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Final Report

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Department of Industrial Engineering
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School of Engineering
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Amherst, Massachusetts

April, 1976

This report is in fulfillment of Grant W2/181/17 of the World Health Organization, Geneva, Switzerland, dated 20 March 1974 and additional support granted in May, 1975, for a feasibility study on the use of bamboo pipes in pressurized water systems. (University of Massachusetts, World Health Organization Trust Fund, Account Number 5-29800).

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LIBRARY
International [illegible] Centre
for Community [illegible] Supply

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Many individuals gave assistance in this study. A few students were able to work part time during a semester. Another student made the trip to Costa Rica. Engineers, foresters, botanists, public health professionals, airline representatives and friends put in an oar from time to time. The pressure of time was always on the work, so that we were busy people imposing on busy people. The courtesies extended by those named and those unnamed are gratefully acknowledged.

Stanley Lippert

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ABSTRACT

The feasibility of using bamboo for pressurized pipe distribution systems, in contradistinction to bamboo pipes used in tube wells and in unpressurized systems, was investigated. A literature search revealed negligible information on pressurized systems.

A laboratory test was devised for determining the pressure capabilities of several species of bamboo. This test revealed high variability between species, high variability within species, and high variability at different locations along the culm, with regard to the ability to withstand pressure in the pipe.

Other less critical properties of these same few bamboo species were also investigated, such as septum removal, joining, sizing, preserving, and strengthening.

A field trip to Costa Rica was made to put into practice in the field some of the tests and fabrication techniques studied in the laboratory.

Recommendations are made for further work in a development stage, based on laboratory and field experiences.

Only material tested
What about domestic joints? p. 132

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INTRODUCTION

The July-August, 1964 issue of WORLD HEALTH described water needs in the developing countries and showed the human effort required to obtain water in some communities. The August, 1965 issue described bamboo used in a pump, bamboo used as an unpressurized conduit, and bamboo used as a container for carrying water.

In 1966, McClure published "The Bamboos, a Fresh Perspective."

In June, 1967, The Third Congress of International Ergonomics Association met in Birmingham, England. One seminar was devoted to invited papers on "Ergonomics in Developing Countries."

In October, 1967, the Human Factors Society at its Eleventh Annual Meeting devoted a session to Human Factors in Developing Countries. The papers given at this session were published in the December, 1968 issue of Human Factors.

In the late 1960's, the VITA (Volunteers for International Technical Assistance) Boston Chapter was actively engaged in studying possible ways of assisting developing countries. The principal investigator of the present project participated in some of The Boston activities. The bamboo pipe problem was not considered at the various meetings.

These publications and meetings led the investigator to the idea that perhaps new technology could contribute to an already highly developed bamboo technology by investigating the feasibility of using bamboo in pressurized pipe systems. In December, 1973, the University of Massachusetts proposal to the World Health Organization for such a study was made. In April, 1974, authority to undertake work was granted, in accordance with a modified work statement by the World Health Organization.

Brief, informal survey work had been done by the principal investigator before the contract award. In January, 1973, a trip was made to the Institute of Tropical Forestry and the Agricultural Research Station in Puerto Rico. A trip to Colombia, December 1973 was made with a University of Massachusetts student. A side trip to Honduras was made by the investigator, January 1974. From inquiries and searches made thus far, no ongoing research in applications of bamboo technology is being undertaken in institutions in Puerto Rico, Colombia, or Honduras. A few individuals had been active earlier.

The active study of bamboo was found in Washington, D.C. at the Smithsonian Institution in the Botany Section, with the major emphasis of the work on botanical aspects of bamboo, not bamboo technology. There is a possibility that some attention will be directed to bamboo technology in the future.

It is now in order to examine the efforts undertaken in the present study. The attempt to locate literature relevant to the use of bamboo in pressurized water pipes is a good place to begin.

LITERATURE SURVEY

The attempt to locate the literature on bamboos in general and on mechanical properties in particular, especially on bursting strength of various bamboo species, began with a search at the University of Massachusetts. The Botany Department was contacted. No one was located with specialized knowledge on bamboo. One small and unhappy bamboo plant was found in a greenhouse on campus. The University Library catalog was searched. A book or two on ornamental uses were located. Inquiries by telephone to museums at Harvard University led to Dr. Thomas Soderstrom, of the Smithsonian Institution, Washington, D.C.

A visit to Dr. Soderstrom revealed that the late F.A. McClure had left his collection of books and papers to the Smithsonian Institution, and had catalogued them in a way most useful to users of bamboo as well as botanists. Those classification terms relevant to the pressurized bamboo pipe problem were used to locate a few documents. Copies of selected references or portions thereof were kindly furnished by the Smithsonian Institution for the present study.

The most extensive bibliography on bamboo located was at the Smithsonian Institution. This was in a report by Sineath, Daugherty, Hutton, and Wastler (1953) of the Engineering Experiment Station of the Georgia Institute of Technology. References cited number 287. Entries in the bibliography numbered 1034. (Entries in the reference list may also be found in the bibliography.) As a crude estimate, these lists refer to 20 percent of the Smithsonian Institution Collection. An extensive discussion of seasoning, preservative treatment and physical properties of bamboo was also obtained from the Smithsonian Institution. This was found in a report by Glenn, Brock, Byars, et al (1954) of the Clemson Agricultural College, The A & M College of South Carolina.

The files of the Institute of Tropical Forestry in Rio Piedras, Puerto Rico were checked. Some references on preservation of bamboo and protection were located. A preliminary report by Heck of the Forest Products Laboratory, U.S. Forest Service, Madison, Wisconsin was found in the files. Later, a copy of the final released report, Heck (1950) on physical properties of some bamboo cultivated in the Western Hemisphere was obtained.

A visit was made to the Federal Experiment Station, Mayaguez, Puerto Rico which provided a few pamphlets from its library. Mature specimens of many bamboo species were inspected at this station.

A librarian at the National University in Medellin, Columbia searched for bamboo information. Nothing of especial interest was found. Professors and researchers who were reported to have an interest in bamboo could not be located, one difficulty being that it was a holiday season. The National University in Medellin has a field station at which bamboo is grown. This is some distance from the University itself, near Santa Fe de Antioquia. A trip was made to the field station, but travel difficulties prevented arrival until just before nightfall. On this trip, a wood technologist was encountered, in the middle of a river which was being forded. He was from the National University in Medellin. He furnished one reference on bamboo. Unfortunately, he was proceeding in the opposite direction from the investigator's party. Further contact with him by mail was not successful.

The card files of the National Library in Bogota, Colombia were searched for references to bamboo. The only document located of interest was a classification of regional plants. A description of Guadua angustifolia was copied.

In June, 1975, Bill Long and Molly Cook of the Agency for International Development Offices in Washington, D.C. and Dale Swisher in Rosslyn, Virginia were visited. The A.I.D. report, AID-UNC/IPSED Series Item 3, October, 1966, "Water Supply and Sanitation in Developing Countries: Water Supply Using Bamboo Pipe," prepared at the University of North Carolina, Chapel Hill, has the only explicit reference to bamboo and water pressure located to date. This useful report cites the Department of Health in Djakarta, Indonesia as its source of information. It is, therefore, a secondary source. The one point in it which refers to pressure in bamboo pipes is not technically documented. Further reference will be made to this report in discussing the mechanical properties of bamboo.

Author F.E. McJunkin →

There is an excellent library at Turrialba, Costa Rica, covering forestry, agriculture, and animal sciences. However, little information on bamboo is available. The librarycarries INDIAN FORESTRY, which has published articles on bamboo. Some early issues were checked for several specific articles on bamboo. Unfortunately, these early sets were incomplete, and not one of the articles on bamboo could be located. The Documentation Center is active and impressive, as noted in the September 2, 1975 Progress Report.

The library of the University of Costa Rica in San Jose was not checked. From contacts at the University of Costa Rica and at the Tropical Agricultural Research and Training Center in Turrialba, no references were made to the University Library as a resource by the Forestry personnel at the University or in Turrialba. Costa Rica has scattered bamboo plantings, but bamboos are by no means a dominant feature of the landscape seen by this investigator between Siquirres and Puntarenas.

The book, "Drawers of Water" by White, Bradley, and White (1972) is highly relevant to pressurized bamboo water pipe studies because of its sophisticated analyses of small water systems, the variety of its observations, the organization of the material, and the attention given to personal and community responses to water supplies. Although bamboo is not discussed, the book should prove of interest to researchers interested in pressurized bamboo pipe systems.

The United Nations, Department of Economic and Social Affairs published a report "The Use of Bamboo and Reeds in Building Construction" (1972). This draws heavily on an earlier report by F.A. McClure (1953), "Bamboo as a Building Material," but adds new information. It is available, whereas the McClure report is out of print.

A book by Oscar Hidalgo Lopez, "Bambu: su cultivo y applicaciones en: Fabricacion de Papel, Construccion, Arquitectura, Ingenieria, Artesania" was published in 1974. It is the best single source of non-botanical information about bamboo. It is written in Spanish, but the excellence of its photographs and drawings makes it understandable without knowledge of the language.

Hidalgo's book is a collection of material from many sources. No mention is made of pressure characteristics of bamboo.

In the past two years, tid-bits of information have filtered in from several sources. Active work in India, where bamboo is used in tube wells, has been reported in newspapers and by personal references. The Intermediate Technology Group in London in one of its publications described how pipes are joined in Ethiopia, using one species of bamboo. The material is based on the Agency for International Development report noted above. The literature of interest is small indeed, does not bear directly on the key problem and is found in scattered and arcane publications. The impression gained is that only a few places in the world have an historical and present interest in bamboo, and publish reports on the uses of bamboo. The Forest Research Institute, Dehra Dun, India is one.

At various times, bamboo is a popular topic. At one time, as a paper source. At another time as a reinforcing agent in concrete, then as a furniture material. Again, as a material for low cost housing or scaffolding or bridges. All the while, it has been used in daily life in a variety of cultures for centuries.

Whether or not new chemicals, new handling methods, and current needs indicate the feasibility of using bamboo to carry water under pressure-- the central purpose of this investigation-- is not properly answered by the literature thus far encountered.

Other than the A.I.D. reference, which cited no specific laboratory determination of the pressure properties of bamboo, no pressure information was found in the literature examined. This is the single most important property of interest to an extension of the uses of bamboo pipe.

In this section, the search process has been noted. More detailed references will be cited in other sections of this report, including the Appendices. McClure's book (1966) contains most references of value. The present literature search really ends up with notes on a particular sub-set of his references.

While the present report was in preparation, a report by Romesh Chandra (1975) was announced by the Food and Agriculture Organization of the United Nations, "Production and Cost of Logging and Transport of Bamboo." Chandra's chapter titles are

Introduction

Structure of Bamboo Forests

Statistical Information

Labour Force

Tranport Systems

Felling and Conversion

Off-Road Transport (Extraction)

Long Distance Transportation

Cost Summary

Mechanization

Rationalization of Harvesting

Conclusions

There are eight appendices with practical information and 32 references, including 13 on bamboo, many on harvesting and transport.

Chandra's report is directed toward the problem of harvesting and transport of bamboo used for paper products. This is large scale industry. Nevertheless, it should prove quite helpful to investigators on pressurized bamboo pipe problems.

The hard copy books and articles in Human Relations Area Files in New Haven, Connecticut and the microfiche copies of similar material in the University of Massachusetts library were searched for possible cultural clues to attitudes towards water in various groups on which anthropological field studies exist. The area covered was South America. Approximately half of the records on 45 societal groups were examined.

In practical terms, a basic library relevant to background information on bamboo might be:

1. McClure's book (1966)
2. Hidalgo's book (1974)
3. The United Nations (1972) report
4. The Agency for International Development Report (1966)
5. The report by Sineath, Daugherty, Hutton and Wastler (1953)
6. The report by Glenn, Brock, Byars, et al. (1954)
7. The FAO report by Chandra (1975)

LABORATORY WORK AT THE UNIVERSITY OF MASSACHUSETTS

The major laboratory task undertaken at the University of Massachusetts was the determination of the ability of sections of bamboo culms to withstand hydraulic pressure. The completion of paper work on the agreement which authorized the expenditure of funds came late in the Spring Semester of 1974, too late to have a choice of qualified students for the summer, the ideal time for accomplishing the work. However, procurement of bamboo was initiated immediately. A request was sent to Sr. Santos Barahona Ulloa, of San Pedro Sula, Honduras, to obtain samples of two different species observed on a tour the principal investigator took with him in January 1974, between San Pedro Sula and Tela, Honduras. These were promptly procured, shipped by air, and picked up promptly after arrival and agricultural inspection. To keep shipping costs low, the bamboo had to be pre-cut into 3 ft. lengths (.914 m). Samples were requested from the lower, central and upper portions of one culm of each species. No one to identify the species was found. Informal information was that a well-known agricultural research station in Honduras, which ordinarily might have been consulted, was not in operation.

A shipment of Guadua angustifolia, from Puerto Rico, was arranged by Mr. Narciso Almeyda of the Federal Experiment Station in Mayaguez. The samples were cut later and arrived about a month later than the Honduras shipment. During this period, no wood technology student was on the project, and the specimens were stored in the laboratory of the Industrial Engineering and Operations Research Department. There were many dry days during the summer, which led to some checking and splitting of the samples. The summer activity consisted of making photographs of record, measuring and storing of the bamboo. Dimensions of the bamboo as received are given in Appendix 11.

Most laboratory activity was carried out in September, October and November of 1974. Discussions on the method of testing led to the decision to cap each end of a test specimen, fill the section of the culm (nodal septa removed) with water, seal the top cap and pump hydraulic oil on top of the water. The first seal tried was automobile body filler. The first caps used were cast iron sewer pipe caps. The first hydraulic pump used was borrowed from one of the engineering shops. The seals required time to prepare, involved considerable rework time if the seal was not tight, and the filler material was difficult to remove from the caps. The local supply of cast iron caps did not include a size large enough for some samples. The available hydraulic pump was not large enough for the job, and required a different scale for the pressures of interest to the bamboo project. The first phase of testing was stopped. An hydraulic pump suitable to specimen testing tank was purchased, an improved clamping technique was tried, and end plates with a sheet neoprene seal was used. The new arrangement permitted rapid testing and easier reading of pressures. The small store of sample materials was soon exhausted. A more detailed description of the pressure test procedure may be found in Appendix 8 by Steven Lord. All bursting patterns of the culms were longitudinal. A crack became a lineal split, which sometimes proceeded right through a node. There was no splintering or debris from the burst specimen. The test method proved quite safe.

During the Fall Semester, two students from the Wood Technology Department lent their assistance to the program. They put specimens into controlled humidity chambers, made test coupons and assisted in running the bamboo tests. When some of the later tests were run, these students controlled the water content of the specimens. There was not a sufficient sample size to test for effect of water content and strength. A report by Whitehouse describes this phase of the work at the University of Massachusetts. A copy of the report is given in Appendix 7.

SOCIETAL ATTITUDES ON WATER

The Human Relation Area Files (HRAF) in New Haven, Connecticut represent several decades of collection and analysis of the anthropological literature. Some 700 codes are used to identify significant remarks found in the literature on the subject of interest. Of these 700 codes, five pertain to water.

Code 271. Water and thirst--use of water for drinking

Code 312. Water supply

Code 364. Water, purification systems

Code 414. Miscellaneous hardware, including plumbing (and pipes)

Code 823. Ethnogeography. Notions about water, topography, minerals, etc.

Approximately 300 societies throughout the world are represented in the literature analyzed, which is made up chiefly of field studies in anthropology. It is possible to locate information on a set of codes, such as the water codes alone, from any society whose studies have been analyzed. HRAF also publishes aids to facilitate such search. The HRAF files may be found in many universities, in hard copy or microfiche form. If one line in a report by the historian or investigator contains a reference to water, it is coded. The coding is done by professional anthropologists. As an example, from an account by

Garcilaso de la Vega circa 1555

(Society SE 13 INCA, Code 312--Water Works)

The Fifth Book of the Royal Commentaries, page 369, Chapter I

"As soon as the Ynca had conquered any kingdom or province, and established his Government amongst the inhabitants according to his laws and idolatrous customs, he ordered that the cultivated land capable of yielding maize should be extended. For this purpose he caused irrigation channels to be constructed, which were most admirable, as may be seen to this day; both those that have been destroyed, the ruins of which are yet visible, and those still in working order. . ." and Fifth Book, Chapter IV, "In the districts where only limited supplies of water for irrigation were procurable, it was distributed by fixed rule and measurement (like everything else that they supplied to the people), for there were no disputes among the Indians on these matters. In the years when there was little rain, the water was supplied by the State. . ." The references on approximately half the South American societies whose anthropological literature has been coded by HRAF were consulted.

The purpose of this exercise was to test a methodology for cultural enrichment on an engineering problem. It seems a good way for individuals not familiar with various societies to gain some insight into the cultural diversities which conceivably might still obtain in some areas, with regard to water. Work did not proceed beyond the selection and collection of data. A more extended study in connection with the actual installation of bamboo pipe systems would be required to see if practical results as well as the pleasure of the inquiry could be obtained.

FIELD WORK IN COSTA RICA

A trip to Costa Rica for the purpose of field testing pressurized bamboo water pipe in the field was undertaken by S. Lippert and T. Prunier during June and early July, 1975. The hydraulic pump and test jig, special fittings, tools and about 100 NO-HUB couplers were transported by private car to Miami. Travel from Miami to San Jose and return was by air. The entire trip took 29 days. Time in Costa Rica was 19½ days. The day by day account may be found in Appendix 11.

Direct negotiations for cooperation involved the Forest Products Laboratory, associated with the School of Engineering and located on the campus of the University of Costa Rica in San Jose. Michael Krones of the Laboratory had made arrangements for the visit. The major field work was accomplished at and near Centro Agronomico Tropical de Investigacion y Enseñanza (CATIE, the Tropical Agricultural Research and Training Center), Turrialba. Arnold Ericson, Secretary of Research and Jacob L. Whitmore, Forester were the major contacts at CATIE. The CATIE operation supports the Forest Products Laboratory. The financial imperative of a brief stay required fast scheduling of the successive steps in the development of a pipe line. Practically all assistance on the project was given without cost and with great patience.

The crucial task was to cut, core, size, pressure test samples and install a representative length of bamboo pipe requiring a pressure head to deliver the water. Three sites were considered. Rio Reventazon borders the CATIE campus. The steepness and height of the cliffs and the relative inaccessibility to the river bed for testing purposes would have required time and effort beyond the available means. Pressure requirements would have been beyond the pressure limits of the Bambusa vulgaris which was selected as the appropriate bamboo. An extremely accessible site was found at ATTIRO. Inspection of the site could not be arranged until later in the program, but the task would not have been rigorous enough at this site. The source was on a gentle slope above the dwellings which could have been supplied.

The site finally chosen was Quinta Elizabeth about 4 km from Siquirres, approximately an hour's drive from Turrialba. Quinta Elizabeth is simply the name of a site about 4 km from Siquirres, on the road from Turrialba to Siquirres. No improvements such as electricity, water or buildings were on the site. The road itself lies on a long ridge, on one side of which lies Rio Siquirres, whose source is several miles above Quinta Elizabeth. The other side of the ridge falls away to the much larger Rio Reventazon. There is a level area at the elevation of the road on the Rio Siquirres side which falls away to another relatively level area. The slope appears to be fill from the grading operation of the road. At the edge of the lower level area, there is a steep ravine leading to Rio Siquirres. This ravine is moist and covered by trees and shoulder-high tropical undergrowth. An uneven footpath winds down to the river, which has a narrow course. Rio Siquirres, at this point at least, is a small stream. Figure 1 is a contour map of the Quinta Elizabeth site.

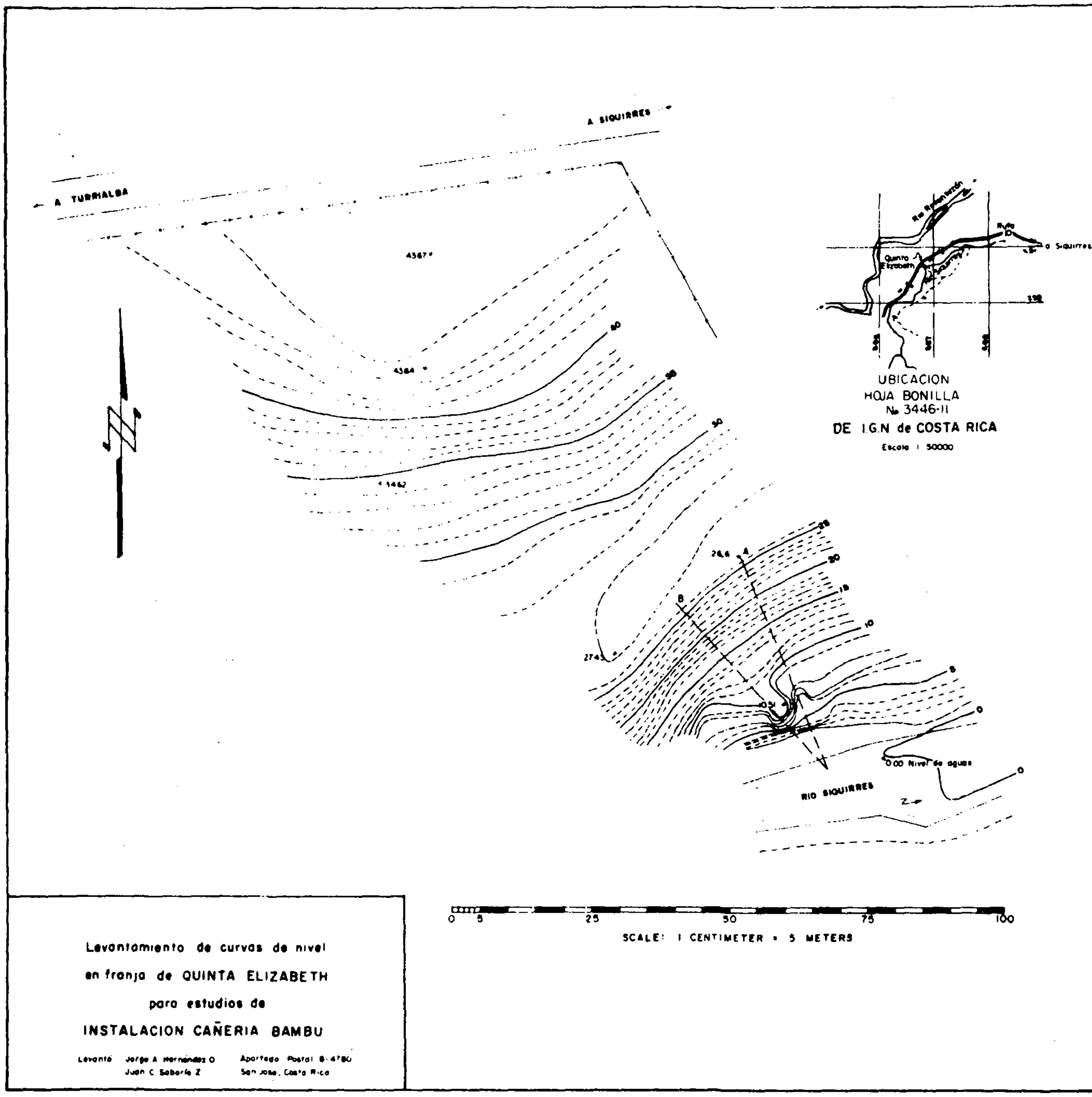
The installation of pipe was planned for a one day job on July 2, 1975. A truck and two workers were provided by CATIE. Prunier made an early morning start from Turrialba with a borrowed pump, pipes and tools. A personal jeep, carrying a total of five assorted professional people and a rented pump, was supplied by Michael Krones. Lippert left San Jose in the morning as a part of this group. Rendezvous was made at CATIE, Turrialba, with three engineering students of the University of Costa Rica who drove down in a personal vehicle, with surveying equipment. The two groups proceeded together to Quinta Elizabeth, reaching the site about noon. By that time, the approximate location of the pipe line had been determined by Prunier, and the pump borrowed from CATIE--a heavy and difficult load for the steep and slippery path--was approximately in place at stream level. The survey party started its work immediately. The volunteer professionals and CATIE personnel began the "laying" of pipe, starting from the top of the second level area. Working in high shrubbery, with no prior clearing operations, on a steep slope that required vertical and horizontal angle changes, made application of some NO-HUB joints difficult at times. Such a difficulty is not serious, since more flexible joints can be made from linking several short pieces. By approximately 2:00 p.m. or a little thereafter, the pipe was in place, supported by tall forked stakes made on the spot.

