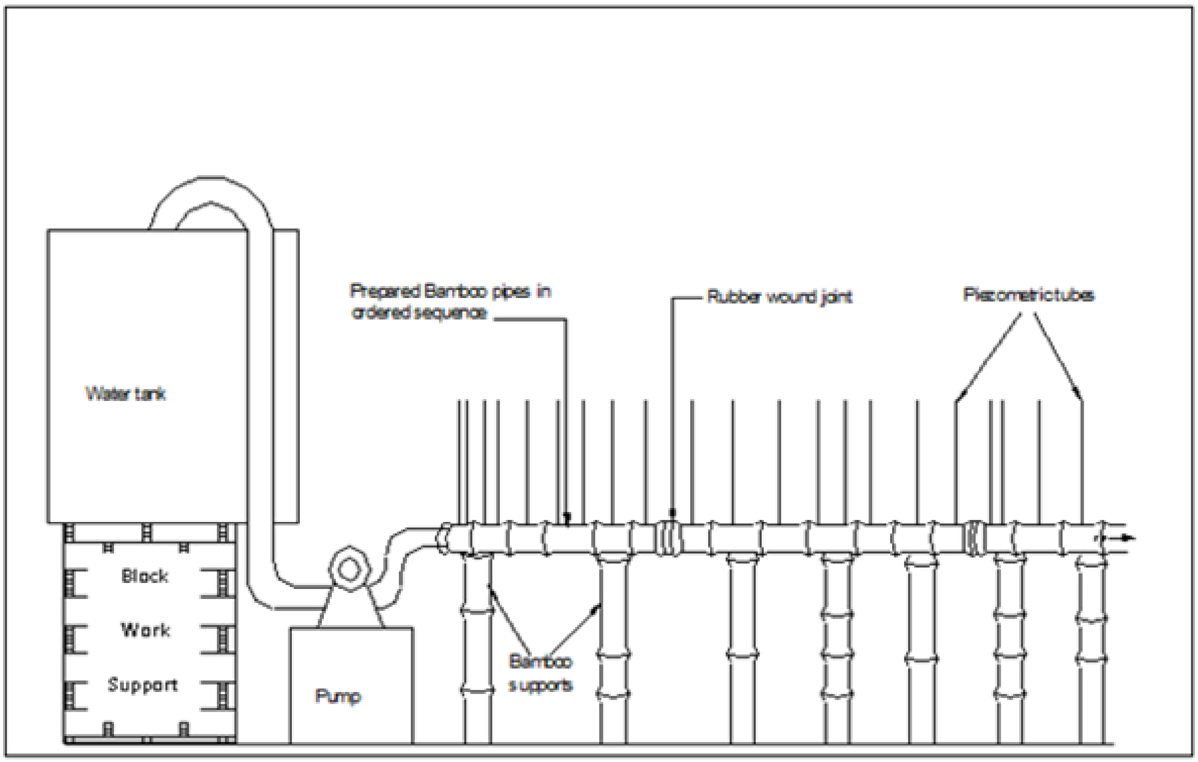

Figure 5: The sketch of the experimental set-up for testing the prepared Bamboo pipes.

where:
f = friction factor
R_e = Reynolds number
The Reynolds number is used to determine type of flow.

2. The pressure drop Δp along the pipe length using the relationship below (Douglas et al., 1997) This is given by

$$\Delta p = \varphi g h \tag{3}$$

where:
Δp = pressure drop along pipe length (m)
φ= the fluid density (kg/m^3)
h = mean head loss for the pipe (m)
g =acceleration due to gravity (m/s^2)

2.4 Data Analysis

The data that evolved from the study were analyzed using SPSS (version 16) to perform one-way analysis of variance (ANOVA), and these were further compared using Duncan post-hoc test.

Table 1: Sequence of the Bamboo Pipes Combinations for the Experiment on the hydraulic characteristics

Experiment	The sequence of the Bamboo pipes combination		
	I	II	III
1.	HSDB‡	EDB	TDB
2.	EDB	TDB	HSDB
3.	TDB	HSDB	EDB
4.	EDB	HSDB	TDB
5.	HSDB	TDB	EDB
6.	TDB	EDB	HSDB

‡HSDB, EDB, TDB mean Bamboo pipes prepared through septa (diaphragms) removal at the nodes using the Hole saw drilling bit (HSDB), Ethiopian drilling bit (EDB) and Tanzanian drilling (TDB)

3 Results and Discussion

3.1 The Time Taken to Remove the Septa (diaphragm)

The times taken (Table 2) to remove the septa (diaphragms) from the 3 metre length BPs were determined with the aid of a table clock. Drilling the BP using the TDB (Figure 6) resulted in the fastest mean time (53.33± 1.633 secs) obtained in removing the diaphragm at the nodes. Pipe samples prepared using the HSDB to drill through the septa, though recorded the slowest time (68.33± 3.011 secs), had the smoothest visually observable pipe inner wall. The higher time taken using the HSDB was probably due to the additional time taken up in changing the hole saw to correspond to the bore diameter of the bamboo as this decreased progressively towards the bottom of the BP sample. The performance of the EDB in terms of time taken to drill through the 3 metres pipe was found to be 62.50±1.971 secs which is also lower than that of HSDB. Comparisons of these values (Table 3) shows that the values are significantly different from one another ($p < 0.05$).

Table 2: Time taken to drill through 3 metres (length) of the *B. vulgaris* culm using different drilling bits

Type of drilling bit	Bamboo culm identification number	Time taken to drill through (secs)
Hole Saw (HSDB)	1	69
-do-	2	68
-do-	3	71
-do-	4	72
-do-	5	66
-do-	6	64
Ethiopian (EDB)	7	62
-do-	8	65
-do-	9	61
-do-	10	64
-do-	11	63
-do-	12	60
Tanzanian (TDB)	13	54
-do-	14	55
-do-	15	53
-do-	16	52
-do-	17	55
-do-	18	51