The rest of the afternoon was spent trying to get the borrowed pump working. This first required mending a tattered hose, getting the pump to run was another problem. The second smaller pump, rented for a back up, was then used. The motor ran, but no one succeeded in making it pump water, even at stream level. (The condition under which both pumps were obtained did not permit testing against a pressure head before going to the site). Had there been a water supply at the top of the pipe system, and water cans or hose, a pressure test could have been made by stopping the lower end and filling the pipe. The pleasure of pumping water up the ravine was denied the team, but the pressure tests made on sample sections of Bambusa vulgaris a few days before in Turrialba and the snug connections made at the joints leave no doubt as to the effectiveness of the pipe.

After 4:00 p.m., everyone except the surveyors left the site. The following day, the surveyors turned in their contour map of Figure 1. Lines A and B of Figure 1 indicate the estimated limits of the location of the pipe line. Figure 2 gives cross sections of the terrain for A and B, to show approximate the location and slope of the line, between the sector defined by lines A and B. Actually, the pipe line had horizontal as well as vertical curvature.

Color photographs of the pipe line installation work were made, but are not included because of cost.

FIGURE 1
SITE FOR THE INSTALLATION OF A BAMBOO PIPELINE AT QUINTA ELIZABETH, NEAR SIQUIRRES, COSTA RICA



REVISED 11/17/75
- SCALE ADDED
- CONTOURS DARKENED
D.R.W.

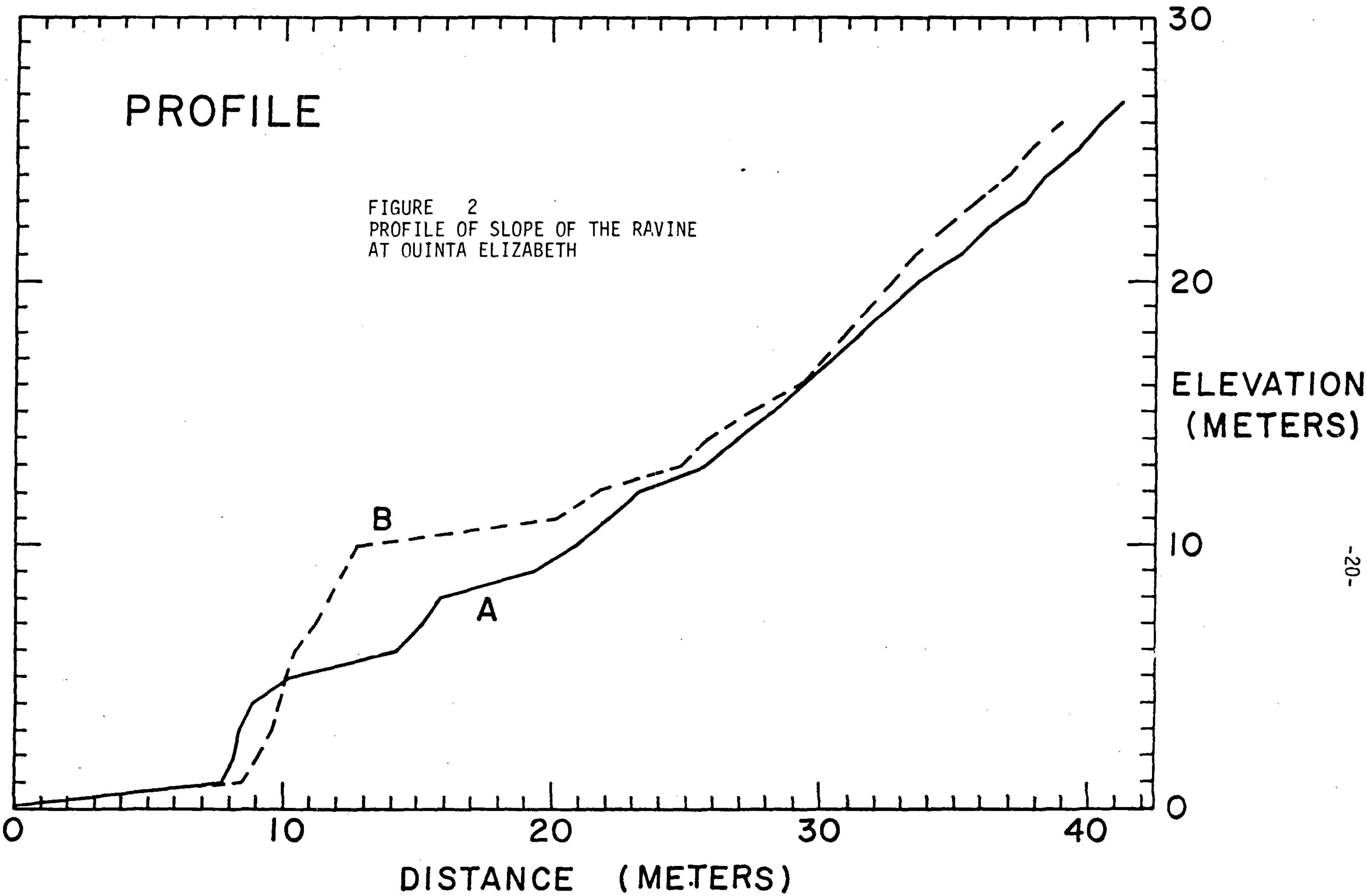


FIGURE 2
PROFILE OF SLOPE OF THE RAVINE
AT OUINTA ELIZABETH

PRESERVATION OF BAMBOO

Of the two identifiable species of bamboo tested in the laboratory or field on this project, two notes on preservation may be found in the United Nations, Department of Economic and Social Affairs Report (1972, p. 84 and p. 86). Bambusa vulgaris is "susceptible to invasion by Dinoderus, the powder post beetle." Guadua angustifolia is "resistant to both rot fungi and wood-eating insects." This same report, (page 91) recommends three different preservatives which, with varying treatments, would give an expected service life of 15 years, as shown in Tables 2 and 3.

Using these chemical treatments of the bamboo would differ according to the end use. The end uses for bamboo pipe would be in the open, sometimes in contact with the ground, sometimes not. Table 3 shows the different treatments (from p. 91). The technical reports or books, on which this information is based, are not cited.

Glenn, Brock, Byars, et al give experimental evidence on preservative treatments using high pressure and high temperatures on short sections of bamboo culms. The treatments do not appear suitable for field work. The value of the treatment is not indicated in the end use manner of the United Nations report. The preservative treatment section of their report requires expert interpretation.

These treatments do not consider the bamboo as pressurized water pipes. The potential effects of chemicals leading into the water supply would require study.

The United Nations Report (1972) on "The Use of Bamboo and Reeds in Building Construction" (page 27) states that "...treated bamboo should be given a water repellent treatment with a material such as paraffin wax or tung oil." The preservation and treatment of bamboo deserves more consideration than was possible under the grant. The Forest Research Institute at Dehra Dun, India appears to be an organization with interests and competence in this research area.

An interim method for the control of leaching is given in the Discussion Section.

TABLE 1

PRESERVATIVE CHEMICALS FOR BAMBOO
(from United Nations, Department of Economic and Social Affairs, 1972)

PRESERVATIVE	
A	Coal tar creosote and fuel oil, 50:50 by weight. In highly termite-infested areas it is preferable to add 1 percent dieldrin and in highly decaying areas 1 percent pentachlorophenol.
B	Copper-chrome-arsenic composition (Ascu). A typical composition of this preservative comprises copper sulphate ($CuSO_4$, $5H_2O$), arsenic pentoxide (AS_2O_5) and sodium or potassium dichromate ($Na_2Cr_2O_7$, $2H_2O$ or $K_2Cr_2O_7$) in the proportion of 3:1:4.
C	Acid-cupric-chromate composition (Celcure). A typical composition of this preservative comprises 1.68 parts of chromium sesque oxide (Cr_2O_3) (equivalent to 2.5 parts of sodium dichromate), 50 parts of copper sulphate and 47.5 parts of sodium dichromate.

TABLE 2

USES OF RECOMMENDED PRESERVATIVES FOR DIFFERENT END USES OF BAMBOO

End use of bamboo	Recommended preservatives[a] Dry Bamboo	Green Bamboo	Concentration of preservative (percentage)	Loading of dry chemical in bamboo (Kg/m^3)	Proposed treatment	Expected service life (years)
Use in the open and in contact with the ground (e.g., posts, pale-fencing, etc.)	A	...	...	80 to 128	Open tank for pressure process	15
	B & C	...	6 to 8	8 to 12	Pressure process.	
	...	B & C	6 to 8	5 to 8	Modified boucherie for 6 to 8 hours or steeping for 35 to 40 days.	
Use in the open but not in contact with the ground (e.g., bridges, scaffoldings, ladders, etc.)	A	...	...	48 to 80	Hot dipping or open tank or pressure process.	15
	B & C	....	5	5 to 8	Pressure process.	
		B & C	5 to 6	5 to 8	Modified boucherie for 4 to 6 hours or steeping for 20 to 25 days.	

A POSSIBLE METHOD OF STRENGTHENING BAMBOO

Since the fibers in the bamboo culm are parallel to each other, the culm tends to split easily. All of the samples tested for bursting strength failed by splitting. If a way could be found to cross-link individual fibers it is possible that the bursting strength might be improved.

Wes MacConnal, a doctoral student from the University of Oregon, with a background in pulp and paper science, suggested the use of formaldehyde and H_2SO_4 to cross-link the parallel fibers. Formaldehyde is a relatively inexpensive industrial chemical produced by catalytic oxidation of methanol.

Britt, in Britt (1970), "The Handbook of Pulp and Paper Technology" (page 380) states that methylene cross-links are formed by formaldehyde with cellulose at low pH and high temperatures. The reaction involved is:

$$2 \text{ cellulose} - O - OH + HCHO \longrightarrow \text{cellulose} - O - CH^2 - O - \text{cellulose}$$

Casey, in "Pulp and Paper" (1960, pages 40-41), states "The tensile strength and stiffness of fibers reacted with formaldehyde is greater than that of untreated fibers because of cross-linkages which diminish the tendency of the chains to slip past one another." (i.e. chains of cellulose molecules)

An effect of the formaldehyde treatment mentioned by Nicholas (1973, page 353) is the resulting severe embrittlement of wood. He notes that as little as 7 percent of bound formaldehyde can reduce swelling in response to water by as much as 90 percent. The probability that bamboo would behave in a similar manner must be considered.

A simple method of treatment of the bamboo could utilize a modified Boucherie process as described by Hunt and Garratt (1967, page 203). An inner tube is cut to make a long tube. One end is securely fastened around the butt end of the log, or bamboo in this case, and the other end suspended in the air. The formaldehyde solution is poured in the upright end and hydrostatic pressure forces the solution in and the sap out.

DISCUSSION

The major emphasis of the body of the report has been to convey the extent of the work accomplished. The appendices furnish much of the detailed information. In this section, the major findings and observations are discussed.

No technical information in the literature was found on the ability of bamboo to withstand hydraulic pressure. The only mention, without test data, was incorrect. The generalization of 30 psi maximum pressure (2.1 kg/cm^2) may be true of many species, but not of those candidate bamboos tested. Not only the species, but the age of the bamboo, its site and other conditions may affect its strength. Generally, maximum pressures that can be sustained fall as the specimens are taken at higher positions on the culm.

Of the three species tested in the laboratory at the University of Massachusetts and in the field at Turrialba

a. Bambusa vulgaris was the best of three species

(1) One laboratory specimen, 3 in (7.62 cm) outside diameter, probably taken from the lower third of the culm, did not burst at 225 psi (15.82 kg/cm^2).

(2) A second laboratory specimen, 2.88 in. (7.3 cm) outside diameter, probably taken from the middle third of the culm, split at 145 psi (10.19 kg/cm^2).

(3) A specimen tested at Turrialba, 2.9 in. (7.4 cm) outside diameter, taken from about 7 ft. above the ground, burst at 75 psi (5.27 kg/cm^2).

(4) A second specimen tested at Turrialba, 2.56 in. (6.5 cm) outside diameter, taken about 1 foot above the ground,

burst at 125 psi (8.79 kg/cm^2).

(5) A third specimen tested at Turrialba, 2.87 in. (7.3 cm) outside diameter, taken from about 10 ft. above the ground, burst at 70 psi (4.92 kg/cm^2).

b. Guadua angustifolia was second best.

(1) Six samples from the lower and middle portions of the culm, with outside diameters ranging from 3.38 in. (8.57 cm) to 4.2 in. (10.66 cm), burst at 70 psi to 100 psi (4.92 kg/cm^2 to 7.03 kg/cm^2).

(2) 1 sample from the upper third of the culm burst at 50 psi (3.52 kg/cm^2).

c. An unidentified specimen from the Catie Campus, Turrialba, outside diameter 2.91 in. (7.4 cm) burst at 35 psi (2.46 kg/cm^2). This specimen was third best, but not in the same class as Bambusa vulgaris and Guadua angustifolia.

d. Highest pressures were obtained on an unidentified specimen from Tela, Honduras, 3.75 in. (9.5 cm) outside diameter approximately 0.7 in. (1.8 cm) mean wall thickness. A pressure of 400 psi (28.1 kg/cm^2) was measured. This pressure could not be sustained with the equipment then in use. As a result of this test, a new hydraulic pump of greater capacity and a new meter was purchased. Later the method of testing the specimens was changed. This unidentified specimen came from a sample cut within 3 ft. (.91 m) of the ground. Specimens taken higher on the culm cracked in drying, so that no useful length of pipe could be tested. An adjacent cut proved to be amenable to machining.

Restated, the laboratory pressure tests showed that Bambusa vulgaris could sustain pressures between 145 psi and 225 psi (10.19 kg/cm^2-15.82 kg/cm^2). Field tests on fresh cut specimens sustained pressures between 70 psi and 125 psi (4.92 kg/cm^2 and 8.79 kg/cm^2). In the laboratory, Guadua angustifolia sustained pressures of 70 psi to 100 psi (4.92 kg/cm^2 and 7.03 kg/cm^2). No field tests were run on Guadua. The data suggested that when material is drawn from mature bamboo clumps of Bambusa vulgaris or Guadua angustifolia, the lower half or lower two-thirds of the culm will sustain 70 psi (4.92 kg/cm^2) or more. This does not meet the 200 psi (14.06 kg/cm^2) criterion discussed by Herrera in Appendix 6. On the other hand, no culture, selection, harvesting, processing, curing and strengthening techniques have been reported specifically for bamboo, and apparently no investment has been made to develop such information. A 70 psi (4.92 kg/cm^2) pressure is the equivalent of the pressure of a column of water 161 ft. (49 m) high. This is approximately twice the lift required to get water from the ravine of the Rio Siquirres at Quinta Elizabeth in Costa Rica, to the first level area.

The pipe installation exercise for Quinta Elizabeth indicated that an appropriate work place for removing the septa for pressure testing and for storing tools and equipment would be desirable as a base of operations if a large pipe installation or a number of small installations were to be made. A portable gasoline operated water pump is needed for places such as Quinta Elizabeth.

One person trained to operate and maintain a pump could service a considerable series of individual sites by pumping water to storage pools or tanks at desired higher locations. For example, one 3 horsepower pump available in a hardware store in San Jose, Costa Rica costs approximately $200.00. The performance chart for this pump gives a delivery rate of 600 U.S. gallons per hour (2.27 m^3/hr) for a 100 ft. (30.5 m) lift. Such a supply would last a household for many days for cooking and other uses. A man with such a pump could possibly service 5 households in a day, 25 to 30 in a week. An average of 7 individuals per household was the estimate for small rural communities in Colombia (see Herrera, Appendix 6). Water consumption is estimated at 40 gallons (.15 m^3) per day per household where there is no bath, shower or toilet. Thus, a community of approximately 200 individuals could be serviced for a pump investment of $1.00 per person, plus operating expenses of the pump and compensation for the man who runs the pump.

In the preparation of the pipe itself, without chemical treatment, approximately $2.00 U.S. is the retail cost of the NO-HUB coupler. At the present time, use of a thin plastic sleeve inside the pipe seems appropriate to eliminate possible bad taste from the bamboo. Prices have not been investigated for the plastic.

A regional workshop, perhaps a travelling work group with drills, bits, saws, an hydraulic pump and miscellaneous tools and equipment, is needed. This would require $1,000.00 minimum.

Transport from the bamboo grove site to a field work station and hence to the community will vary greatly. An analysis of the engineering information plastic on the pipe lines for small communities in Colombia would provide excellent information on the variability of requirements in largely mountainous terrain. The transport costs of bamboo for the paper industry in India is outlined in Chandra's (1975) report on the production and cost of logging and transport of bamboo. This report describes large scale operations and heavy transport, at the other extreme from the small community operations to which this pressurized bamboo water pipe feasibility is addressed.

A 20 ft. (6.1 m) length of dry Bambusa vulgaris would weigh approximately 40 lb. (12.2 kg), dry weight. A 20 ft. (6.1 m) length of dry Guadua angustifolia would weigh approximately 48 lbs. (14.8 kg) or less.

Some estimate of the variability of physical properties of a few candidate bamboos can be made by examining selected data taken from McClure (1944) as shown in Appendix 2. The numbers are rounded off. The material was Guadua angustifolia obtained in the Canal Zone. The manufactured part was a bamboo ski pole. Manufacturing control was excellent. Testing was accomplished by the United States Bureau of Standards. Table 1 presents a partial recapitulation of mechanical properties of Guadua angustifolia.

TABLE 3

MECHANICAL PROPERTIES OF BAMBOO SKI POLE SHAFTS PREPARED BY THE ORVIS COMPANY FROM GUADUA ANGUSTIFOLIA USING SYNTHETIC CEMENT

BASED ON McCLURE (1944) TABLE 19 DATA, AS SUMMARIZED IN APPENDIX 2, TABLE 1

Number of samples 15

	Dimension	Standard Deviation	Coef. of Variation
Mean thickness at top	0.51 in.	.008 in.	2$^-$%
Mean thickness at butt	0.64 in.	.012 in.	2$^-$%
Weight	.44 lb.	.04 lb.	9$^-$%
Deflection	30. lb	2.7 lb.	9$^-$%
Compressive load (column)	176. lb.	27. lb.	15$^+$%
Transverse Span Breaking	365. lb.	64. lb.	18$^-$%
Cantilever Test	31. lb.	8. lb.	24$^+$%
EStimated age of sample	40$^+$ months	13+ months	33$^+$%

In all but compressive load, the coefficient of variation is greater with the synthetic cement and the specimens from the older culms of the ORVIS Company.

Much greater variability should be expected in the village technologies anticipated in the use of bamboo for pipes taken from uncultivated stands and treated and assembled in the field. The above findings suggest an upper limit to quality control that might be expected.

For pressurized water pipe, a fair sampling of species, sites and clumps is required to establish variabilities of the material, with the lowest permissible pressure for suitability defined.

For bamboo pipelines some reasonable small sample testing to get statistical information is needed. However, small sub-assemblies, say of 5 pipe lengths, can be tested at the fabrication site before being carried to the field for placement.

RECOMMENDATIONS

1. The use of bamboo pipe to carry water under pressure is feasible.
2. Immediate use with pressures approximately 70 psi ($4.92\ kg/cm^2$) is possible.
3. Support for development and production should be based on the potential for agriculture and the need for water in the residence.
4. Several aspects of the work can benefit from work-study projects of undergraduate and graduate university students. See, for example, the contour map presentation of Quinta Elizabeth made by 3 students of the University of Costa Rica, School of Engineering, and the potential analysis of the plastic pipe projects for small communities carried out in Colombia.
5. Some half-dozen sites should be selected for test installations. Expert assistance on bamboo identification is required.
6. Central coordination of the effort is needed, but a major portion of the work can move to regional research and agencies actual sites. A major contribution of the central coordination would be to reproduce some of the extant literature, for distribution.
7. In some areas, large land owners may be in a position to introduce the use of bamboo pipe earlier than national government agencies or small communities. The present need is to get some bamboo pipes into representative water systems. Then service life, costs, priorities for improvement and other matters can be checked before large-scale efforts are attempted.
8. Plans for further work should be predicated on a two-three year funding period. (The present project was accomplished with short term

funding and a heavy reliance on volunteer assistance. The monies came through just when students were already committed for vacation). This allows for effective use of personnel.