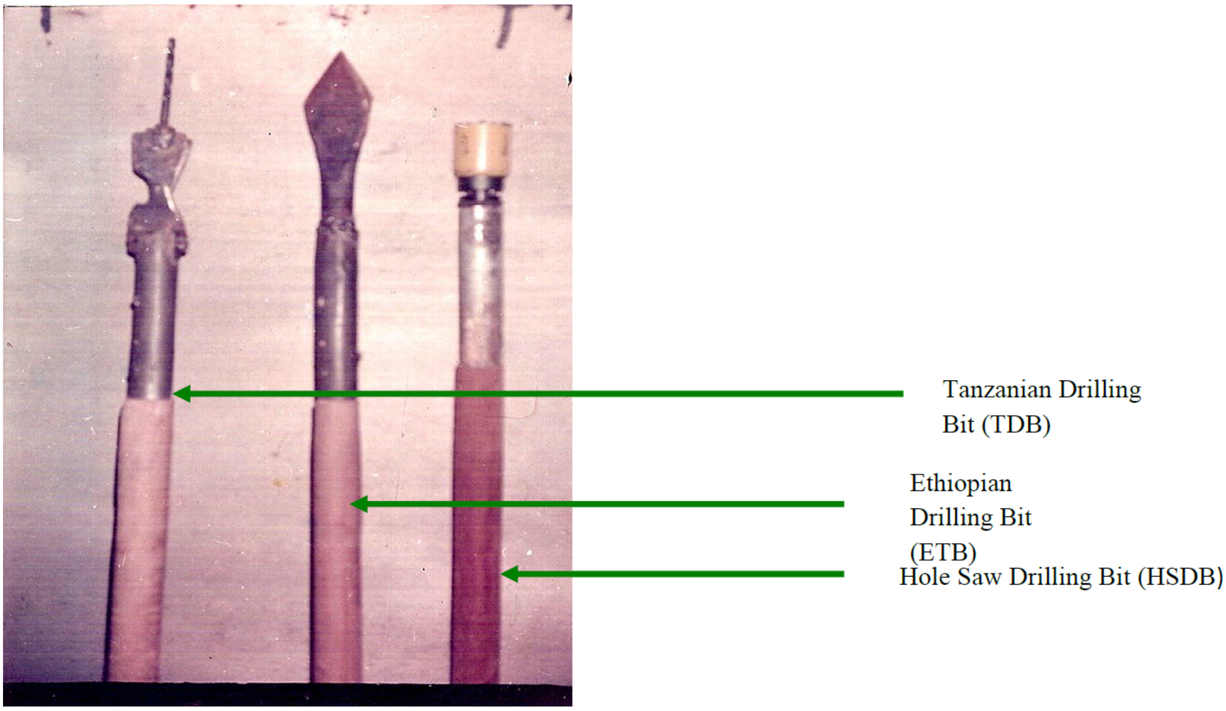

Figure 6: The fabricated drilling bits used to remove the Bamboo nodal diaphragms (Septa)

Table 3: Mean Time Taken (±SD) to Drill through 3metres of Bamboo Culm with Different Drill Bits

Type of Drill Bit	Mean Time Taken (secs) to Drill through 3 metres of Bamboo Culm	(±SD)
HSDB	68.33^{a}	3.011
EDB	62.50^{b}	1.971
TDB	53.33^{c}	1.633

(Values with the same letters are not)
(significantly different from each other at $p = 0.05$)

3.2 Head Loss at the Nodes and the Internodes

Table 4 shows the values of the head loss in mm for the nodes and the internodes and Table 5 shows the analysis of the results. The visual observable smoothness of the HSDB drill bit in the removal of the septa at the nodes as mentioned in section 3.1 probably resulted in the prepared pipes using this drilling bit giving the lowest head losses at the nodes (35.33 ± 0.398 mm) which is significantly better than the 45.77 ± 0.516 mm for TDB and 50.10 ± 0.358 mm for EDB. It was also observed that the values of the head loss at the nodes exceeded those at the internodes (Table 4) for all cases of the prepared bamboo pipes irrespective of the drilling bits used in preparing the pipe. This implies that there are less friction along the internodes compared to the nodes probably because the passage through the nodes were artificially created by drilling through a closed passage (septa) with sharp-edge instruments (drilling bits) which introduced jagged and rough edges thus increasing the roughness. For the internodes the head loss again was observed (Table 5) to be significantly less for the HSDB (30.15 ± 0.187 mm) prepared pipes than for TDB (30.78 ± 0.306 mm) and ETB (30.52 ± 0.258 mm) prepared BPs. This may be due to the fact that the HSDB did not introduce noticeable roughness to the intermodal section during drilling through the septa, since the appropriate sizes of the drilling bit corresponding to the changing diameters of the internodes were used. The other two bits affected the wall of the internodes as the process of drilling progressed especially towards the smaller diameter sections of the pipe thus introducing roughness. It is therefore advisable to use the hole saw drilling bit (HSDB) to remove the septa in order to obtain reduced head loss for the pipe. In addition, the efficiency of the pipes in conveying water was also calculated by subtracting the average head loss from the average piezometric head and finding this as percentage of the average piezometric head (Table 4).The efficiency (%) of the pipes using HSDB was observed to be higher than those for TDB and EDB ($97.7\% > 97.3\% > 97.2\%$) as shown in Table 6. The low value of head loss and better conveyance of water led to increased efficiency of the pipe in agreement with White (2003).

3.3 The Bamboo Pipe (*B. vulgaris*) Hydraulic Characteristics

The summary of the hydraulic characteristics obtained for the *B. vulgaris* pipes are shown in Table 6. From the table, bamboo pipes prepared by septa removal using the fabricated Ethiopian drilling bit (EDB) recorded the highest head loss in pressure (for water flowing through the pipe). This showed that such pipes have high resistance to water flow (i.e. high frictional value). Those prepared using the Tanzanian drilling bit (TDB) showed better performance (lower resistance to flow) while those prepared by the off-shelf Hole saw drilling bit (HSDB) were the best. The average head loss was in the order of 40.4mm (for EDB), 38.1mm (for TDB) and 32.8mm (for HSDB). The higher the value of the head loss the rougher the inner wall of the bamboo pipe. However, all the pipes still exhibited potential of good water conveyance structure as head loss recorded for the pipe lengths are still within the acceptable limit. Miller (1996) submitted that the mean head loss for 1000m of pipe is about 10m (i.e. 1%). The values of the percentage head losses obtained for the bamboo pipes using the three