9. If development and installation work is accomplished and shows high utility, research support for organizations and individuals with long term interests in the technical aspects of bamboo culture and use should be given major research support.

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**See Appendix 1

***This publication does not deal with bamboo pipe, but is a recent bibliography on rural water supply.

APPENDICES

The appendices contain much of the detailed information on which the body of the report is based. In the reports by Herrera and Whitehouse and in the progress reports, issued in the course of the study, page numbers had already been assigned. The original numbers have been kept, but are now enclosed by a circle. For convenience, the pagination of the body of the report is maintained throughout the appendices as noted by -35-, etc.

APPENDIX 1

SELECTED INFORMATION FROM "BAMBOO STUDIES"

BY

YOSHIO TAKENOUCHI

Tokyo: 1932

In the literature cited by McClure (1966), the reference is explained as follows:

> Take no kenkyu [Bamboo studies; in Japanese; with bamboo names in Latin] (Tokyo). Citations in the present work refer to the pagination in a manuscript English translation begun by F.A. McClure and Kam Hok-chau and completed by R.A. Young and Mary Schoff, and deposited in the Library of the U.S. Department of Agriculture. ...

STUDIES ON THE BAMBOOS

by Yoshio Takenouchi (1932)

The Smithsonian Institution has a copy of this book in Japanese, plus a carbon copy of an English translation. A reference system devised by F.A. McClure led to Part VIII, Chapter 1-- Utilization of Bamboos on the Basis of Their Physical Characteristics. This chapter contains interesting information. Takenouchi says, "In general, the uses of the culms may be clarified according to the following characteristics:"

1. Splitting quality of the culm
2. Elasticity
3. Weight resistance
4. Bending resistance
5. Pressure resistance
6. Fistulous character

The "pressure resistance" is not a bursting pressure, the chief physical property of interest in pressurized bamboo pipe.

Part X of Takenouchi contains information on the elasticity of bamboo culms for four species, as a function of elapsed time and height of culm.

This reference is noted because it discusses physical properties. Perusal of the translation of the document at the Smithsonian Institution and reading of xeroxed portions of it do not indicate it to be of direct interest for the pressurized pipe problem. Furthermore, the bamboos studied were not the ones which this project was able to test. Only one of the four bamboos on which elasticity data were collected in Takenouchi's Table 28 is included in McClure's (1953) list of bamboos suitable for pipes, the Giant Timber Bamboo, Phyllostachys bambusoides("Madake" in Japanese, "Kam Chuk"in Chinese).

APPENDIX 2

STATISTICAL SUMMARY OF MECHANICAL PROPERTIES OF SKI POLE SHAFTS FABRICATED FROM GUADUA ANGUSTIFOLIA

The information in this APPENDIX is based on Tables 19 and 21 of WESTERN HEMISPHERE BAMBOOS AS SUBSTITUTES FOR ORIENTAL BAMBOOS FOR THE MANUFACTURE OF SKI POLE SHAFTS(U.S. NATIONAL RESEARCH COUNCIL. COMMITTEE ON QUARTERMASTER PROBLEMS. FINAL REPORT QMC-24)

by

F.A. McCLURE

APPENDIX 2

MECHANICAL PROPERTIES OF BAMBOO: PERFORMANCE OF SKI POLE SHAFTS

The primary property of bamboo on which information is desired for the design of pressurized water pipes is bursting strength. No technical information was found on this subject. The literature contains some information on other physical properties.

In January, 1975, a visit was made to the Charles P. Orvis Company in Manchester, Vermont. This company, which has been making bamboo fishing rods since the 19th century, was kind enough to provide a tour through their plant for S. Lippert and Richard Hoffman (a graduate student in Wood Technology). The factory imports ungraded "Tonkin cane" (Aurundinaria amabilis) then selects the individual culms for size, color and quality. The selected parts are cut, heated, chemically treated, milled into an equilateral triangular cross section to a tolerance of one quarter of a mill (0.00025 in.). The triangular shape is also tapered from the base of the finished rod to the top. Six triangular sections are cemented together to form a rod with a hexagonal cross-section with nodes offset to prevent a local weak spot. The present factory is new, has a stable work force, and is immaculately clean and well ordered. The quality and precision of the bamboo work thus represents an intimate knowledge of bamboo and extraordinary skill in its fabrication into poles.

The supervisor of the factory gave Lippert a Xerox copy of a 1944 report by F. A. McClure, on bamboo ski poles. The supply of Tonkin cane was cut off during the war. The U.S. Army was interested in determining if other bamboos might be utilized, and so authorized a search for various bamboo species and a testing program on mechanical properties. McClure travelled to Central and South America to collect samples of various bamboos. These were sent to the Charles P. Orvis Company, then in an older facility, and to the Montague Rod and Steel Company, Montague City, Massachusetts, for the fabrication of test specimens of ski poles. The ski pole specimens were then tested by the United States Bureau of Standards. The Orvis Company used essentially the same methods in the 1940's as used in the 1970's. A synthetic binder was used, then and now. The Montague Rod and Steel Company, no longer in existence, used animal glue in the assembly of its experimental ski poles.

From McClure's 1944 report, statistical information has been collected on physical properties of the ski poles. Attention is directed to Guadua angustifolia because that is one of the candidate bamboos for pressurized pipe. Tables I and II summarize the information found in Tables 19 and Table 21, respectively, of McClure (1944). The tables are given to four decimal places for convenience in checking the work and changing from English to metric units.

Botanical and commercial information on Aurundinaria amabilis and Guadua angustifolia may be found in McClure's book (1966).

TABLE I

Statistical Summary of Results from Table 19 of McClure, 1944

Performance of Ski Pole Shafts
Guadua angustifolia (H.B.) Kunth.Canal Zone
Manufacturer of poles, Charles P. Orvis Company, Manchester, Vermont *

NUMBER OF SAMPLES		UNITS	STANDARD DEVIATION	COEFFICIENT OF VARIATION
15	Mean Thickness Tip	0.5145 in. 1.307 cm.	0.0082 in. 0.021 cm.	1.5891%
15	Mean Thickness Butt	0.6408 in. 1.68 cm.	0.0123 in. 0.053 cm.	1.9233%
15	Weight (48" long specimen) (121.9 cm.)	0.4395 lb. 0.199 kg.	0.0386 lb. 0.018 kg.	8.7930%
15	Test No. 1 Deflection	30.0000 lb. 13.608 kg.	2.6726 lb. 1.212 kg.	8.9087%
15	Test No. 2 Column Load (Maximum Compressive Load)	176.0000 lb. 79.834 kg.	26.9391 lb. 12.220 kg.	15.3063%
8	Test No. 3 Transverse span breaking test. Span 15.5 in. starting 8 in.(20.32 cm.) from small end of specimen	364.7500 lb. 165.451 kg.	64.2045 lb. 29.123 kg.	17.6023%
7	Test No. 4 Cantilever Test	31.0000 lb. 14.062 kg.	7.5498 lb. 3.425 kg.	24.3543%
11	Estimated Age of Sample at time of cutting, Months	40.3636 mo.	13.4408 mo.	33.2992%

* Cemented with Bakelite compound.

TABLE II

Statistical Summary of Results from Table 21 of McClure, 1944

Performance of Ski Pole Shafts
Guadua angustifolia (H.B.) Kunth. Colombia *
Manufacturer of poles, Montague Rod and Steel Company, Montague City, Massachusetts

NUMBER OF SAMPLES		UNITS	STANDARD DEVIATION	COEFFICIENT OF VARIATION
26	Mean Thickness Tip	.5092 in. 1.293 cm.	.0077 in. 0.020 cm.	1.5092%
26	Mean Thickness Butt	.6577 in. 1.671 cm.	.0121 in. .031 cm.	1.8456%
26	Weight (48 in. long specimen) (121.9 cm.)	.4381 lb. 0.199 kg.	.0160 lb. 0.007 kg.	3.6579%
26	Test No. 1 Deflection	31.7308 lb. 14.393 kg.	2.0505 lb. 0.930 kg.	6.4622%
26	Test No. 2 Column load (Maximum compressive load)	211.92 lb. 96.127 kg.	41.378 lb. 18.769 kg.	19.5251%
13	Test No. 3 Transverse Span 15.5 in. starting 8 in. (20.32 cm)from small end of specimen	336.3077 lb. 152.885 kg.	25.2170 lb. 11.438 kg.	7.4982%
13	Test No. 4 Cantilever Test	29.6154 lb. 13.730 kg.	5.1241 lb. 2.324 kg.	17.3022%
26	Estimated Age of sample, Months	26.7692 mo.	5.1560 mo.	19.2610%

* Cemented with animal glue

Appendix 3

SEASONING, PRESERVATIVE TREATMENT AND PHYSICAL PROPERTIES STUDIES OF BAMBOO

by

H. E. Glenn
D. C. Brock
E. F. Byars
J. L. Edwards
J. M. Ford
J. D. Glenn
J. C. Hubbard
H. W. Humphreys
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R. Hendricks
R. L. Perry

The Clemson Agricultural College
The A & M College of South Carolina

June 1954

Physical property tests were conducted on 38 bamboo species, "mostly hardy running types" obtained from two field locations of the United States Department of Agriculture Barbour Lathrop Plant Introduction Garden, Savannah, Georgia. The same tests were run on 18 species of bamboo obtained from the United States Department of Agriculture Federal Experiment Station, Mayaguez, Puerto Rico.

Seasoning tests were also conducted on the same 56 species.

Preservative treatment tests were confined to one species, Phyllostachys bambusoides specimens obtained at the Savannah, Georgia site.

Only the information on Bambusa vulgaris and Guadia angustifolia specimens, both taken from the Mayaguez, Puerto Rico site, have been extracted for the present bamboo pipe study.

APPENDIX 3 TABLE 1A

PHYSICAL PROPERTIES OF GUADUA ANGUSTIFOLIA
AND BAMBUSA VULGARIS
FROM TABLES 4, 6, AND 8, GLENN, BROCK, BYARS, EDWARDS, ET AL,
1954, "SEASONING, PRESERVATIVE TREATMENT AND
PHYSICAL PROPERTY STUDIES OF BAMBOOS", ENGINEERING EXPERIMENT STATION
OF THE CLEMSON AGRICULTURAL COLLEGE

ENGLISH UNITS

		Number of Specimens	Average Tensile* Strength lbs/in^2	Number of Specimens	Modulus of Elasticity lbs/in^2
			TENSION		
Guadua angustifolia	Without Node	6	36,600	3	4,180,000
	With Node	6	19,600	3	4,510,000
Bambusa vulgaris	Without Node	6	37,200	3	3,560,000
	With Node	6	16,000	3	3,750,000
			COMPRESSION		
Guadua angustifolia	Without Node	11	10,800	6	2,110,000
	With Node	7	9,800	5	1,840,000
Bambusa vulgaris	Without Node	9	10,800	5	2,000,000
	With Node	6	11,000	3	1,800,000
			RUPTURE IN FLEXURE		Modulus of Rupture lbs/in^2
Guadua angustifolia	Without Node	6	26,400	5	2,120,000
	With Node	6	23,800	6	2,930,000
Bambusa vulgaris	Without Node	6	27,500	6	2,260,000
	With Node	6	27,100	6	3,050,000

* Failure between nodes for specimen without node.
Failure at node for specimen with node.

APPENDIX 3 TABLE 1B

PHYSICAL PROPERTIES OF GUADUA ANGUSTIFOLIA
AND BAMBUSA VULGARIS
FROM TABLES 4, 6, AND 8, GLENN, BROCK, BYARS, EDWARDS, ET AL,
1954, "SEASONING, PRESERVATIVE TREATMENT AND
PHYSICAL PROPERTY STUDIES OF BAMBOOS", ENGINEERING EXPERIMENT STATION
OF THE CLEMSON AGRICULTURAL COLLEGE

METRIC UNITS

		Number of Specimens	Average Tensile* Strength Kg/cm^2	Number of Specimens	Modulus of Elasticity Kg/cm^2
			TENSION		
Guadua angustifolia	Without Node	6	2,531	3	293,854
	With Node	6	1,378	3	317,053
Bambusa vulgaris	Without Node	6	2,615	3	250,268
	With Node	6	1,125	3	263,625
			COMPRESSION		
Guadua angustifolia	Without Node	11	759	6	148,333
	With Node	7	689	5	129,352
Bambusa vulgaris	Without Node	9	759	5	140,600
	With Node	6	773	3	126,540
			RUPTURE IN FLEXURE		
					Modulus of Rupture Kg/cm^2
Guadua angustifolia	Without Node	6	1,856	5	149,036
	With Node	6	1,673	6	205,979
Bambusa vulgaris	Without Node	6	1,933	6	158,878
	With Node	6	1,905	6	214,415

*Failure between nodes for specimen without node.
Failure at node for specimen with node.

APPENDIX 4

PROPERTIES OF SOME BAMBOOS CULTIVATED IN THE WESTERN HEMISPHERE

G.E. Heck, United States Forest Service

Forest Products Laboratory Report D 1765

Madison, Wisconsin, May 1950

This report describes the methods used in testing the physical properties of several species of bamboo. Photographs of test apparatus and tables and graphs showing the results are included in the report. Culms of Bambusa vulgaris obtained from the Federal Agricultural Experiment Station, Mayaguez, Puerto Rico constituted one of the four species on which most of the tests were performed. More limited tests were performed on Guadua angustifolia, obtained from Ecuador.
Table 1A shows the mechanical properties of Bambusa vulgaris in English units, Table 1B in metric units.

Heck contrasted the properties of Bambusa vulgaris when culms were tested and when splints were tested. Splints are test samples of material cut from between the nodes, and worked into a rectangular shape in plan and cross section. In this process, some of the soft inner surface of the culm is removed, and some of the outer surface. His comparison is summarized in Table 2. The physical irregularities of the nodal region found in the culm are removed when splints are tested.

APPENDIX 4 TABLE 1A

COMPOSITE DATA ON

Bambusa vulgaris Schrad. ex Wenl.

from Heck (1950)

ENGLISH UNITS

Source: Mayaguez Township, Mayaguez County, Puerto Rico

Number of Culms: Four, each cut into five-foot sections.

Storage: Two to four months in a ventilated shed, from date of cutting (Mayaguez), to date of shipping to the Forest Products Laboratory, (Madison, Wisconsin)

DESCRIPTION OF CULMS

	Age when cut, year	Height, Feet	Outside Diameter, Inches	Wall Thickness, Inches	Spacing of Nodes, Inches
Average	2.0	34	1.97	0.27	11.5
Minimum	1.5	22	1.14	0.15	10.0
Maximum	2.5	45	3.09	0.56	14.0

TENSILE STRENGTH, PARALLEL TO GRAIN OF INTERNODAL BAMBOO SPLINTS

Tested at about 10 percent moisture content.

	Specific Gravity Based on weight and volume when oven-dry	Number of Tests	Proportional Limit Stress psi	Ultimate Stress psi	Modulus of Elasticity 1,000 psi
Average	0.70	8	15,160	26,130	1,865
Minimum	0.48		5,970	14,940	1,030
Maximum	0.89		28,230	39,000	2,913

COMPRESSION, PARALLEL TO GRAIN, CULMS

Tested at about 10 percent moisture content.

	Specific Gravity Based on weight and volume when oven-dry.	Number of Tests	Fiber Stress at Proportional Limit (psi)	Maximum Crushing Strength psi	Modulus of Elasticity 1,000 psi
Inter-nodal sample, Node not included	0.70	13	5,230	8,300	2,162
Sample, with Node included	0.67	15	5,200	8,280	2,201

BENDING STRENGTH OF CULMS

Tested at about 10 percent moisture content.

Specific Gravity, Based on weight and volume when oven-dry	Number of Tests	Fiber Stress at Proportional Limit (psi)	Modulus of rupture (psi)	Modulus of Elasticity 1,000 psi	Work to Proportional Limit In.-lb per cu. in.	Work to Maximum Load In.-lb per cu. in.
0.70	10	9330	17,840	2,270	2.62	19.03

APPENDIX 4 TABLE 1B

COMPOSITE DATA ON

Bambusa vulgaris Schrad. ex Wenl.

from Heck (1950)

METRIC UNITS

Source: Mayaguez Township, Mayaguez County, Puerto Rico

Number of Culms: Four, each cut into five-foot sections.

Storage: Two to four months in a ventilated shed, from date of cutting (Mayaguez), to date of shipping to the Forest Products Laboratory, (Madison, Wisconsin)

DESCRIPTION OF CULMS

	Age when cut, year	Height, meters	Outside Diameter, cm	Wall Thickness, cm	Spacing of Nodes, cm
Average	2.0	10.36	5.0	0.7	29.2
Minimum	1.5	6.71	2.9	0.4	25.4
Maximum	2.5	13.72	7.8	1.4	35.6

TENSILE STRENGTH, PARALLEL TO GRAIN OF INTERNODAL BAMBOO SPLINTS

Tested at about 10 percent moisture content.

	Specific Gravity Based on weight and volume when oven-dry	Number of Tests	Proportional Limit Stress kg/cm^2	Ultimate Stress kg /cm^2	Modulus of Elasticity 1,000 kg/cm^2
Average	0.70	8	1,066	1,837	131
Minimum	0.48		420	1,050	72
Maximum	0.89		1,985	2,742	205

COMPRESSION, PARALLEL TO GRAIN, CULMS

Tested at about 10 percent moisture content.

	Specific Gravity Based on weight and volume when oven-dry	Number of Tests	Fiber Stress at Proportional Limit (kg /cm^2)	Maximum Crushing Strength kg/cm^2	Modulus of Elasticity 1,000 kg /cm^2
Inter-nodal sample, Node not included	0.70	13	368	583	152
Sample, with Node included	0.67	15	366	582	155

BENDING STRENGTH OF CULMS

Tested at about 10 percent moisture content.

Specific Gravity, Based on weight and volume when oven-dry	Number of Tests	Fiber Stress at Proportional Limit kg/cm^2	Modulus of Rupture kg/cm^2	Modulus of Elasticity 1,000 kg/cm^2	Work to Proportional Limit cm-kg per cm^3	Work to Maximum Load cm-kg per cm^3
0.70	10	656	1,254	160	.184	1.338

APPENDIX 4

TABLE 2

COMPARISON OF VALUES FOR AIR-DRIED CULMS AND INTERNODAL SPLINTS OF BAMBUSA VULGARIS, REPORTED AS THE RATIO OF CULM VALUES TO SPLINT VALUES

Heck (1950)

1.	Specific Gravity	113%
2.	Fiber Stress at Proportional Limit	82%
3.	Modulus of Rupture	87%
4.	Modulus of Elasticity	109%
5.	Work to Proportional Limit	76%
6.	Work to Maximum Load	61%
7.	Maximum Crushing Strength	91%

Appendix 5

STRENGTH TESTS ON BAMBOOS

A. C. Sekhar and B. S. Rawat

Forest Research Institute
Dehra Dun
1956

Indian Forest Leaflet No. 147
(Timber Mechanics)

This report does not report directly on experimental work on mechanical properties of bamboo at Dehra Dun, but alludes to it. Sections 4 and 5 of the report may prove to be of value because of comparison of test methods and a statement of tentative testing standards at Dehra Dun.

What follows is verbatim from Leaflet No. 147.

4. Testing of Bamboo--At present there does not seem to be any standard method for evaluating mechanical and physical properties of bamboo corresponding to that in timber. However, various attempts have been made in different parts of the world to evaluate some of the most important properties in different ways. A bibliography of available references is given at the end.

In the selection and testing of full diameter culms Heck (4) and Limaye (6) followed as far as possible the A.S.T.M. standards for small clear specimens of wood with the difference that the former has conditioned all the specimens at 64% Relative humidity and 75° F and the latter has divided the specimens into green and kiln-dry conditions. Espinosa (2) making tests on highest grade of bamboos available in the local markets, selected specimens for 5 feet span and also 28 inches span in Static Bending, 48 inches height and 14 inches height in compression parallel to grain. His rate of the movement of the head of machine was 0.225 inch/min. in bending and 0.042 inch/min. in compression. In the sampling process, Limaye (6) has however taken greater care to introduce factors of seasoning, age, disposition of nodes relative to loading point and position along the culm for making the investigations systematic and exhaustive. While Limaye has evaluated only Fibre Stress at Elastic Limit, Modulus of Rupture and Modulus of Elasticity in bending, Maximum Crushing Strength in Compression parallel to grain and Specific Gravity, Heck has evaluated also Work to Proportional Limit and Work to Maximum Load in bending in addition to the above properties. Espinosa however, has given only the general load bearing capacities of the sizes and span tested as they were claimed to be of direct importance in actual use.

Strength and miscellaneous tests have also been conducted on split bamboos by Heck (4), Motoi Ota (8, 9, 10, 11, 12, 13) and Espinosa (2). Espinosa has tested on a span of 12 inches for bending and height of 1 inch for compression. Heck seems to have generally followed the A.S.T.M. methods for small clear specimens in wood. Motoi Ota however has done on Japanese species Tensile, Compressive and Shear tests and has attempted for relationship between Moisture content and strength, between Specific Gravity and Strength, and on the exact location of the Fibre Saturation Point. His sizes of the specimens varied according to the individual experiments.

Some of the conclusions by these workers are of interest. It has been generally concluded by Limaye (6) that in Static Bending specimens with node at the central load point showed higher strength but lower stiffness than specimens with the load between nodes. In compression the difference has not been significant. Also the strength values from bending experiment were significantly higher in the bottom and decreased gradually at the top, but not so in Compression parallel to grain. The age at which bamboos attain mechanical maturity seem to be more than 2½ years but this point needs further investigation. Kiln dried bamboos increased in strength by about 40% to 60%, the improvement being higher in the case of younger ones than in older.