Table 4: Values of head loss in different pipe sections of the *B. vulgaris* culm

Drilling bit used to drill the pipe	Bamboo identification number	Average Piezometric head (mm)	Average Head loss in culm section (mm)	
			Nodal Section	Internodal Section
Hole Saw	1	1438	35.8	30.2
-do-	2	1442	34.9	30.4
-do-	3	1440	35.6	30.1
-do-	4	1442	35.5	30.3
-do-	5	1436	34.8	29.9
-do-	6	1437	35.4	30.0
Ethiopian	7	1444	50.3	30.7
-do-	8	1441	50.4	31.0
-do-	9	1443	49.6	31.2
-do-	10	1438	49.8	30.4
-do-	11	1439	50.5	30.9
-do-	12	1447	50.0	30.5
Tanzanian	13	1433	45.1	30.9
-do-	14	1425	46.0	30.8
-do-	15	1431	45.4	30.4
-do-	16	1435	45.7	30.5
-do-	17	1426	46.6	30.3
-do-	18	1430	45.8	30.3

Table 5: Mean Values of the Head Loss (±SD) at the Nodes and Internodes

Type of Drill Bit	Mean Head Loss (SD) at the Nodes (mm)	Mean Head Loss (SD) at the Internodes (mm)
HSDB	35.33 (±0.398)^a	30.15 (±0.187)^d
EDB	50.10 (±0.358)^b	30.78 (±0.306)^e
TDB	45.77 (±0.516)^c	30.53 (±0.258)^e

(Values with the same letters are not significantly different from each other at $p = 0.05$)