Working on splints Motoi Ota has found that the compressive strengths of outer layers are higher than the inner layers, being similar to what is observed in Specific Gravity (8). There is found to be a high degree of linear correlation between Specific Gravity and Compressive strength. Heck (4) has reported from his Static Bending experiments on culms and splints that Strength Specific Gravity relationship showed higher powers of Specific Gravity than in wood excepting in work. Effect of Moisture content on Compressive strength has been found by Motoi Ota to be similar to that of wood, with the exception that the Fibre Saturation Point of bamboo is much lower than in wood and that the ratio of Compressive strength to Specific Gravity is higher than wood above the Fibre Saturation Point (9). In

Tensile strength a maximum is found to have reached between 5% and 15% of Moisture content, but the Fibre Saturation Point calculated from the Tension tests seemed to be in good agreement with those obtained in Compression tests (10). But from the determination of Fibre Saturation Point from Shrinkage and Swelling tests the values seem to be lower than those obtained from Compression and Tensile tests (11). From experiments on stair-type specimens in determining Shear parallel to grain, he has come to the conclusion that the proper dimensions of height of the Shearing face and the width of the maintaining part should be equal (about 2 cms.) for a standard Shear test specimen (12). Examining the effect of Moisture Content on Shearing, he concludes that Shearing strength increases and reaches maximum at about 8% and then decreases linearly with the increase of Moisture Content from oven-dry condition to Fibre Saturation Point and there afterwards remains constant (13). The Fibre Saturation Point calculated from Shearing test is reported to be higher than that from the previous test on Compression, Tension and Shrinkage.

Recently the authors have done some experiments on splints of Bambusa nutans and Dendrocalamus strictus in Tension parallel to grain, Bending, Izod, Charpy and Shear tests. Experiments were also done on full diameter culms in Static Bending, Compression parallel to grain and Impact tests on a Hatt Turner machine. While it is not intended to discuss in detail in the present paper the actual data of these experiments, it is considered to be of interest if certain experiences with regard to these tests are recorded with a view to help in standardization of the specimens in bamboo testing.

Almost all the specimens in green condition in Tension parallel to grain have failed mostly in Shear and have indicated values much less than those obtained in bending. The exact form of the specimens in the central and gripping portions of Tension specimens still requires experimentation.

In Compression parallel to grain a series of tests at the Forest Research Institute indicated that the length of the specimens should not be greater than about 10 times the thickness of the wall as otherwise buckling may occur. Testing on Swinging Pendulum Impact machines indicated that the material tested compared very well with tougher species in wood, like Anogeissus latifolia, Dalbergia sissoo etc. The bending experiments were done with the exterior face downwards. In this connection it may be pointed out that Heck's (4) observations on splints in bending experiments with and without nodes, indicate that the strength values are higher when the load is applied on the face nearest to periphery with the exception of Work to maximum load. It was found by the authors that the strength increases from centre to periphery. With regard to Static Bending and Impact Bending in full diameter culms tested on 28 inches span, special saddles were required for supports at the ends. Without the saddles the splitting failures occurred initially at the supports and with the saddles these occurred at the load points at the bottom surface of the specimens. Previous workers did not seem to have attached much importance to failures but Espinosa (2) interestingly observed that in the case of full bamboos most of the failures, specially in bending, were due to splits, though in Compression tests some Compressive failures were also observed in addition to splitting. In the case of bending of split bamboos the failure was due to tension on the lower side and longitudinal shear when the specimens were bent with the exterior side upwards. On the other hand, with the exterior side downwards, the failure was mostly due to longitudinal shear as well as due to actual crushing of the specimen, where the load was applied and ultimately tension on the exterior side.

5. Present Standards employed--The following is the brief description of the Standards followed tentatively at present at the Forest Research Institute

for intercomparison of different species.

(a) Selection of Material--Ten full length culms of any particular species are to be selected from any particular locality of a known age. Where possible the silvicultural and Field data regarding the bamboos are recorded.

(b) Marking and Layout--Each culm is weighed, measured in length, nodes counted and divided into three parts--top, middle, and bottom and suitably marked.

From these parts specimens are taken as under:--

(1) Static Bending--Two internode specimens each of 30 inches length from each part to be randomly selected--one to be tested in green and one to be tested in kiln dry condition.

(2) Impact Bending--Two internode specimens each of 30 inches length to be randomly selected from the middle part one to be tested in green and one to be tested in kiln dry condition.

(3) Compression Parallel to grain--Two internode specimens to be randomly selected from each part--one to be tested in green and one to be tested in kiln dry condition. The length of each specimen is not to be more than 10 times the wall thickness.

(4) Specific Gravity--Two pieces each of about 1 inch long, one without node and the other with node, are selected from tested pieces of Static Bending specimens.

(5) Moisture content--It shall be determined on discs taken from every tested specimen.

(6) Miscellaneous other tests--From the remaining available

material mechanical and physical tests on split bamboos, shrinkage etc., on full diameter culms are studied. [Conventionally at present shrinkage is studied on two specimens each of 4 inch long (one with node and the other without node) from the lowest portion of the bottom part]. Wherever possible, variation of strength with moisture content may also be studied.

(c) Loading Conditions--The shape of the loading blocks, the rate of loading, etc., are exactly the same as those applied for testing small clear specimens in wood. But in the case of bending, special saddles are provided at the supports to suit the curvature of the specimen under test.

(d) Properties evaluated and Formulae employed at present:

1. Static Bending--

(i) Fibre Stress at Elastic Limit $= 71{\cdot}301 \times P'd/(d^4 - d_1^{\,4})$.

(ii) Modulus of Rupture $= 71{\cdot}301 \times Pd/(d^4 - d_1^{\,4})$.

(iii) Modulus of Elasticity $= 9317 \times P'/(d^4 - d_1^{\,4})\Delta$.

2. Impact Bending--

(i) Fibre Stress at Elastic Limit $= 7130{\cdot}13 \times dH/(d^4 - d_1^{\,4})\Delta$.

(ii) Modulus of Elasticity $= F.S. \times 130{\cdot}67/d\Delta$.

3. Compression Parallel to Grain--

(i) Maximum Crushing Strength $= P/[0{\cdot}7854 \times (d^2 - d_1^{\,2})]$.

4. Specific Gravity-- $= 0{\cdot}6102\ W/0{\cdot}7854\ (d^2 - d_1^{\,2})L$.

Where--

P' = Load at Elastic Limit (pounds).

P = Maximum Load (pounds).

d = Outer diameter at mid-span (inches)

d_1 = Inner diameter at mid-span (inches)

Δ = Deflection at Elastic Limit (inches)

W = Weight of specimen (gms.)

L = Length of specimen (inches)

H = Height of drop at Elastic Limit (inches)

Conclusion--In the present paper the different types of Mechanical and Physical tests done by various workers are surveyed and tentative standards adopted at Forest Research Institute for the purposes of systematic study with reference to different species, different age groups, different heights in the culms etc., are indicated. The various structural uses of bamboo particularly with reference to the Indian Species are discussed in a general way. It is hoped that all this information would be more useful for future testing of bamboos and for formulating uniform standards for comparison of different species.

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APPENDIX 6

FEASIBILITY STUDY ON THE USE OF BAMBOO IN PRESSURIZED WATER SYSTEMS

May 25, 1974

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This project was prepared in partial fulfillment of the requirements for the Master of Science Degree in Industrial Engineering and Operations Research

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ACKNOWLEDGEMENT

This project deals with a feasibility study on the use of bamboo in pressurized water systems. The report has been written as a partial fulfillment of the requirements for the Master of Science Degree in Industrial Engineering and Operations Research at the University of Massachusetts.

The World Health Organization furnished partial support for the study. I also wish to express my appreciation to Professor Stanley Lippert for his encouragement and continuous support. My sincere gratitude to engineer Jaime Mora of Colombia's INPES, Investigaciones especiales del Instituto Nacional para programas de salud (National Institute of special programs for public health), whose information and personal viewpoints have proved helpful. My thanks are also due to Professors Klaus E. Kroner and William Duffy for their constructive criticism of some aspects of the project.

Eulogio O. Herrera

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TABLES AND FIGURES

INTRODUCTION

OBJECTIVE OF THE STUDY

The main purpose of this project is a feasibility study of the potential utility and cost of bamboo in a pressurized water system. Certain bamboos, including at least one growing in Colombia, South America, appear to have suitable qualities which permit conversion into pipes which will hold pressure, if easy means of joining, preserving, and servicing can be devised.

FIELD TRIP TO COLOMBIA

A field trip to Colombia was taken during intersession (mid-December 1973 - mid-January 1974), to look for sites where:

1. Bamboos suitable for piping might be found.
2. An active bamboo technology is practiced.
3. There is a need for an improved water supply.
4. The improvement requires a pressurized water system.
5. The economic conditions of the community require low cost installation.
6. Residents of the community show a willingness to participate in constructing a pressurized line.

Other purposes of the trip were to establish contacts with government officials to determine what has been done about water systems for small communities, and to get cost data for bamboo and plastic (PVC) water supply systems. At this point, the mechanical properties of pressurized pipe of bamboo in general and Guadua angustifolia in particular are not known. However, Professor Dietger Grosser of West Germany, is testing

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the properties of some bamboos. An inquiry on his work was sent to him recently. At the time of writing, no answer has been received. Some of the information needed on mechanical properties is not available at the University of Massachusetts at present. A visit to the Smithsonian Institution's special collection of literature on bamboo, reportedly the finest in the world, is planned by other investigators.

The present report covers mostly economic aspects of the pressurized pipe problems which set the stage for more technical studies to follow.

BACKGROUND ON COLOMBIAN STUDIES

The government of Colombia is already involved in the construction of village water systems using plastic pipes for villages with population between 50 and 2,500 persons. A study showing the location and number of these villages has been done by the Colombian Ministry of Public Health through INPES, the National Institute of Special Programs for Public Health (Investigaciones Especiales del Instituto Nacional para Programas de Salud). Nothing, however, is being done at the present time for communities fewer than 50 persons. Systematic visits to small communities were not feasible in the time and circumstances of the trip to Colombia. Primary attention was devoted to locating bamboo sites and contacting key people. INPES reports tabulate information on the total number of towns and villages between 50 and 2500 persons located within Colombia. They also report on the number of villages and the population number of villages which already have electrical services, sanitary services, primary schools, and community action programs. Finally, INPES reports on towns and villages inspected for potential plastic pipe water supply systems. Mora (1973) indicated that the INPES small community water system construction program was approximately 20 percent complete.

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LOCATION OF THE BAMBOO FOUND ON FIELD TRIP

A bamboo native to Colombia (Guadua angustifolia), has properties desirable in the design of water pipes. For one thing, its surface is very smooth and the nodes are well spaced and free of side branches for many feet in their early growth stage. Six days of surface travel were used for site inspection of bamboo. Figure 1 shows the areas visited by automobile, except for the Barranquilla - Cartagena road, on which no appreciable plantings were observed. Observations from commercial airplane flights, when weather and altitude permitted, revealted no major bamboo areas.

Guadua are grown in many regions of Colombia, but there are four departments (States) where the specimen is found is good quantities. Figure 1* indicates the major area of ground travel by daylight which was searched for Guadua. The names of the provinces and towns are shown. Figure 2 shows size judgements of bamboo clumps observed while driving. In Figure 2, small clumps of bamboo means a clump which could be used for a potential length of several miles of pipe. Medium means clumps which will provide approximately 20 miles of potential pipe and large means any clump which could be used for a much larger supply of pipe.

1. ANTIOQUIA: Inquiries at the National University in Medellin indicated that two towns, Santa Fe de Antioquia and Rionegro had Guadua. Santa Fe de Antioquia is located 112 kms. (70 miles) Northwest of Medellin. A few Guadua clumps grow in "Hacienda El Paso" (El Paso farm, two miles from Santa Fe de Antioquia). This farm belongs to Universidad Nacional de Medellin (National University of Medellin) and is used as an experimental site by Wood Technology students of this University. Therefore, the

*Adapted from information in Colombia at a Glance. Tourist and shopping guide. Edited by PUBLICAR LTDA., in cooperation with Corporacion Nacional de turismo (Colombian Corporation of Tourism) - Colombia 1973/74.

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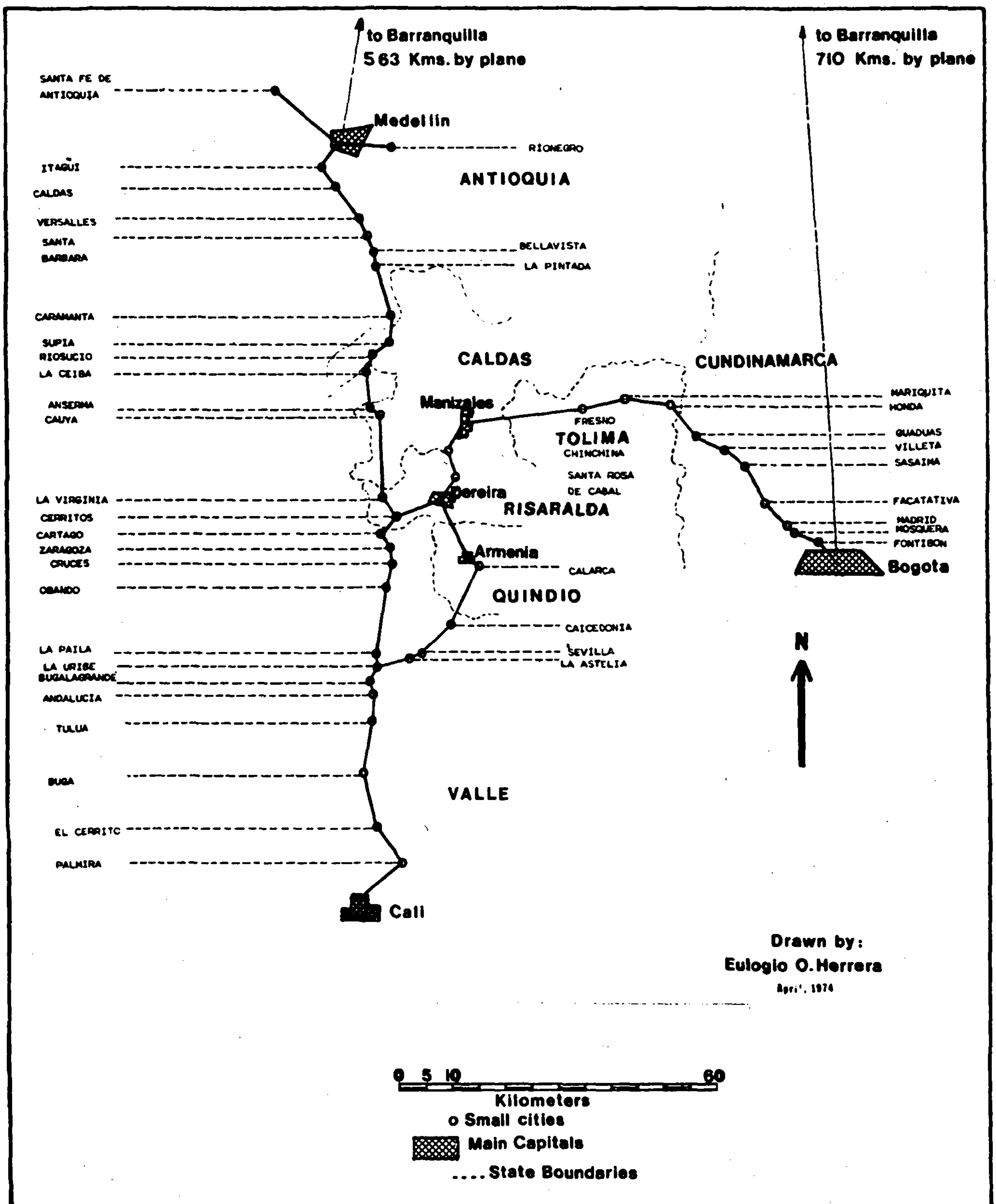
FIGURE 1

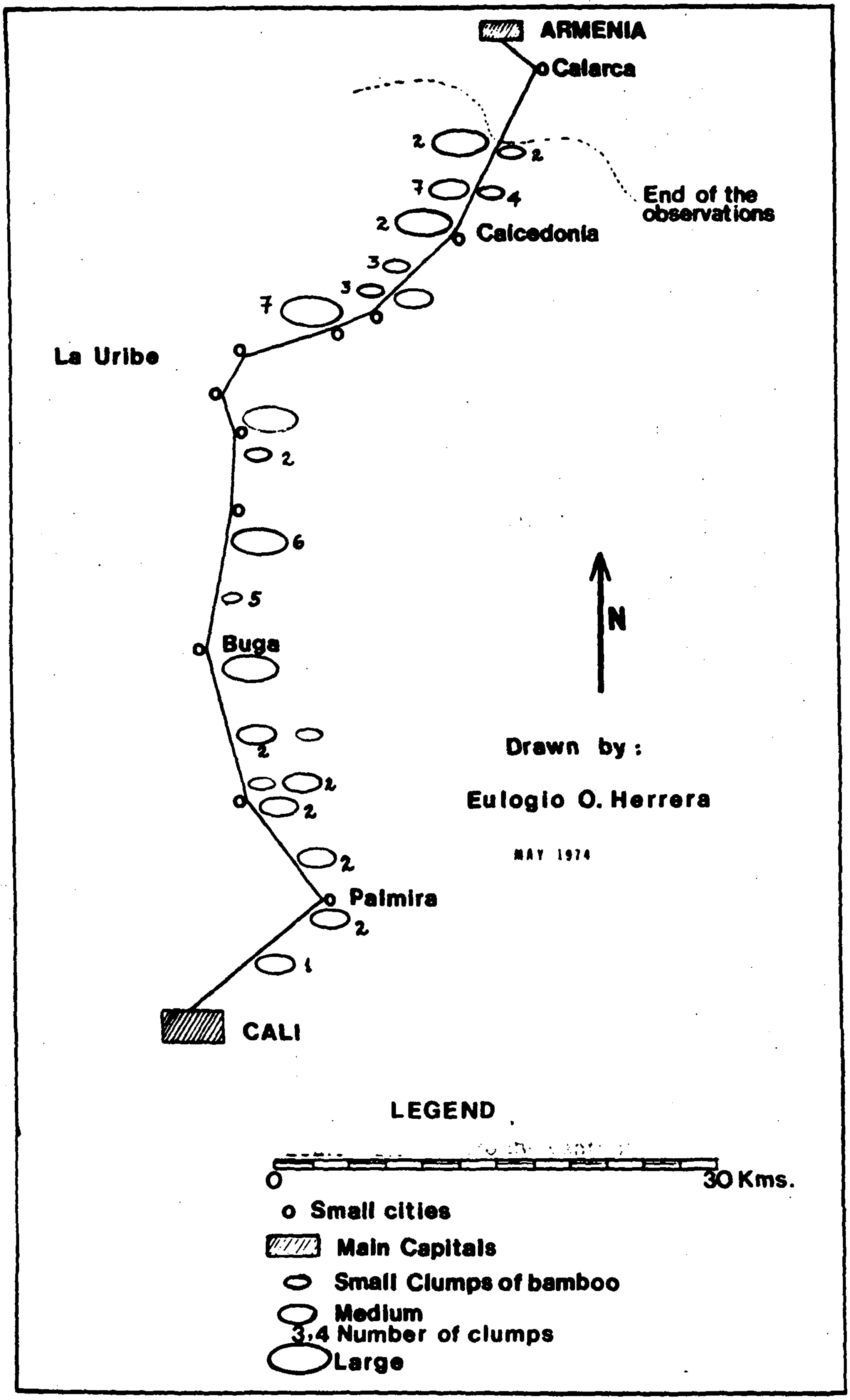
FIELD TRIP TO COLOMBIA



(5)

FIGURE 2

LOCATION OF THE BAMBOO FOUND ON THE FIELD TRIP



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cooperation of this University might be essential to the eventual success of a bamboo study. Rionegro is located approximately 90 kilometers (56 miles) east of Medellin. A clump which could be good for 20 miles of pipe was located near this town.

2. VALLE-QUINDIO-RISARALDA: The nicest and biggest "guadua clumps" are found along the road joining these departments. Some other clumps, less extensive, were also observed along the same road.

USES OF THE BAMBOO WATER SYSTEM

The proposed bamboo water system for villages is domestic such as for drinking, cooking, and possibly gardening. The quality, quantity, and rate of use for individual dwellings are of interest in this study. Utilization of bamboo for irrigation systems, for example, is another possibility, but is not treated in this report.

QUANTITY OF WATER REQUIRED BY THE VILLAGES OF THE DEPARTMENTS VISITED

The quantity of water required by a village depends upon the rate of use per house and the number of houses of the village. The unit which will be used in this report is expressed in gallons/day/house. According to Mora (1973) who is presently working in the National Institute of Special Programs for Public Health, a special branch of the Colombian Ministry of Public Health at Bogota, the consumption per house is approximately 40 gallons/day. This figure, however, does not include individual city houses with bath, showers, and toilets. In order to calculate the number of gallons/year of water required for all the communities of each department without water service, a subtraction of the number of dwellings with water service from the total number of dwellings of each department was

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done. The result was the number of dwellings which required water service. Table I shows the results. Only data for those departments visited will be considered. The data used is only on the small communities between 50 and 2500 persons which need water facilities, located within these departments.

TABLE I

NUMBER OF COMMUNITIES, DWELLINGS, AND TOTAL POPULATION WITHOUT WATER SERVICES

Note: Data derived from Colombian government (Sanitary study of rural communities) Bogota, Colombia, 1973.

DEPARTMENTS	TOTAL NO. OF RURAL COMMUNITIES WITHOUT WATER SERVICE*	NO. DWELLINGS WITHOUT WATER SERVICE	TOTAL POPULATION WITHOUT WATER SERVICE
ANTIOQUIA	350	16,554	117,314
QUINDIO	37	613	4,122
RISARALDA	49	2,400	18,215
VALLE	134	9,301	66,953

*Population between 50 and 2500.

If the ratio of total population without water service to number of dwellings without water service is taken for the four departments, an approximate figure of 7 persons/house is found. This number is also in accordance with a statement from Mora (1973). These previous numbers lead to the conclusion that the consumption per capita is 5.65 gallons/day.

The total number of gallons/day delivered into all the dwellings of a department requiring water service can be expressed mathematically as follows:

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$$Z = (C*N)\frac{\text{Gallons}}{\text{day}}$$

C = consumption per dwelling (40 gallons/day)

N = number of dwellings which require water is all villages of a department

TABLE 2

TOTAL QUANTITY OF WATER PER DAY REQUIRED BY THE DWELLINGS OF THE DEPARTMENTS VISITED

			gallons/day		liters/day
Antioquia:	Z = 40 x 16,554	=	662,160	=	2,506,530
Quindio:	Z = 40 x 613	=	24,520	=	92,818
Risaralda:	Z = 40 x 2,400	=	96,000	=	363,398
Valle:	Z = 40 x 9,301	=	372,040	=	1,408,320

FACTORS AFFECTING THE QUANTITY OF WATER REQUIRED BY THE VILLAGES

The previous numbers should not be taken for granted and could be adjusted according to two other factors which might have some influence upon the consumption per capita in the rural areas of these departments:

a) Climate. More water is used for different purposes in villages having high temperatures. This might well be the case for 70 percent of these villages.

b) Pressures. More water will flow from service fixtures under high pressure than under low pressure, hence it should be expected that the consumption per capita could be higher in villages where unusually high pressures should be maintained. High pressures of up to 150 psi are common for a large sample of the villages in Colombia, according to Mora (1973), one of the members in charge of the construction and design of water supply systems for rural communities.

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CHARACTERISTICS OF A WATER PIPE

In designing pipe lines, the engineer has a choice of several different materials: cast iron, steel, aluminum, wood, and plastic for example. The fundamental requirements of a water pipe are strength, durability, capacity, care of installation and economy. Other factors which might influence the choice of pipe are local availability and the ease and cost of transportation to the site. The final selection of material and type should be based upon a careful consideration of these requirements. Since plastic pipe is used by the government of Colombia in the design of rural water systems, the potential utility of bamboo will be compared to plastic.

COMPARISON OF BAMBOO AND PLASTIC BASED ON DESIRABLE CHARACTERISTICS OF A WATER PIPE

STRENGTH. Plastic provides both high tensile and high impact strength. In plastics testing, the term tensile strength is the load in pounds per square inch (psi) or kilos per square centimeter (kg/cm^2) of original cross-sectional area, supported at the moment of rupture by a piece of test sample when it is being elongated. In the plastic industry, impact strength means resistance or mechanical energy absorbed by a plastic part to such shocks as dropping and hard blows. Another required property of water pipe is its resistance to internal fluid pressure.

Studies have shown that PVC pipe will withstand high internal pressures for long periods, within a certain temperature range (Table 3).

It should be mentioned, however, that as the temperature increases, the maximum working pressure decreases. A "temperature de-rating factors" is used to describe the decrease as shown in Table 4. The effect of temperature on the maximum working pressure of pipes of 2, 3, and 4 inches diameter is given in Tables 5, 6, and 7. These sizes

(10)

TABLE 3

MAXIMUM WORKING PRESSURE of PVC pipes of 2, 3, and 4 inches diameter for temperatures of 73.4°F

Nominal Pipe Size	Working pressure at temperatures 73.4°F and below, (psi)*
2	200
3	190
4	160

*In Colombia, temperatures in most villages very rarely fall below 32°F, and very seldom rise to 90°F.

TABLE 4

TEMPERATURE DE-RATING FACTORS (to be applied at 73.4°F)

Working Temperature (°F)	De-rating Factor
73	1.00
80	0.88
90	0.75
100	0.62
110	0.51
120	0.40
130	0.31
140	0.22

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TABLE 5

EFFECT OF TEMPERATURE ON WORKING PRESSURE OF 2" PIPE

TEMPERATURE (°F)	WORKING PRESSURE (psi)
73	200
80	176
90	150
100	124
110	102
120	80
130	62
140	44

Figures based on Tables 3 and 4

TABLE 6

EFFECT OF TEMPERATURE OF WORKING PRESSURE OF 3" PIPE

TEMPERATURE (°F)	WORKING PRESSURE (psi)
73	190.0
80	167.2
90	142.5
100	117.8
110	96.9
120	76.0
130	58.9
140	41.8

Figures based on Tables 3 and 4

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TABLE 7

EFFECT OF TEMPERATURE ON WORKING PRESSURE OF 4" PIPE

TEMPERATURE (°F)	WORKING PRESSURE (psi)
73	160.0
80	140.8
90	120.0
100	99.2
110	81.6
120	64.0
130	49.6
140	35.2

Figures based on Tables 3 and 4.

(13)

are chosen because engineer Mora said that these are the sizes needed; a 4 inch pipe will supply a community of 2500 persons which is the maximum size of concern to his project. Guadua angustifolia, a bamboo found in Colombia, can provide comparable diameters.

As far as bamboo is concerned, an undocumented statement from the University of North Carolina at Chapel Hill, reports that bamboo piping can hold pressure up to 30 psi.* This simply means that the unknown bamboo could not beat plastic even when the temperature is very high. One of the first tasks of a study of Guadua angustifolia would be to determine its natural bursting strength under various conditions of harvesting and curing. A working pressure approximately six times 30 psi would be desirable.

EASE OF TRANSPORTATION. The nominal weight per foot for a two inch plastic pipe is 0.521 pounds and for a three inch pipe is 1.106 pounds. Therefore, 20 foot length of two inch and three inch plastic pipes weigh 10.42 and 22.12 pounds respectively. These are very light weights and would be easy to work with in the field. Twenty-foot length pipes are selected because this size seems to be a standard one. This is also the approximate standard length of plastic pipes delivered in Colombia (6 meters).

Bamboo, on the other hand, is an extremely light material to transport and carry around.

DURABILITY. The consistently uniform raw material used in the production of PVC pipe combined with the rigid quality control system employed, assures great dependability and long service life. Tests that have been

*The determination of pressure limits of candidate bamboos is one of the prime reasons for a feasibility study of bamboo pipes.

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run in Florida indicate that little physical degradation will take place for many years. Typical installation of plastic pipes have been in continuous service for periods up to 30 years and are still giving satisfactory service.*

According to a statement from the University of North Carolina the life expectancy of bamboo pipe is about three to four years; some bamboo will last up to five to six years. This suggests that techniques should be developed to protect the natural joints of bamboo, where deterioration and failure usually occur.

RESISTANCE TO DETERIORATION. Plastic pipes are very resistant to insects and corrosion but not to puncture and can work under very extreme conditions. Scratches or surface abrasions do not provide points where corrosion can attack.

This is a weak point of bamboo, because insects attack the surface of some bamboos originating a possible failure.

LOCAL AVAILABILITY. Plastic pipe is available in diameters ranging from 1/8 to 30 inches. Its transportation to the particular site is very convenient and is all arranged by the plastic producing company in Colombia.

Guadua angustifolia, although not a predominant feature in Colombia, is found growing well in the four departments previously mentioned.

SMOOTHNESS OF THE SURFACE. By means of nomographs for flow of water in bamboo and plastic pipes, the head loss and water velocity will be compared for sizes of two and three inches.** After a few calculations and conversions from one system of units to another, the results in Tables 8 and 9 are obtained.

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*Catalog of a U.S.A. manufacturer of PVC products.

**For sources of information see tables 8 and 9.

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TABLE 8

A COMPARISON OF THE HEAD LOSS AND WATER VELOCITY FOR BAMBOO AND PLASTIC PIPES OF 2" DIAMETER

Material	Inside diameter of pipe in inches	Water flow in gallons/minute	Water velocity in feet per second	Head loss in feet per 100 feet of pipe
Bamboo	2	31.70	3.116	8.7
Plastic	2	31.70	3.350	2.3

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TABLE 9

A COMPARISON OF THE HEAD LOSS AND WATER VELOCITY FOR BAMBOO AND PLASTIC PIPES OF 3" DIAMETER

Material	Water flow in gallons/minute	Water velocity in feet per second	Head loss in feet per 100 feet of pipe
Bamboo	31.70	1.394	1.44
Plastic	31.70	1.520	0.34

The previous figures have been obtained from nomographs based on the Williams and Hazen formula*,

$$f = .2083 \left(\frac{100}{C}\right)^{1.852} \times \frac{g^{1.852}}{d^{4.8655}}$$

Where: f = friction head in feet of water per 100 feet.
d = inside diameter of pipe in inches.
g = flowing gallons per minute
C = constant for inside roughness of the pipe (C = 150 for thermoplastic pipe).

The value of C varies according to the roughness of the surface; for very rough surfaces it has a value of 60 (in foot units).

The nomograph is used by lining up values by means of a ruler. Two independents variables must be set to obtain the other values.

*from Addison (1964).

(17)

As it can be observed from the tables, the smooth interior surface of PVC pipe assures low friction loss with resultant higher water velocities both initially and after long service. However, the results also show that the differences are relatively small, and that an adequate treatment of the inside surface of bamboo could be tried out to improve its condition.

COST COMPARISON OF PLASTIC PIPES PRODUCED IN COLOMBIA AND IN THE UNITED STATES

It was felt that a cost comparison of plastic pipes produced in Colombia and in the United States, would be desirable. This would help to determine costs in Latin American countries which do not have their own raw materials for making plastic pipes. It would also serve as a check against a single source price in Colombia.

The requirement that a water supply system should furnish water at the lowest possible cost consistent with other requirements as to quality, quantity, and reliability is, of course, a fundamental one in all engineering projects.

People used to think that water was as free as air; however, the average citizen of today recognizes that a satisfactory water for a public supply is a manufactured product, and therefore must carry costs of production. Plastic pipes are commonly used because they reduce installation costs.

The cost of plastic pipes gives a rough idea as to how feasible it would be to use bamboo pipes, from an economic point of view.

Tables 10, 11, and 12 give the price lists for plastic pipes of several diameters. Table 12 gives the 11/4 inches diameter plastic pipes prices of a wholesaler (U.S. company), a retailer (U.S. outlet), and that given by Mora(1973).

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TABLE 10

LIST PRICE OF PLASTIC PIPES (200 psi) OF SEVERAL DIAMETERS IN COLOMBIA
(Standard Length - 20 feet)

Nominal pipe size in inches	Colombian Pesos*	U.S. Dollars Per 100 feet**
1/2	96.20	3.85
3/4	195.00	7.80
1 1/4	394.40	15.75
2	993.75	39.75
3	1,414.80	56.60

*One Colombian peso equals U.S. $0.04 approximately.
**These are special prices given to the Colombian Government (1973) from purchases of large quantities. These prices also include the cost of delivery from the PVC factory to any site.

TABLE 11

LIST PRICE OF PLASTIC PIPES (200 psi) ACCORDING TO A 1974 CATALOG FROM ONE U.S. COMPANY (Standard length - 10 or 20 feet)

Nominal pipe size (inches)	U.S. Dollars per 100 feet (FOB)
1/2	12.80
3/4	13.91
1 1/4	28.36
2	56.16
3	119.20

TABLE 12

COMPARATIVE PRICES FOR PLASTIC PIPE PVC 200 psi COLD WATER

Source	Diameter in Inches	U.S. Dollars per 100 feet	Ratio of prices
RETAIL (outlet, U.S.) (Shipping cost incl)	1 1/4	23.74	1.51
INPES, Colombia (shipping cost incl.)	1 1/4	15.75	1.00
WHILESALE (U.S.) FOB	1 1/4	28.36	1.80

(19)

AN ECONOMIC COMPARISON OF COLOMBIAN BAMBOO AND PLASTIC PIPE

Up to this point in the discussion, a cost comparison of the bamboo found in Colombia and the plastic produced in the same country has not been made. Such information would permit an estimate of maximum improvement costs of bamboo before it becomes unfeasible from the economic point of view.

Information obtained from a material construction shop at Barranquilla indicates that most of the bamboo sold is used in the construction of buildings. In general, these shops typically carry bamboo of three-inch diameter. The reason for this is that this is the size most likely to be found in the region shown in Figure 2. According to Mora (1973), three-inch pipes are used to supply water to some villages in the population range of 50 to 2500. Therefore, a cost comparison of a three-inch bamboo pipe versus a three-inch plastic pipe will be made.

MATERIAL	U.S. DOLLARS PER FOOT
Bamboo*	0.0731
Plastic**	0.5660

*Price of bamboo given by a shop in Barranquilla.
**Price as shown in Table 10.

This simply means that U.S. $0.4929 per foot is the maximum that can be spent in the treatment of bamboo to make it a competitive material against plastic pipe in the design of rural water systems, all other considerations being equal.

FUTURE RESEARCH

Several investigations are required to complement and expand some of the findings of the present report.

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Since the interview with Mora (1973), several questions have come to mind:

1. According to his studies, sometimes pressures of 200 psi are needed in the design of water systems for small communities. However, we do not have any knowledge of the percentage of villages requiring this kind of pressure. It would be important to know not only this percentage, but also the kind of pressures needed by other villages. Colombian village requirements are probably much stricter than would be found in less mountainous countries.

2. Mora's studies also show that different lengths of pipe line are used for certain communities. Sometimes only two kilometers of pipe are needed as opposed to 20 kilometers which is required occasionally. It would be helpful to have a distribution function of the length of the pipe lines.

3. A statistical analysis of the uphill and downhill components of Colombian pipelines would help to define criterion requirements of design for rugged terrain.

RECOMMENDATIONS

As mentioned previously, a study of some of the primary attributes required in a pipe should be made for bamboo. Some of these attributes are mechanical strength, resistance to deterioration or rot, length of service, and pipe fittings to be used.

a. Mechanical Strength - The mechanical strength of the pipe is a very important consideration. The pipe must not burst, break, or leak. The wall thickness must therefore be sufficient to enable the material to support

   i. Tangential wall stresses due to internal pressure. This is usually the predominant stress. This is calculated very easily be means of the following formula from Addison (1964):

$$f_t = \frac{pd}{2t}$$

where: p = pressure

d = diameter of the pipe

t = thickness of the pipe

   ii. Longitudinal stresses resulting from the friction of the water actually touching the pipe wall.

(21)

b. Resistance to deterioration - Some steps will probably have to be taken to protect the surfaces of bamboo against insects and rot.

c. Durability - Methods should be developed to increase the life expectancy of bamboo as a suitable pipe material so that material and labor costs give a good service life to the water system.

d. Pipe Fittings - Bamboo pipes come in lengths of approximately 20 to 40 feet. The joining of these parts into main and branch lines has an important influence not only on the cost of laying and maintaining the pipe, but also on the resistance that the pipe offers to the flow of the water. Therefore, careful attention should be given to this aspect.

During the summer of this year, special attention will be given in follow-on studies on mechanical properties of bamboo.

CONCLUSIONS

It is difficult at this point to make a total judgement about the feasibility of bamboo in a pressurized water system. Many field and operational variables require evaluation. This project gathers information on the economic aspects of the decision process. Mechanical properties of bamboo must also be considered. The mechanical properties of bamboo must be improved up to a competitive level with plastic. The cost of obtaining such improvements would have to be added to the cost of the raw material. Moreover, before a final economic analysis can be made, a consideration should be given to the fact that the two materials in question have different life expectancies. However, one of the aims of the project is to increase the life period of bamboo pipes.

As far as Colombia is concerned, there is no need of bamboo pipes. The program of the Colombian government to solve the water problems of small villages by means of plastic pipes delighted us because of its excellent planning, good engineering records, sensitivity to the communities, and

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scheduling. Though Colombia may not benefit from the use of bamboo, we think that it could well be used as an experimental site. We believe that if the feasibility of bamboo could be proved in Colombia, it could then be tested elsewhere.

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*Publications from DANE can be obtained in Bogota, Colombia, S.A.

Recd 5-28-75

APPENDIX 7

DETERMINATION OF TENSILE STRENGTH OF TWO SPECIES OF BAMBOO AND THEIR ADAPTABILITY TO FLUID CONDUCTION UNDER PRESSURE

(Section 2 of 2 Sections)

submitted to:

Dr. William Rice
Special problem
May 23, 1975

submitted by:

Paul K. Whitehouse
undergraduate
May 23, 1975

TABLE OF CONTENTS

ABSTRACT

This is a continuation of the bamboo study initiated in September of 1974, dealing with the " determination of the feasibility of utilizing bamboo as a low cost water pipeline in developing nations."

INTRODUCTION

This report will deal primarily with the strength characteristics of the bamboo fiber, both the soft inner fiber layer and the much denser outer layer.

Since it is not possible to get all of the bamboo culms needed for a pipeline with the exact same outside diameter, it will be necessary to mill the ends of the culms in order to develope an adequate joint. By evaluating fiber strength we can determine whether or not the machining of the culm ends will invariably effect the total strength of the pipe system.

The samples used for this test are the same as before, specifically:

(A) Guadua angustifolia

(B) Bambusa vulgaris

The variables under which these samples were prepared for testing are:

(A) Dry (less than 4% MC)

(B) Wet (approximately 10% MC)

LITERATURE REVIEW

1. **PROPERTIES OF SOME BAMBOOS CULTIVATED IN THE WESTERN HEMISPHERE**
   G. E. HECK, Engineer
   Forest Products Laboratory
   Forest Service
   U.S. Department of Agriculture
   (reviewed and reaffirmed 1962)

2. **STUDIES ON THE BAMBOOS**
   YOSHIO TAKANOUCHI
   1932

3. **BAMBOO AS A BUILDING MATERIAL**
   F. A. McCLURE
   Field Service Consultant
   Foreign Agricultural Service
   United States Department of Agriculture
   May 1953

OBJECTIVE

The principle objective of this report is to determine the approximate fiber strength of two species of bamboo, (Guadua angustifolia and Bambusa vulgaris), both parallel and perpendicular to the grain.

The major limitation on this study is again the sample size that was tested. It must be remembered that this is only a feasibility study, designed to illustrate potential. Before this material can be put into actual use, further study, in much greater depth will be necessary.

PROCEDURE

A LISTING OF STEPS TAKEN TO ACCOMPLISH THE RESULTS:

(1.) Initial weights were taken of all samples prior to conditioning. (to the nearest .01gr. and .001kg.)

(2.) The samples were then conditioned in the following manner:

(A) Dry - A determination of moisture content indicated that the samples were less than 4%MC

(B) Controlled - These samples were placed in a humidity chamber where temper - ature and relative humidity were controlled (wet bulb 61 and dry bulb 70, yielding an EMC of approximately 10.9%)

(3.) When the samples reached the approximate EMC% they were removed from the conditioning environment and prepared for testing. The preparation envolved the following steps:

(A) Test sections of each species were cut (2½ x 2½ inches) and were approp - riately notched for both the parallel and perpendicular to the grain tests. These samples contained both shell and core fiber. (figure 1)

(B) Test sections of each species were cut (2½ x 2½ inches), sanded down to remove the denser shell fiber, and were appropriately notched for both the parallel and perpendicular to the grain tests. These samples contained only the less dense core fiber. (figure 1)

(4.) All results were recorded and presented in graph and table format.

(Figure 1)

These figures illustrate the size of the test samples utilized for tests parallel and perpendicular to the grain.

(A) illustrates the samples (face and end view) used for the Core tensile strength tests.

(B) illustrates the samples (face and end view) used for the Shell and Core tests

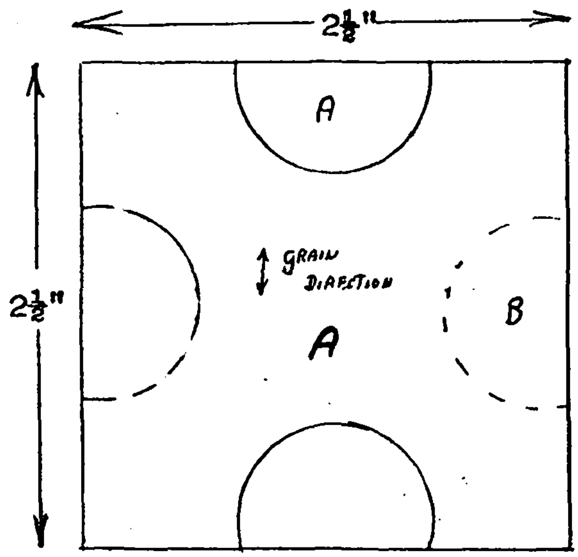
Notches were made in the test samples to enable the test machine to grasp the sample without damaging the fibers

(notch A) - for testing perpendicular to the grain

(notch B) - for testing parallel to the grain

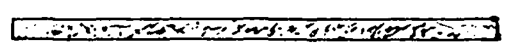
(Figure /)

(face view)



notched insert

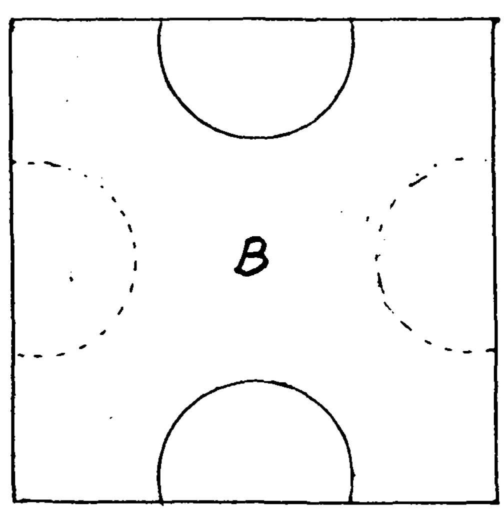
(end view)



outer shell fiber

inner core fiber

(face view)



(end view)

outer shell fiber

inner core fiber

EQUIPMENT

"RIEHLE TESTING MACHINE"
Model FS-60
Universal Screw Power Testing Maching

Serial Number R-92922

EXPERIMENTAL RESULTS

(Bambusa vulgaris)

The dry shell and core results, both parallel and perpendicular to the grain are illustrated in (Tables 1A,1B).

The wet shell and core results, both parallel and perpendicular to the grain are illustrated in (Tables 2A ; 2B).

The results of the core tests, perpendicular to the grain, are illustrated in (Table 3) for the dry samples, and (Table 4) for the wet samples.

A comparison of the averages of the above data is illustrated by means of bar graphs. (Figures 2 + 3)

(Guadua angustifolia)

The results of the shell and core tests, both parallel and perpendicular to the grain, are listed in (Tables 1A,1B) for the dry samples, and (Tables 2A,2B) for the wet samples.

The results of the core tests, perpendicular to the grain, are listed in (Table 3) for the dry samples, and (Table 4) for the wet samples.