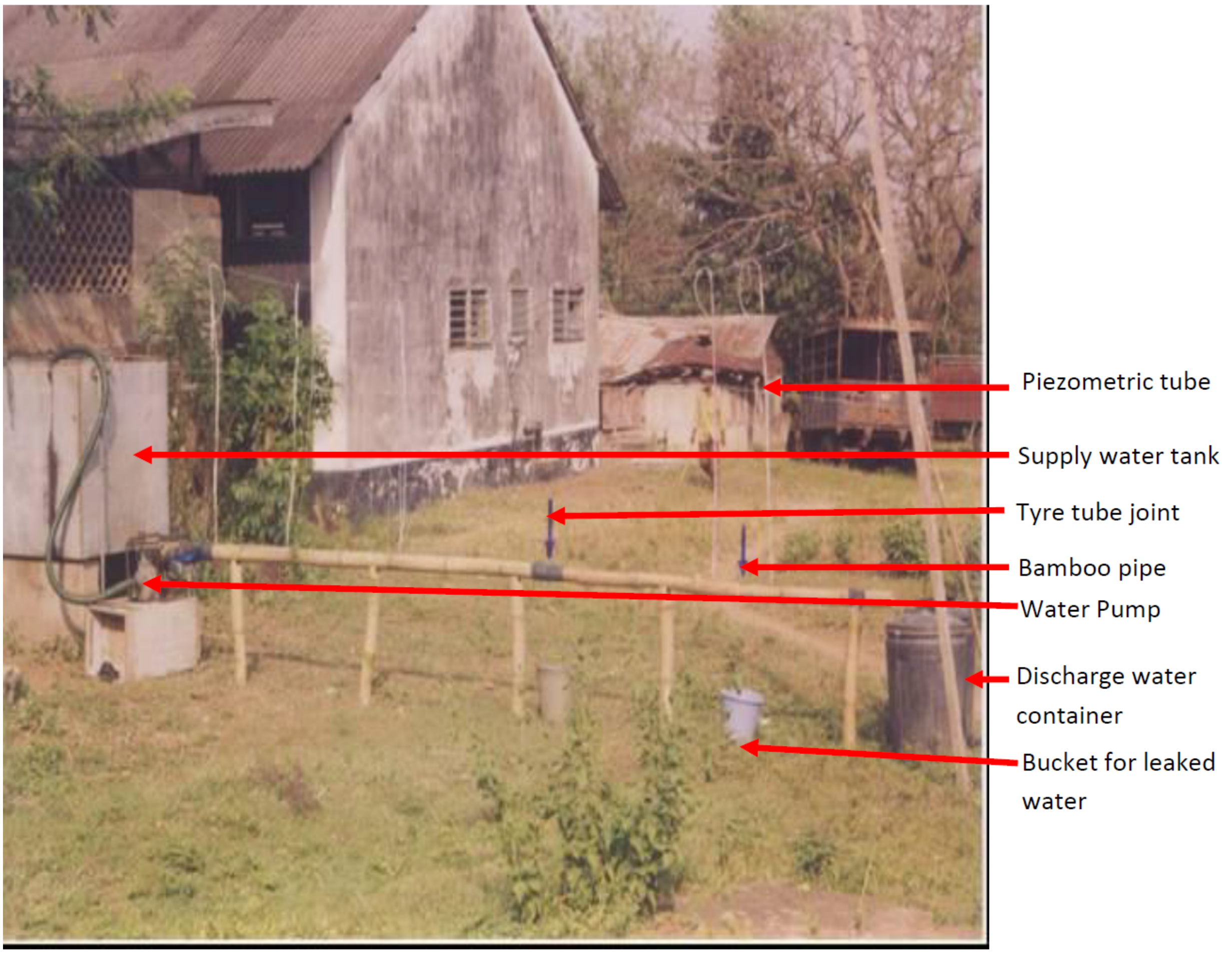

Figure 7: The experimental setup to determine the hydraulic characteristics of the Bamboo

drilling bits (Figure 6) were 0.37% for the HSDB prepared pipes; 0.45% for the EDB prepared pipes and 0.42% for the TDB pipes, all of which are less than the allowable percentage of 1%.

The flow of water in the pipe (Figure 7) was also observed to be turbulent with Reynolds number $(R_e)5.22 \times 10^4, 5.28 \times 10^4 and 5.47 \times 10^4$ (Table 4) for bamboo pipes prepared using TDB, EDB and HSDB respectively. White (2003) stated that for turbulent flow $R_e \geq 2000$. From the same Table, average friction factors obtained for the bamboo pipes were of the order 0.037, 0.047 and 0.049 for pipes prepared using HSDB, TDB and EDB respectively. These values also showed that the pipes prepared using HSDB had the least roughness probably due to the fact that the drilling bit was manufactured within the factory where more accurate precision would have been ensured compared with the fabricated bits (TDB and EDB). However, comparing all these values of the friction factor with pipes of other materials, the bamboo is not as smooth as plastic pipes with friction factors of between 0.003 to 0.03 but smoother than aluminium pipes, with friction factor of between 0.1 to 0.3 (Jensen, 1980). Both of these other pipes are currently in use in irrigation and / or drainage works. The choice of pipe materials for water conveyance is based on the ease of water flow within the inner bore of the pipe. The values of friction factors obtained for the bamboo pipes show that water can flow easily through it and it is good enough for water conveyance in irrigation and drainage practices on agricultural land.

Table 6: Values of head loss in different pipe sections of the *B. vulgaris* culm

Item No	Measured Hydraulic Parameters	Drilling Bits used to make the pipe HSDB	EDB	TDB
1	Average Internal diameter(d), mm	80.3	80.0	80.1
2	Average flow velocity (v), m/s	0.681	0.658	0.652
3	Average head loss (h_f), mm	32.8	40.4	38.1
4	Average friction factor (f)	0.037	0.049	0.047
5	Pressure drop $(\Delta p) N/m^2$	321.8	396.3	373.8
6	Reynolds's number $(R_e = \rho V d/\mu))$	5.47×10^4	5.26×10^4	5.22×10^4
7	Average Piezometric head,(mm)	1439	1442	1430
8	Pipe Efficiency, (E_p) %	97.7	97.2	97.3
9	Average Head Loss (%)	0.37	0.45	0.42

NOTE:

% head loss to the pipe length=$\frac{\text{Total head loss}\times 100}{\text{Total pipe length}(=9m)}$

$V = 4Q\pi/d^2; Q$ =discharge rate=$3.45 \times 10^{-3} m^3/s$

$f = 2gdh_f/LV^2$ (Equation 1)

L=3 metres (Length of the pipe of each type)

$\Delta p = \rho gh$ (Equation 3)

E_p (Item 7-Item 3)/Item 7

4 Conclusion

The study showed that Bamboo pipes (*Bambusa vulgaris* (Schrad)) have inner walls which are smooth enough to allow the passage of water with little head losses. Even with the rough edges resulting from the use of the drilling bits to remove the septa (diaphragms) at the nodes, the pressure drops were minimal. The head losses, along the internodes and pressure drops due to the nodes, were all within the acceptable limits. Therefore, aside its low cost and availability, pipes of *B. vulgaris* are also hydraulically suitable to be used in water conveyance.