A comparison of the averages of the above data is illustrated by means of bar graphs. (Figures 4 + 5)

SHELL AND CORE TESTS OF DRY SAMPLES

(Table 1A)

(PARALLEL TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(cm.)	P.S.I.	Thickness(cm.)	P.S.I.
1.20	945	1.10	645
1.30	960	1.10	950
1.40	750	1.10	975
Avg. 1.30	885	Avg. 1.10	857

(TABLE 1B)

(PERPENDICULAR TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(cm.)	P.S.I.	Thickness(cm.)	P.S.I.
1.10	190	1.00	155
1.10	271.5	1.00	170
1.10	335	1.00	208
Avg. 1.10	265.5	Avg. 1.00	178

SHELL AND CORE TESTS OF WET SAMPLES

(Table 2 A)

(PARALLEL TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(cm.)	P.S.I.	Thickness(cm.)	P.S.I.
1.00	469	0.70	295
1.00	430	0.70	170
1.00	560	0.70	140
Avg. 1.00	486	Avg. 0.70	202

(TABLE 2 B)

(PERPENDICULAR TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(cm.)	P.S.I.	Thickness(cm.)	P.S.I.
1.00	172	0.80	102
1.00	90	0.80	127
1.00	95	0.80	134
Avg. 1.00	119	Avg. 0.80	121

CORE TESTS OF DRY SAMPLES

(Table 3)

(PERPENDICULAR TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(mm.)	P.S.I.	Thickness(mm.)	P.S.I.
1.20	171.3	2.22	107
1.12	172	2.66	129
2.56	177	2.81	169
Avg. 1.63	173.43	Avg. 2.56	135

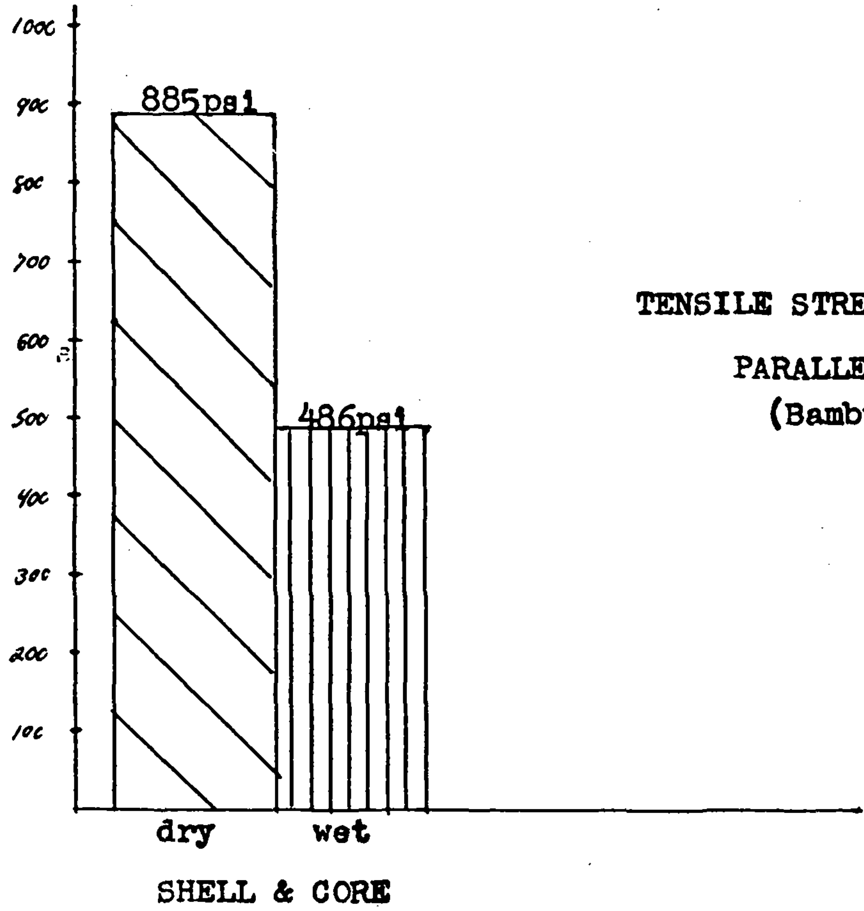
CORE TESTS OF WET SAMPLES

(Table 4)

(PERPENDICULAR TO THE GRAIN)

BAMBUSA VULGARIS		GUADUA ANGUSTIFOLIA	
Thickness(mm.)	P.S.I.	Thickness(mm.)	P.S.I.
1.58	63	2.75	164.5
1.62	89	2.26	148
1.41	66	3.29	175
Avg. 1.54	73	Avg. 2.77	162.5

(Figure 2)

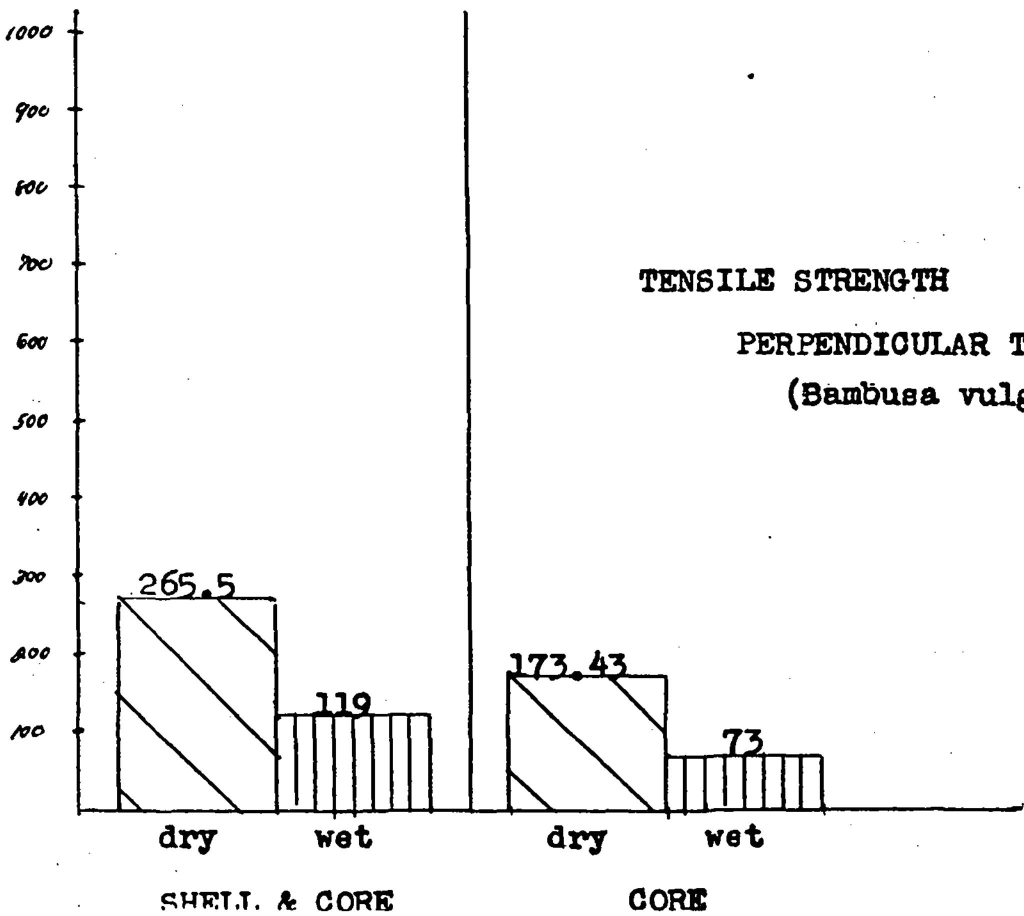


(P.S.I.)

TENSILE STRENGTH

PARALLEL TO THE GRAIN
(Bambusa vulgaris)

(Figure 3)

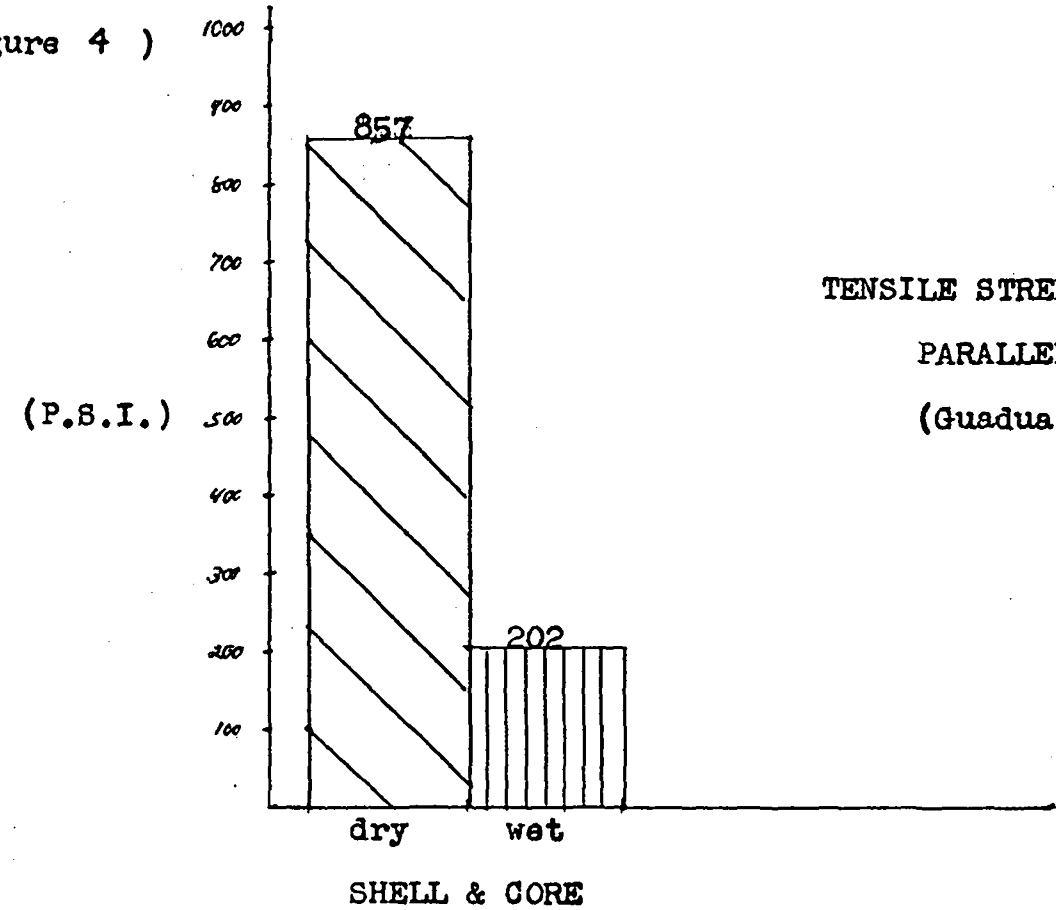


(P.S.I.)

TENSILE STRENGTH

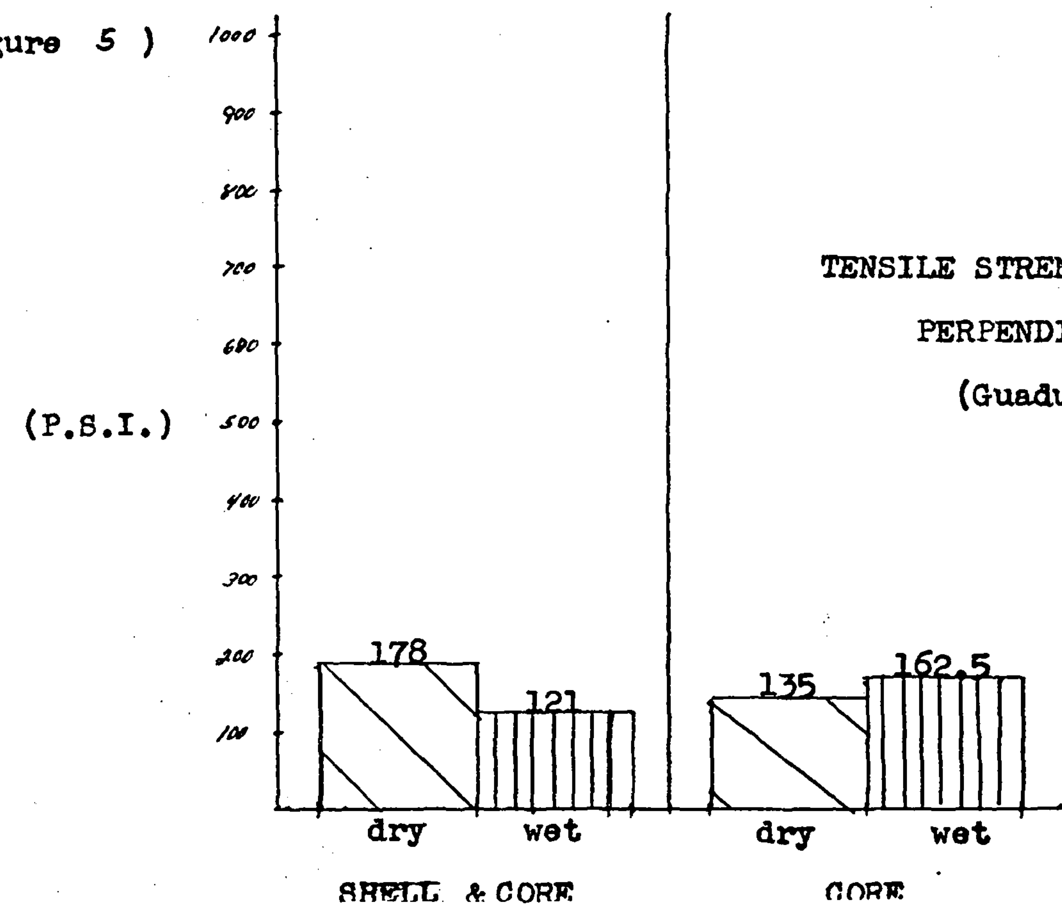
PERPENDICULAR TO THE GRAIN
(Bambusa vulgaris)

(Figure 4)



TENSILE STRENGTH
PARALLEL TO THE GRAIN
(Guadua angustifolia)

(Figure 5)



TENSILE STRENGTH
PERPENDICULAR TO THE GRAIN
(Guadua angustifolia)

DISCUSSION

When considering the utilization of bamboo as a pipeline for the conduction of a fluid, emphasis should be placed on tensile strength perpendicular to the grain and bursting strength. Since the results of bursting strength tests were reviewed in section one of this report, this discussion will center primarily on the tensile strength perpendicular to the grain of sections of a bamboo culm.

TENSILE STRENGTH PERPENDICULAR TO THE GRAIN

In the shell and core tests of both species the dry samples illustrated a 47 to 123% average higher tensile strength (in pounds per square inch) than the wet samples.

In the core tests, Bambusa vulgaris exhibited a 138% higher average tensile strength in the dry samples than in the wet samples. Conversely, the dry samples of Guadua angustifolia exhibited a 20% lower average tensile strength than the wet samples. Since tensile strength should increase as the average moisture content decreases, with regards to woody fiber, I believe that further testing of the wet and dry core samples of Guadua angustifolia is necessary. Although the moisture content of the samples was checked prior to testing, this does not necessarily remove the probability of some degree of experimental error entering into this facet of the testing. This is not entirely impossible, especially when one considers the relatively small sample population used in this feasibility study.

COMPARISON OF CORE TESTS WITH SHELL AND CORE TESTS

(Bambusa vulgaris)

Both the dry and wet shell and core samples exhibited a higher tensile strength than those of the core samples. Specifically; dry S&C (53% higher), wet S&C (63% higher) than the core samples. (Figures 2 & 3)

(Guadua angustifolia)

The dry shell and core samples exhibited a 32% higher average tensile strength than the dry core samples. (Figure 5)

The wet shell and core samples exhibited a 34% lower average tensile strength than the wet core samples. (Figure 5)

Considering the correlation between test results and moisture content as regards to both species of bamboo the results of the bursting strength tests were converse to the results of the tensile strength tests. Specifically, bursting strength was high with the wet samples (10.9% MC) and low with the dry samples (less than 4% MC), whereas tensile strength was high with the dry samples and low with the wet samples.

I feel that the end sections of the bamboo culms can be milled, forming a better joint without any appreciable loss in strength. This can be accomplished by shaping a female end, that is, removing some of the core material, increasing the inside diameter. The male end is shaped by removing some of the shell material, decreasing the outside diameter. The end result is a male end of primarily inner core material, and a female end of primarily outer shell material (Figure 6). The resulting joint therefore has the same constituency as the rest of the pipe; shell and core material. In effect the joint would essentially be stronger that the pipe itself, since the joint would be additionally secured by means of a reinforced hose clamp. (Figure 7)

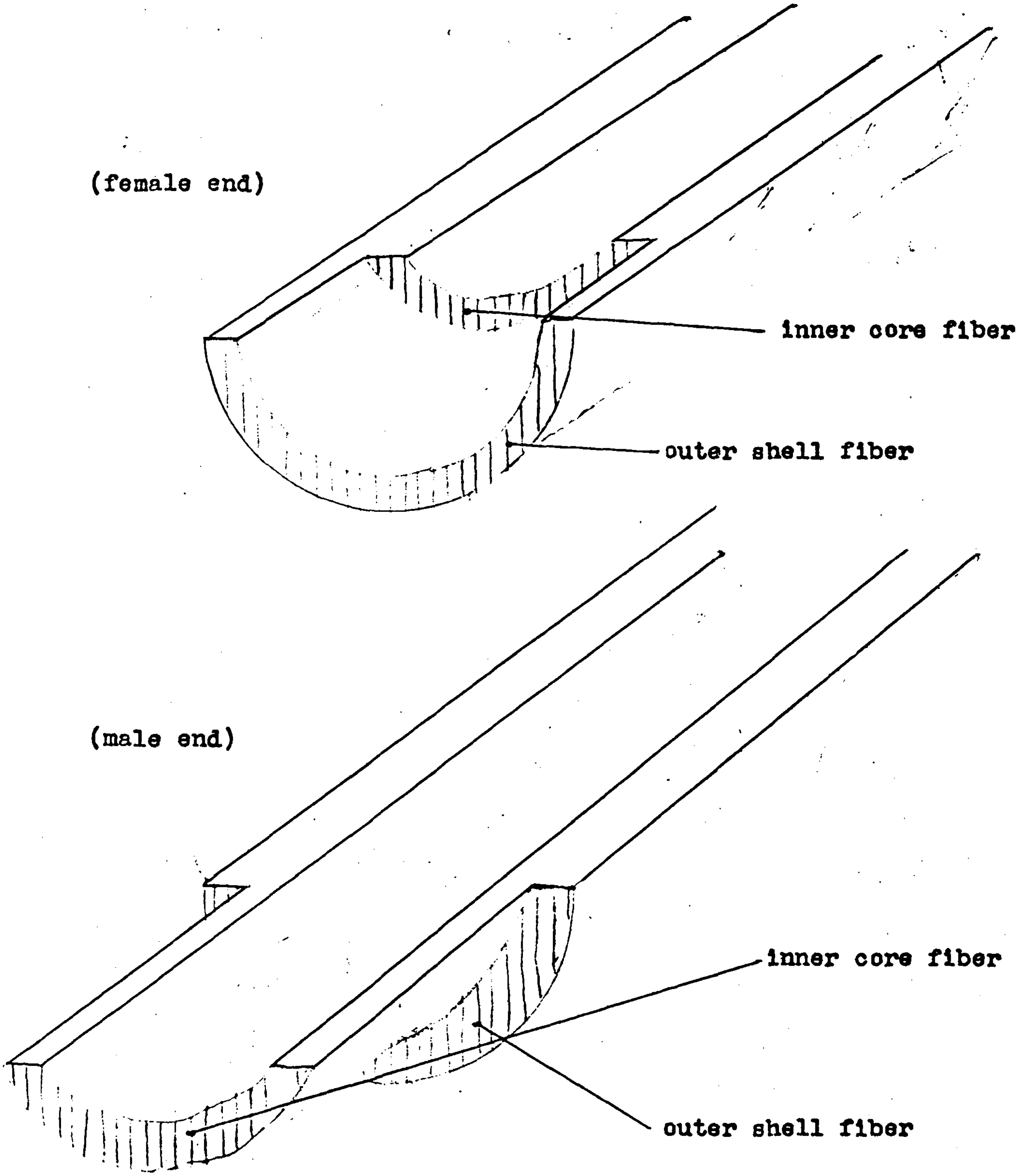
It was noted that the samples subjected to controlled conditions in the humidity chamber were subject to the attack of mold. The samples, conditioned to an EMC of 10.9% for a prolonged period were equally subject to mold attack, irregardless of species. The mold attacked the shell area as well as the core area of both species, although a greater mold growth appeared to be concentrated on the inside (core) walls of both species.

All shell and core and core tests were made with samples that had already been attacked by mold growth. The mold was easily wiped off prior to testing, and no apparent external damage was noted among the test samples. The results were sufficiently high enough to support feasibility of utilizing this material for a fluid conductor, but further study will be necessary to determine exactly what types of mold will attack the moist material and what extent of external and internal damage can be expected to accrue over time.

This leaves us with the problem of finding a suitable preservative that is toxic to these fiber destroying organisms yet will not be harmful to human and animal life forms, primarily by leaching of toxic materials into the fluid medium.