References

[1] Armstrong, W.P. Bamboo Remarkable Giant Grasses. `http://www.waynesworld.edu`. (2006) Accessed 10/06/2006.

[2] Banik, R.L. and A.N. Rao, 1995. Bamboo: Strategies for Improvement. In Ganapathy, P.M., Janssen, J.A., Sastry, E.B. eds., Bamboo, People and Environment. Vol. 3, Engineering and Utilization. Proceedings of the 5th International Bamboo Workshop and IVth International Bamboo Congress, Ubid Bali, Indonesia. pp 1-17.

[3] Douglas, J.F., J.M. Gasiorek and J.A. Swaffield, 1997. Fluid Mechanics, 4th edition, Pearson Education Publishers, New York, USA.

[4] FAO, 1990. Design and Optimization of Irrigation Distribution Networks. Irrigation and Drainage. Paper 44. FAO Rome.

[5] Gaur, R.C., 1990. Bamboo Research in India, Systematic Botany Branch. Forest Research Institute and College, India. pp 26-31.

[6] Gib. C., 2005. General Bamboo Information, American Bamboo Society. `http://www.americanbamboo.org`. Accessed 12/09/2005.

[7] Heuvel, K. Vandes, 1981. Wood and Bamboo for Rural Water Supply a Tanzanian Initiative for Self-Reliance. Published by Delft University Press, the Netherlands

[8] Higuchi, T., 1989 (b), Bamboo. Concise Encyclopaedia of wood and wood-based materials edited by Arno Schniewind pp 19-26.

[9] Janssen. J.J.A., 2000. Designing and Building with Bamboo. A Technical Report. Published by International Network for Bamboo and Rattan, No. 20, pp 1-10.

[10] Jensen, M.E. 1980. Design and Operation of Farm Irrigation Systems. An ASAE Monograph Number 3 published by American Society of Agricultural Engineers, Michigan USA, 829pp.

[11] Jonas, M.K., 1992. Steady Incompressible Flow Through Pipes. In Essentials of Engineering Hydraulics. Published by the Macmillan Press Ltd. Basingstoke, London, UK, pp 17-60.

[12] Kirchoff, W., 1988. Wastewater Treatment of Low Cost Bamboo Trickling Filter and Pond Systems. Bamboos Current Research. Proceedings of the International Bamboo, CAF, China and IDRC, Canada 7pp.

[13] Liese, W., 2004. Structures of a Bamboo Culm Affecting its Utilization. `http://www.inbar.int/publication`. Accessed on 10/06/2005.

[14] Lipangile, T.N., 1989. Maintenance and Operation of Bamboo Pipe Water Supply System. Bamboos Current Research. Proceedings of International Bamboo Workshop Organized by CAF, China and IDRC, Canada 4pp.

[15] Perdue, R.E., 2005. Raw materials for More Paper. United States Department of Agriculture, Crop Research Division, Agricultural Research Service, Bellsville, Maryland, USA, 6pp

[16] Sanghvi, A.B., 1985. The Use of Bamboo and Timber Pipes in Rural Water Supply Scheme and Irrigation, Seminar on the Role of Engineers in Agriculture, pp 1-14.

[17] Verma, L.R., 1998. Indigenous Technical Knowledge for Watershed Management in Upper Northwest in Himalayas of India. PWTMA Programme GCP/RAS/161/NET, FAO. `http://www.org/docrep`. Accessed 06/06/2005.

[18] White, F.M., 2003. Fluid Mechanics 5th edition McGraw Hill Book Company, New York, USA, pp 52-78.