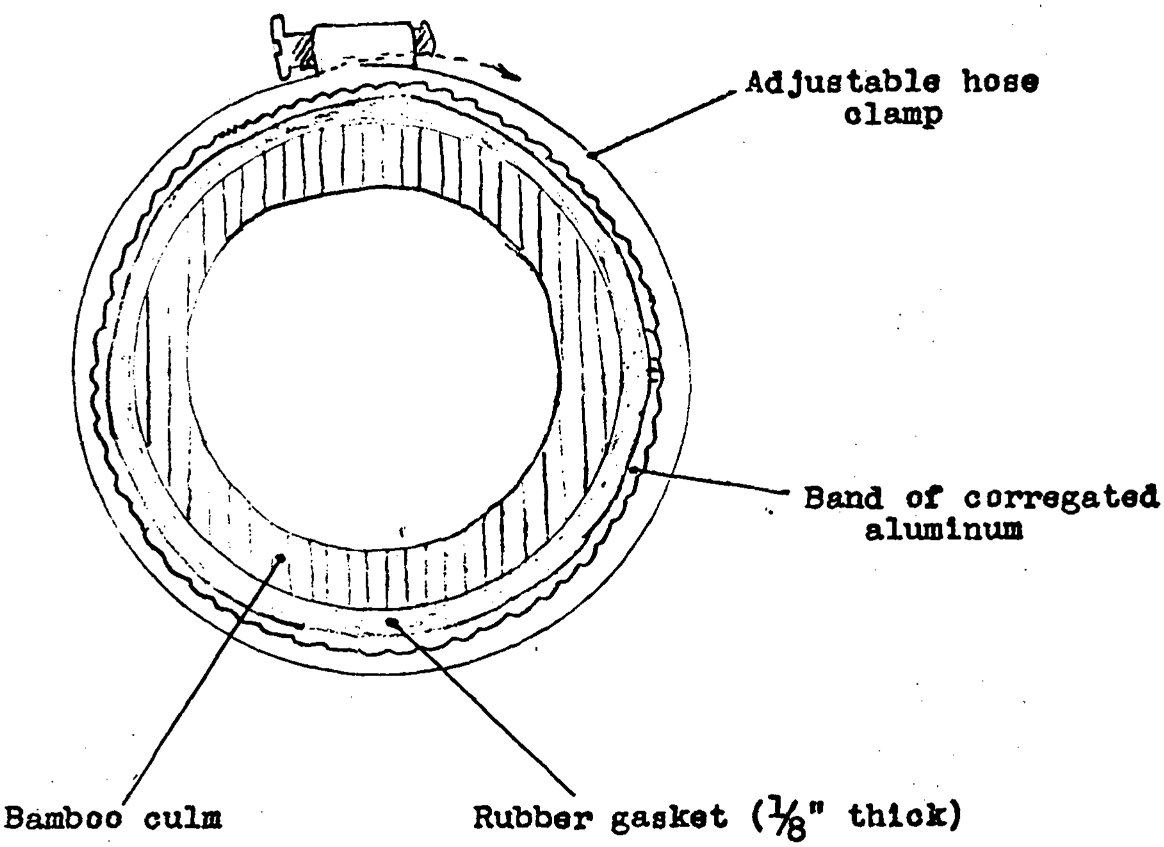
JOINT DESIGN

(Figure 6)



Exposed View of Joint

(Figure 7)



CONCLUSIONS

1. As indicated by the overall results, the feasibility of utilizing bamboo as a pipeline definitely exists. However, a more in-depth study utilizing a much larger sample population size with more stringent variable control is necessary before this material can be put into actual, practical use.

2. Of the two species of bamboo tested, (Bambusa vulgaris) illustrated the greater potential for utilization.

3. Due to the high susceptibility of the moist bamboo to mold and fungus attack it will be necessary to treat the culms with a preservative system that will remain toxic to these organisms yet will not be harmfull to human or animal life forms. An oil-borne preservative such as copper-8-quinolinolate shows promise, but much extensive research will be needed prior to acceptance.

4. The mold and fungus readily attacks both the inside (soft inner core of fiber) and the outside (hard outer shell of fiber) of the bamboo culms. Since the bamboo pipe will continuously contain water, emphasis must be placed here. Irregardless of what preservative system is used, with continuous intimate contact with both stationary and flowing fluid there is the ever present problem of the leaching of toxic material into a potable water system.

   To avoid this problem the inside of the bamboo culms should either be coated with a vinyl type sealer or a thin plastic tube (pipe) can be placed within the culm section, acting as a pipe within a pipe.

4. An effective joint was made utilizing a typical hose clamp reinforced with corregated aluminum surrounding a rubber gasket approximately $\frac{1}{8}$ inch thick. The rubber gasket covers approximately two (2) inches of each end section of adjoining pipes. The reinforced hose clamp is then wrapped around the gasket and torqued securely. This clamping system lends itself to a high degree of flexibility and adaptability and at a relatively low cost per clamp.

5. All factors considered, an extensive cost analysis must be determined regarding the preparation of this material for suitability and longevity as a pipeline for potable water. What is the cost comparison of this system, con - sidering preparation, maintenance and installation, as opposed to conventional PVC (polyvinyl acetate)?

6. The end sections of the bamboo culms can be milled to form a more complete joint with little or no effect on the total strength once two end sections are joined, forming a complet joint. Further support is applied with the utilization of the reinforced hose clamp.

SUMMARY

Sections one (1) and two (2) of this report indicates that two species of bamboo (Bambusa vulgaris and Guadua angustifolia) have the potential for utilization in a pressurized water system. It, again, must be remembered that this study was not designed to provide a working system (complete), studying all possible variables and limitations, but rather to determine whether or not these two species of bamboo have use potential.

Before this system can be put into practical use much extensive research must be done on adequate preservative systems. The bamboo, when moist, is readily attacked by wood fiber destroying organisms, which will invariably effect the strength of the pipe sections.

Since extensive preparation is necessary to make this system suitable for transporting potable water, lending itself towards longevity, an accurate cost analysis must be done on the system. Once done, a viable comparison can be made between this system and proven alternatives. It is my opinion that the cost factor of this system is (will be) comparable to that of the suitable alternatives.

APPENDIX

KILN SAMPLE RECORD

Project: Bamboo
Species: Bambusa Vulgaris
Kiln footage:
Material size:
Kiln No.:
Date started: 03/11/75
Date finished:

Moisture sections					
Sample No.	L1	L2	L3	L4	L5
Species	La Lima	—	—	—	—
Thick					
Green wt.	18.20 g.	37.20 g	37.10 g	35.75 g.	35.30 g
O. D. wt.	17.10	35.20	35.05	33.90	33.40
Pct. M. C.	6.43	5.68	5.85	5.46	5.69

AVG M.C. = 5.82

Kiln samples					
Green wt.	890 g				
Calc. dry wt.	841.05				
Coating wt.					

Date	Time	total Time	Remarks	Dry bulb	Wet bulb	EMC %	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.
3/11/75	2100	0		70	61											
3/13/75	2100	48		70	61	10.9	900	7.01								
3/15/75	1730	87.5		70	61	10.9	906	7.72								
3/17/75	2130			70	61	10.9	913.5	8.61								
3/23/75	2100			70	61	10.9	922	9.62								
3/26/75	1900			70	61	10.9	929	10.46								
3/30/75	1800			70	61	10.9	931	10.69								
3/31/75	2130			70	61	10.9	932	10.81								
4/1/74	2100			70	61	10.9	932	10.81								
							877									
							870									

Kiln operator

Final					
M. C. sections					
Shell					
Core					
Average					

Case hardening data

KILN SAMPLE RECORD

Project Coppens [illegible]
Species Guarea [illegible]
Kiln footage
Material size
Kiln No. Humidity Chamber
Date started 03/11/75
Date finished

Moisture sections					
Sample No.	G1	G2	G3	G4	[illegible]
Species	[illegible]	—	—	—	—
Thick					
Green wt.	40.03g	41.70g	38.60g	55.[illegible]g	50.06g.
O. D. wt.	37.80g	39.25	36.40.	52.6[illegible]	47.90
Pct. M. C.	5.90	6.24	6.04	5.89	4.51
Avg MC. = 5.72	**Kiln samples**				
Green wt.	580 g	1106 g	273 g	265	
Calc. dry wt.	548.62	1046.16	258.23	250.66	
Coating wt.					

Date	Time	total Time	Remarks	Dry bulb	Wet bulb	EMC %	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.	Wt.	% M.C.
3/11/75	2100	Ø		70	61											
[illegible]	2100	48		70	61	10.9	587.8	7.14	1111	6.20	276.1	6.92	[illegible]	7.08		
3/15/75	1230	87.5		70	61	10.9	590.7	7.67	1115	6.58	278	7.66	269.5	7.52		
3/17/75	2130			70	61	10.9	593.9	8.25	1120.5	7.11	279.5	8.24	270.9	8.07		
3/23/75	2100			70	61	10.9	599.3	9.24	1131	8.11	282.1	9.24	273.6	9.15		
3/[illegible]/75	1700			70	61	10.9	601.1	9.57	1143.5	9.30	283	9.59	274.5	9.31		
3/30/75	1800			70	61	10.9	604.3	10.15	1146	9.55	284.05	10	275.7	10.01		
3/31/75	2130			70	61	10.9	604.1	10.11	1147	9.64	284.3	10.10	276	10.11		
4/1/75	2100			70	61	10.9	604.2	10.13	1147.5	9.69	284.5	10.17	276	10.11		
									983		283.85					

Kiln operator

Final					
M. C. sections					
Shell					
Core					
Average					

Case hardening data

APPENDIX 8

Measurement of the Bursting Pressure of Two Bamboo Species

Steven Lord
Department of Mechanical Engineering
University of Massachusetts
Amherst, Massachusetts
January, 1975*

ABSTRACT:

Reliable estimates for the bursting pressure of bamboo tubes of varying diameters and wall thicknesses were needed to determine the feasibility of using bamboo pipes in public water systems. A series of tests performed on several samples of these species of bamboo yielded bursting pressure values ranging from 55 psi to 100 psi (4.0 kg/cm^2 to 7.0 kg/cm^2) for Guadua angustifolia whose outside diameters ranged from three to four inches (7.6 cm. to 10.2 cm). A nearly three-inch diameter sample of an unknown species taken from a clump at La Lima, Honduras burst at 145 psi (10.2 kg/cm^2). A three-inch sample was tested to 225 psi and did not burst.

MECHANICAL PRINCIPLES:

If a bamboo culm is modeled as a long tube of circular cross section composed of a uniform material, integral summation of the interior forces due to fluid pressure shows that the stress in the walls equals:

$$\sigma = \frac{P}{(D_o - D_i)/D_i} , \qquad \text{where} \qquad (1)$$

P = the fluid pressure, D_o = the outer diameter, and D_i = inner diameter.

At some pressure P_B this stress will exceed the ultimate tensile strength of the wall material and the pipe will split. If the bursting strength is designated σ_B, which is purely a property of the material, then:

$$P_B = \sigma_B \left(\frac{D_o - D_i}{D_i}\right) \qquad (2)$$

Once σ_B is found by experiment for a single sample of pipe, it can be

*Now at Massachusetts Institute of Technology used to find P_B for any size under the assumption that the pipe material has uniform properties for different sizes. Bamboo is not such a uniform material, and a more complicated analysis is required.

1. Bamboo culms are not exactly circular in cross section.
2. The walls are not uniform thickness. This produces more concentrated stresses at some points than at others, and lowers the bursting pressure that might otherwise be expected.
3. The strength of the wall material itself varies between species.
4. There is variability within species.
5. The age of the specimen affects physical properties.
6. The type and time of curing bamboo affects physical properties.
7. There is variability between individual culms.
8. There is variability within a culm.
9. There is variability in physical properties at the node.

A more realistic expression for the bursting pressure of a bamboo pipe that would account for some of these variables is

$$P_B = KS_fA_fC_f\left(\frac{D_o-D_i}{D_i}\right) \qquad (3)$$

where σ_B is replaced by $KS_fA_fC_f$ where k is a roundness factor, S_f an appropriate ultimate tensile stress figure for the species being considered, A_f an age factor, and C_f a curing factor. But even if these factors were given approximate values through a series of future experiments, only a rough approximation to the actual bursting pressure could be expected, due to the variations characteristic of individual members of any given species. A further source of difficulty arises from the fact that the composition of the bamboo wall varies radially, from a hard outer "skin" to a much softer inside layer. If this variation does not retain the same proportions from thicker to thinner walled samples, the equation given above would not apply.

No literature with explicit experimental evidence on bamboo was found on bursting strength. The program of testing at the University of Massachusetts was confined to finding an effective means of testing bamboo safely and easily and to bring bursting strength out of a guessing game and into reality.

TEST PROCEDURE FOR DETERMINING BURSTING PRESSURE OF BAMBOO PIPE

Step 1.

a. The internal septa were removed from the bamboo sample.

b. The samples, three feet (approximately 1 meter long) long or less had parallel transverse cuts made so that the sample could be fitted properly into the test device.

c. The piece was set up vertically and filled with water through a screw fitting in the top seal. The end of a flexible hydraulic hose from a hand-operated pump was then screwed into the fitting and the pressure was increased by slow stages, pumping oil onto the top of the enclosed water column until the sample burst. All samples tested burst safely, with the development of longitudinal breaks. Approximately half of the breaks progressed through the bud.

The major difficulty encountered in the test procedure, at first, was that the ends of the samples were sealed in cast iron cups, using automobile body filler to prevent leaks under pressure. When the plastic was still soft, the ends of the bamboo tube were inserted into the cups with the body filler. The plastic then hardened around the bamboo, sealing the ends. It was found advantageous to roughen the ends of the bamboo with coarse sandpaper ahead of time, with the sanding grooves running around the tube rather than lengthwise, to improve the seal. The top cast iron cap was drilled and threaded beforehand to accept a fitting, and a wooden dowel was used during the sealing process to preserve a passage through the plastic and to keep it from leaking out the hole. As soon as the bamboo was set into the iron caps, three long pipe clamps made from half-inch plumbing pipe and No. 52 "Pony" clamp fixtures were applied to hold the iron caps in place and prevent them from being forced off by water pressure when the sample was tested. The pipe clamps also formed an effective base permitting the sample to stand vertically during filling and testing. Figure 1 shows a cross sectional view of this type of test setup.

A second sealing method was tried later and adopted because the first seemed excessively time-consuming, awkward, and expensive. The second method sometimes failed to provide a good seal, particularly if the pressure test was delayed and the bamboo was given time to dry out further after the plastic had hardened. The second sealing system consisted of two flat 6" square by one-half inch (1.3cm.) thick steel plates, covered with 1/8 inch (.3 cm.) thick rubber gasket material on the inner sides, and pulled in against the ends of the bamboo sample by a half-inch (1.3 cm.) round threaded rod passing lengthwise through the hollow center of the bamboo tube. A cross sectional view of this system is shown in Figure 2. The threaded rod was welded into one of the plates and passed through the second, being secured by a nut. One plate contained a hole drilled and threaded to accept a hydraulic hose fitting and a second similar hole to permit air to escape easily while the specimen was being filled with water prior to testing. A set of four pipe clamps identical to those described previously were applied to provide extra sealing pressure and a stable base.

This second system required about thirty minutes set-up time per test, as opposed to about three times as much for the first system, and the recurrent expense of pipe caps ($6-8 per pair) and plastic filler ($3-4 per quart) was avoided. Though the pipe caps are not damaged by the test and could be re-used, the time-consuming necessity of chipping or burning out the solidified plastic after each test makes re-use impractical.

The test itself proceeds by filling the sealed specimen with water, screwing the hydraulic hose from the pump into the threaded opening in the top seal, and by slow stages increasing the pressure until the sample bursts. The pump used in most of the successful tests was an "Enerpac" P-80 hydraulic hand pump, purchased specifically for this project at a cost of $115. It was selected on the basis of its large displacement volume per stroke (about 1 cubic inch), large fluid reservoir, and relatively low cost. It has proven entirely satisfactory thus far. A twenty foot hydraulic hose with a specified pressure limit of 1800 psi (127kg/cm^2) was used between the pump and the test setup for safety reasons, and obstructions were kept between the observers and the test rig to block any flying debris resulting from the burst. The specimen was observed by means of mirrors. A pressure gauge was placed in the line shortly below the pump outlet by means of a "T" fitting, in a position easily readable by the man operating the pump. The most satisfactory scale range on the gauge for this purpose was from 0 to 300 psi. (0 to 21 kg/cm^2), marked off in minor divisions of 5 psi. (.35 kg /cm^2) and major divisions of 25 psi. (1.76 kg/cm^2). A gauge of this type was purchased for about $18.00. The usual procedure in testing was to start at 25 psi. and increase pressure slowly by 25 psi. stages, holding for two minutes at each stage.

TEST RESULTS AND CONCLUSIONS:

The results of individual tests are detailed in Table I. Indications thus far are that pipes made from large Guadua angustifolia culms may be expected to withstand about 50 psi. safely. Very possibly this figure could be increased by selecting culms of optimum age and by proper curing. The samples obtained for these tests were of unknown age and had been stored in a dry, uncontrolled atmosphere for months before proper manpower, equipment, and procedures could be obtained. Well controlled field tests and preparation of material might provide significantly different figures. Some of the later tests were run on specimens which had been soaked in chambers of controlled humidity and temperature. These were removed from the test chamber, wrapped in plastic to preserve moisture, then brought to the testing apparatus.

Tests on two specimens of bamboo from La Lima showed high bursting pressures. It appears that the unknown species from La Lima, or other bamboo species, might be better suited for water pipe than Guadua angustifolia. The La Lima species will probably carry at least 100 psi (7.0kg $/cm^2$) safely, but this should be confirmed by more extensive tests.

The data obtained from the Guadua angustifolia samples show little correlation with the bursting pressure equation proposed in the Mechanical Principles section. This may be due to the uncontrolled drying conditions the samples were subjected to over the three month testing period, or it may reflect inadequacy in the model. Further tests under more controlled conditions and better sampling techniques are needed to resolve this point.

TABLE 1

BURSTING PRESSURES OF TWO BAMBOO SPECIES

TESTED AT THE UNIVERSITY OF MASSACHUSETTS

Specimen	Outer Diameter		Inner Diameter*		Bursting Pressure		Notes
	Inches	Centimeters	Inches	Centimeters	Pounds per Square Inch	Kilograms per Square Centimeter	
A Guadua angustifolia from Mayaguez, Puerto Rico							
1A	4.05	10.28	2.85	7.24	75	5.27	Split on bud line
1B	4.20	10.66	3.13	7.95	80	5.62	Holds 20 psi. with crack
1C	4.05	10.28	3.15	8.00	70	4.92	Soaked in water for 5 days. Split off bud line.
2A	3.85	9.77	3.05	7.75	100	7.03	
2B	3.60	9.14	2.86	7.26	70	4.92	Split off bud line
2C	3.375	8.57	2.81	7.14	75	5.27	
3A	2.94	7.47	2.38	6.05	50-60	3.52-4.22	Small, narrow crack; no sharp sound on bursting
B Bambusa vulgaris from La Lima, Honduras							
1	2.88	7.32	2.20	5.59	145	10.19	Split opposite bud line
2	3.00	7.62	2.28	5.79	225	15.82	Specimen did not burst at 225 psi. Test was stopped due to excessive seal leakage

*Minimum (top) diameters given, as these should govern bursting pressure.

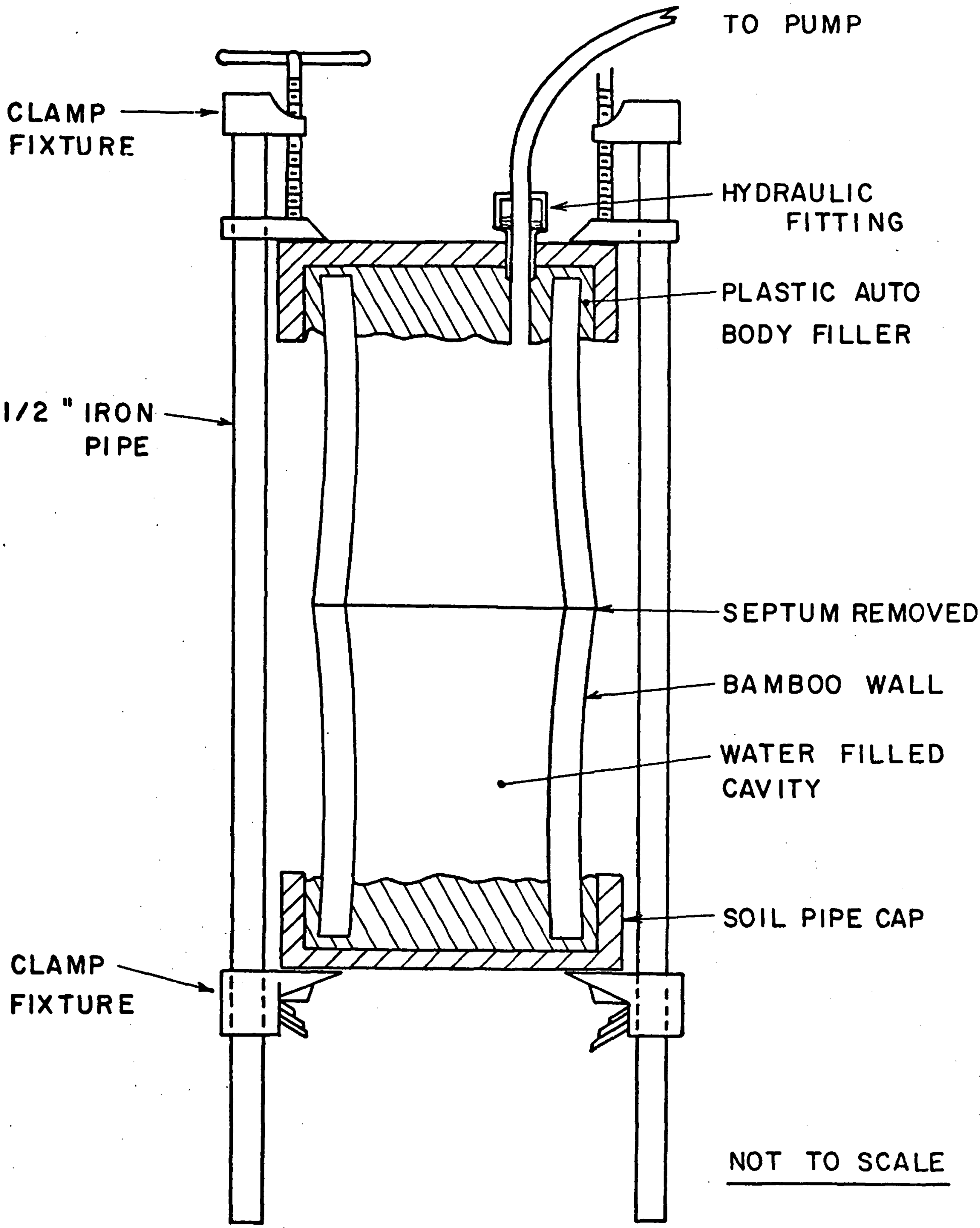


FIGURE 1 ORIGINAL PRESSURE TEST CONFIGURATION FOR BAMBOO PIPE

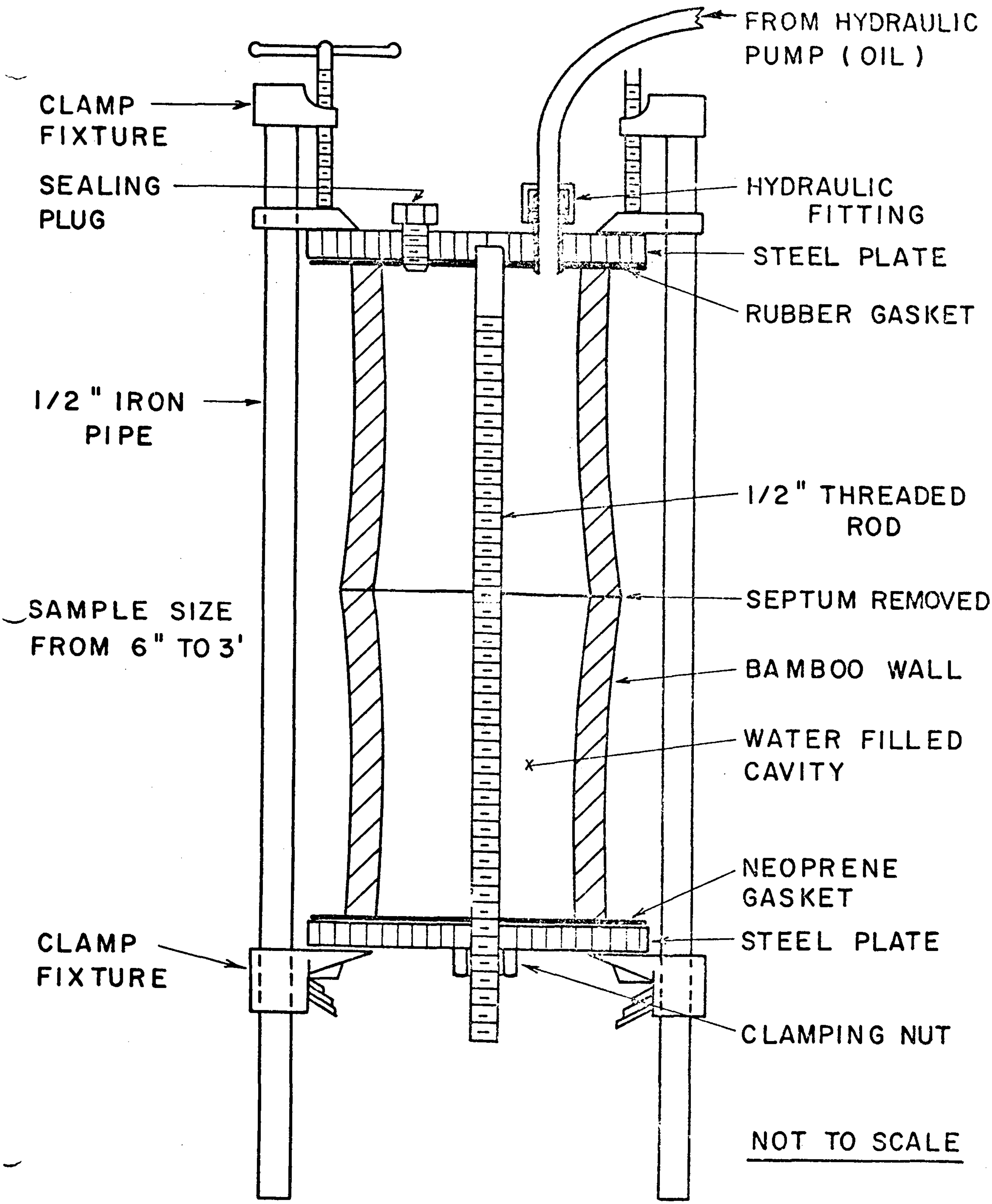


FIGURE 2 FINAL PRESSURE TEST CONFIGURATION FOR BAMBOO PIPE

APPENDIX 9

FIELD WORK ON PRESSURIZED BAMBOO PIPE

COSTA RICA

June 16, 1975-July 5, 1975

Thomas L. Prunier

JANUARY 1976

INTRODUCTION

This report describes briefly the field work accomplished at the Tropical Agricultural Research and Training Center (CATIE), Turrialba, Costa Rica, and at a test site at a place called Quinta Elizabeth, near Siguerres, Costa Rica, in an attempt to determine the feasibility of using bamboo pipes for pressurized domestic water supply systems.

Two species of bamboo were cut, sized by diameter and cut into lengths. Selected short samples were then pressure tested. Only one of these two species was known by name. A third species of considerable size, also unidentified (reputedly from India) was furnished from a site in Atirro, near Turrialba, but a day or two too late to be tested. The clump of the unknown species which was pressure-tested furnished large handsome culms, which appeared to be excellent pipe material, but the smaller Bambusa vulgaris proved to have a considerably higher bursting strength. Bambusa vulgaris was therefore selected for the test pipeline. The sections which follow present the major elements of the bamboo work, plus discussions on improvement of strength and resistance to fungi, bacteria and insects.

SAMPLE SELECTION

At a residential location called Caveria, on the CATIE grounds, three species of bamboo were inspected. Two of these appeared suitable for testing, one a tall, green species, one of whose culms was measured at nearly 90 feet (29.5 m) the other, Bambusa vulgaris, with yellow stems and dark green stripes, was of more modest height, about 52 feet (nearly 16 m), Tables 1A, 1B, 2A and 2B give the details.

SIZING OF BAMBOO PIPES

After the bamboo was cut, it was sized, not by length but by diameter. A piece of wood 1 foot x 3 feet x 1 inch (30.5 cm x 91.4 cm x 2.5 cm) was used to make the sizing gauge. Three holes, 2 inches (5.1 cm), 3 inches (7.6 cm) and 4 inches (10.2 cm) were cut along the midline of the gauge board.

The bamboo was sized by cutting the culm where it obviously could fit into the smallest diameter hole and then inserting it into the hole until it stopped. The culm was then cut on the side of the board from which the small end protruded. The culm was then inserted into the next larger hole until it stopped and again was cut off on the small side. If the remaining section was long enough the process was then repeated at the next larger hole.

Branches had to be trimmed off to allow the bamboo to be measured at its fullest diameter. Sometimes the bamboo was cut at an off-round point. This might produce a bad joint so the culm was cut at a place close to the correct diameter but more nearly round.

Care was taken in the handling of the culms so as not to crush or crack the cut ends.

CUTTING THE CENTER DIAPHRAGM IN THE BAMBOO SECTIONS

A Millers Falls No. 828 1.5 inch (3.81 cm) Heavy Duty Bit was arc-welded to a 9/16 inch (1.43 cm) diameter steel rod approximately 16 ft. (5 meters) long. The opposite end of the rod was ground with 3 flats to be accepted by a 1 inch (2.54 cm) electric drill chuck.

This extended drill was used to cut out the center diaphragms of a piece of bamboo up to some 30 feet (10 meters) long.

The operation was most easily accomplished with two people, one to hold the electric drill and another to place the cutting tool in the end of the bamboo culm and hold the culm secure. Considerable torque is generated so caution should be exercised at both ends of the operation. An extension cord is needed when cutting holes in long lengths of bamboo. The drill did not cut a perfectly round hole but this would not happen if the bit had been larger in diameter. An adjustable chuck welded to the end of the rod would facilitate use of varied width drill bits.

It is possible for one person alone to drill the centers by securing the bamboo section to a tree or post by means of a rope wrapped around both.

In any kind of routine operation, an assortment of drills, probably of a kind better suited to the specific task would be employed. A good work station would readily be laid out, and simple jigs developed.

FIELD TESTS TO DETERMINE BURSTING STRENGTH

Pressure tests were run on fresh cut, untreated samples of two species of bamboo, one Bambusa vulgaris, the other an unknown green colored species.

The diaphragms at the nodes were cut out as previously described. The samples were cut into approximately 1 meter sections and the ends cut square and sanded to present a smooth surface to the neoprene gaskets which were clamped against the pipe sections.

The testing apparatus consisted of a heavy steel plate into which a threaded steel rod was placed. The threaded rod ran through the section of bamboo culm to be tested and through a second steel plate. A heavy nut below the lower plate was used to press the two plates together. A heavy rubber gasket was placed between the steel plates and the ends of the bamboo to create a seal. In addition to the clamping action of the threaded rod, a long pipe clamp was used on each of the edges of the steel plates.

Attached to this device via a high pressure (2750 psi, 193.3 Kg/cm^2) hydraulic hose was a hydraulic pump and pressure gauge appropriate to the testing requirements. After the bamboo section was clamped in the testing apparatus it was filled with water via a threaded hole in one steel plate.

This accomplished, the threaded hole was sealed, and the pressure was applied in 10 psi (0.72 Kg/cm^2) increments until the section burst.

The field test results are shown in TABLE 3.

Non uniformity see p. 141 diff in diam between top and bottom

ASSEMBLY OF PIPE SECTIONS WITH THE NO-HUB JOINT

The bamboo sections were joined with the No-Hub joint. This joint was made up of a 2-inch wide, 1/8-inch thick, 4-inch diameter neoprene collar for the 4-inch joint. Around this neoprene collar was a 2-inch wide corrugated sheet stainless steel collar 15.5 inches long. The ends of this collar overlappped and as the sleeve was tightened, the ends slid past each other.

Screw activated hose-type clamps were attached to each edge of the stainless steel collar with small rivets. These caps were designed to be driven by a specially calibrated torque wrench made by the Rigid Tool Company, that would not allow over-tightening. The joint is available in 1.5 in., 1.5 in. x 2 in., 2 in., 3 in., 4 in., 5 in., 6 in., 8 in., and 10 in. diameters.

The joint is most commonly used to join hubless cast iron soil pipe and fittings made according to C.I.S.P.I. Standard 301-72. The No-Hub joint is a product of the East Penn Foundry Co..

Two bamboo sections were inserted into each end of the joint until they butted against each other at the mid-point and the clamps were tightened evenly until the torque wrench slipped.

The No-Hub joint was previously tested to 200 psi without leakage in the laboratory and a 4-inch No-Hub joint assembly withstood 900 lbs. in tension before slippage occurred. Both these tests were made using 4-inch (10.16 cm) diameter cast iron pipe, with a fresh turned surface.

CONSTRUCTION OF THE PIPELINE

The requirement for the site of the pipeline was a supply of water near a hill in the vicinity of the Turrialba base of operations. Such a site was found four kilometers west of Siquirres on the road to Turrialba. It consists of steeply sloping land with two level terraces. From the river to the lower terrace was an 85 ft. lift over a steep, vine-covered slope.

Approximately 20 ten meter sections of pre-drilled and sized bamboo pipes were carried on the top of a Toyota Land Cruiser to the site. These were hauled, along with a large pump, down the bank of the highest terrace to the lip of the second terrace. The pump was carried to the river bed and the assembling of the bamboo section with the No-Hub joint started at the second terrace. The bamboo pipe was assembled a piece at a time and snaked down the slope. However, when bent over uneven terrain, the bamboo sometimes pulled out of the joint. This problem was alleviated by assembling the pipe in place. The sections laid over steep terrain were secured with rope and twine to trees for support.

The pump was tested before being attached to the bamboo pipe and was found to be inoperable even though it was in use the day before. It could not be repaired at the site so a back-up pump was brought to the river and tried out. This one also failed to pump water and could not be repaired either.

Eight people excluding the surveyors were on hand for five hours each to construct the pipeline. Excluding time spent coaxing the pumps to work an estimated 25 person hours were spent constructing the pipeline. The pipeline consisted of 10 sections of bamboo, 4 inches in diameter, and included a lift of 85 vertical feet. A total of 150 linear feet of pipe was laid.

This day proved valuable as it showed the proper techniques for constructing a pipeline over rugged terrain using bamboo and that such a pipeline could actually be constructed. It also provided an estimate of time and labor needed to construct a pipeline of such length over rugged terrain.

APPENDIX 9 TABLE 1A

DESCRIPTION OF ONE BAMBOO CULM: INTERNODAL LENGTHS

SAMPLE TAKEN FROM CLUMP #1 (SPECIES NOT IDENTIFIED), AT CAVERIA (ON CATIE CAMPUS)

8:00 AM, MONDAY, JUNE 23, 1975

LIVE HEIGHT, 89.5 FEET: CUT MADE 2.5 FEET ABOVE GROUND LEVEL
(27.3 METERS) (.76 METERS)

Internode	In	Cm	Internode	In	Cm
1*	18.0	46	26	26.1	67
2	19.3	49	27	24.6	63
3	22.8	58	28	24.6	63
4	23.8	61	29	25.4	65
5	26.1	67	30	84.1	62
6	26.6	68	31	20.7	53
7	27.3	70	32	19.5	50
8	26.5	68	33	14.8	38
9	28.0	72	34	15.6	40
10	27.7	71	35	12.1	31
11	26.9	69	36	13.3	34
12	22.2	57	37	10.9	28
13	18.7	48	38	11.3	29
14	23.0	59	39	9.0	23
15	28.7	74	40	9.4	24
16	30.0	75	41	8.2	21
17	30.4	78	42	9.8	25
18	30.0	77	43	9.0	23
19	30.0	77	44	9.8	25
20	25.4	65	45	9.8	25
21	28.9	74	46	9.8	25
22	28.9	74	47	10.5	27
23	30.0	75	48	12.1	31
24	28.0	72	49	10.1	26
25	28.0	72	50	9.0	23

*First internodal distance above basal cut, etc.

DESCRIPTION OF DISTRIBUTION OF INTERNODAL LENGTHS

	In.	Cm
Sum of Lengths	1022 = 85.17 ft	2597 = 25.97 m
Number of Internodal Lengths	50	50
Mean Internodal Length	20.4	51.9
Standard Deviation	7.87	20.0
Coefficient of Variation	38.5%	38.85%

APPENDIX 9 TABLE 1B

DESCRIPTION OF ONE BAMBOO CULM, CIRCUMFERENCE MEASUREMENTS

SAMPLE TAKEN FROM CLUMP #1 (SPECIES NOT IDENTIFIED) AT CAVERIA (ON CATIE CAMPUS)

LIVE HEIGHT 89.5 FEET: CUT MADE 2.5 FEET ABOVE GROUND LEVEL

MEASUREMENTS TAKEN AT EVERY THIRD INTERNODE

TIME: 9:50 AM, MONDAY, JUNE 23, 1975

Location Between Nodes	Circumference		Calculated Diameter	
	In	Cm	In	Cm
1-2	11.4	29	3.63	9.23
4-5	12.2	31	3.88	9.87
7-8	12.6	32	4.01	10.19
10-11	11.8	30	3.76	9.55
13-14	11.0	28	3.51	8.91
16-17	10.2	26	3.26	8.28
19-20	9.1	23	2.88	7.32
22-23	7.9	20	2.51	6.37
25-26	6.7	17	2.13	5.41
28-29	5.5	14	1.75	4.46
31-32	4.1	10.5	1.32	3.34
34-35	3.0	7.5	0.94	2.39
37-38	2.0	5.0	0.78	1.97
40-41	1.2	3.0	0.38	0.95
43-44	0.7	1.8	0.23	0.57
46-47	0.6	1.5	0.19	0.48
49-50	0.5	1.2	0.15	0.38

APPENDIX 9 TABLE 2A

DESCRIPTION OF ONE BAMBOO CULM: INTERNODAL LENGTHS
SAMPLE OF BAMBUSA VULGARIS, AT CAVERIA ON CATIE CAMPUS
10:00 AM, MONDAY, JUNE 23, 1975
LIVE HEIGHT 52 FEET, CUT MADE 1 FT ABOVE GROUND LEVEL
(15.8 METERS) (.3 METERS)

Internode	In.	Cm.	Internode	In.	Cm.	Internode	In.	Cm.
1*	8.1	24	21	11.3	29	41	7.8	20
2	10.1	26	22	10.9	28	42	7.0	18
3	10.5	27	23	11.3	29	43	7.4	19
4	11.3	29	24	11.7	30	44	6.6	17
5	11.5	29.5	25	12.1	31	45	7.5	19
6	12.1	31	26	12.5	32	46	6.2	16
7	12.5	32	27	13.5	34.5	47	5.1	13
8	13.3	34	28	14.0	36	48	6.6	17
9	13.3	34	29	14.4	37	49	5.8	15
10	13.6	35	30	14.4	37	50	5.5	14
11	13.6	35	31	14.4	37	51	5.8	15
12	14.0	36	32	14.0	36	52	5.5	14
13	14.0	36	33	14.5	37	53	5.5	14
14	13.3	34	34	13.6	35	54	5.1	13
15	14.0	36	35	13.3	34	55	4.9	12.5
16	14.0	36	36	12.0	31	56	4.7	12
17	14.0	36	37	11.9	30.5			
18	13.3	34	38	10.1	26			
19	12.5	32	39	9.8	25			
20	10.9	28	40	7.8	20			

*First internodal distance above basal cut, etc.

DESCRIPTION OF DISTRIBUTION OF INTERNODAL LENGTHS

	In.	Cm.
Sum of Lengths	602 = 50.2 Ft	1528 = 15.28 m
Number of Internodal Lengths	56	56
Mean Length	8.75	27.3
Standard Deviation	3.3	8.4
Coefficient of Variation	30.8%	30.8%

APPENDIX 9 TABLE 2B

DESCRIPTION OF ONE BAMBOO CULM: CIRCUMFERENCE MEASUREMENTS
SAMPLE: BAMBUSA VULGARIS FROM CLUMP AT CAVERIA (ON CATIE CAMPUS)
LIVE HEIGHT 89.5 FEET. CUT MADE 2.5 FEET ABOVE GROUND LEVEL
MEASUREMENTS TAKEN EVERY THIRD INTERNODE.
TIME: 10:00 AM, MONDAY, JUNE 23, 1975.

Location Between Nodes	Circumference		Calculated Diameter	
	In.	Cm	In.	Cm
1-2	9.72	24.7	3.09	7.86
4-5	10.04	25.5	3.02	8.12
7-8	10.35	26.3	3.30	8.37
10-11	10.63	27.0	3.38	8.59
13-14	10.28	26.1	3.27	8.31
16-17	10.00	25.4	3.18	8.09
19-20	9.45	24.0	3.01	7.64
22-23	8.74	22.2	2.78	7.07
25-26	7.87	20.0	2.51	6.37
28-29	6.97	17.7	2.22	5.63
31-32	5.94	15.1	1.89	4.81
34-35	4.72	12.0	1.50	3.82
37-38	3.31	8.4	1.05	2.67
40-41	2.48	6.3	0.84	2.13

APPENDIX 9 TABLE 3

Pressure Tests on Bamboo Specimens
Catie Campus, Turrialba, Costa Rica
June 25, 1975

Pressure Test #1. Unidentified Species (See Tables IA and IB for Description)
Date Cut: June 23, 1975. Date Tested: June 25, 1975.

DISTANCE, BASE OF CULM TO BASE OF TEST SPECIMEN	30 ft	9.14 m
OUTSIDE DIAMETER	2.91 in	7.4 cm
INSIDE DIAMETER	2.52 in	6.4 cm
WALL THICKNESS	0.20 in	0.5 cm
LENGTH OF SPECIMEN	29.13 in	74.0 cm
BURSTING PRESSURE	35 psi	2.46 Kg/cm^2

Pressure Test #2. Bambusa Vulgaris
Date Cut: June 25, 1975. Date Tested: June 25, 1975

DISTANCE, BASE OF CULM TO BASE OF TEST SPECIMEN	7 ft	2.13 m
OUTSIDE DIAMETER	2.9 in	7.0 cm
INSIDE DIAMETER	2.20 in	5.6 cm
WALL THICKNESS	0.24-0.31 in	0.6-0.8 cm
LENGTH OF SPECIMEN	33.07 in	84.0 cm
BURSTING PRESSURE	75 psi	5.27 Kg/cm^2

Pressure Test #3. Bambusa Vulgaris
Date Cut: June 25, 1975. Date Tested: June 25, 1975

DISTANCE, BASE OF CULM TO BASE OF TEST SPECIMEN	1 ft	0.30 m
OUTSIDE DIAMETER	2.56 in	6.5 cm
INSIDE DIAMETER	1.69 in	4.3 cm
WALL THICKNESS	0.35-0.47 in	0.9-1.2 cm
LENGTH OF SPECIMEN	18.11 in	46.0 cm
BURSTING PRESSURE	125 psi	8.75 Kg/cm^2

Pressure Test #4. Bambusa Vulgaris
Date Cut: June 25, 1975. Date Tested: June 25, 1975

DISTANCE, BASE OF CULM TO BASE OF TEST SPECIMEN	10 ft	3.04 m
OUTSIDE DIAMETER	2.87 in	7.3 cm
INSIDE DIAMETER	2.28 in	5.8 cm
WALL THICKNESS	0.24-0.28 in	0.6-0.7 cm
LENGTH OF SPECIMEN	26.9 in	69.0 cm
BURSTING PRESSURE	70 psi	4.92 Kg/cm^2

Appendix 10

PHYSICAL DIMENSIONS OF BAMBOO SPECIMENS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974

Sr. Santos Barahona U., of San Pedro Sula, Honduras, arranged to secure sections from bamboo clumps seen on a trip taken by Lippert and Barahona on January 1, 1974. The site of one clump was near La Lima, Honduras. A second selection was made from a bamboo clump on the old United Fruit Company golf course at Tela, Honduras, now a community facility. The bamboo were received June, 1974. Long after the bamboo had been received, Dr. Thomas Soderstrom, of the Botanical section of the Smithsonian Institution, informally identified the La Lima specimens as Bambusa vulgaris Shcrader ex Wendland. The Tela specimens were never identified. A former caretaker at the golf course thought that the bamboo had come from India.

Guadua angustifolia was obtained from the Federal Agricultural Experiment Station at Mayaguez by Narciso Almeyda, from a site shown to Lippert on his trip to Puerto Rico, January, 1973. These samples arrived about one month after the material from Honduras. The bamboos were measured and weighed, and later photographed during the summer and fall of 1974. In the fall, some of the bamboo was cut and subject to various informal tests, before a standardized pressure test procedure was developed. The tables in this appendix describe the dimensional aspects of the samples.

APPENDIX 10

TABLE 1A. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES, AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974
Guadua angustifolia from Mayaguez, Puerto Rico, cut about July 1, 1974

ENGLISH UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM								
	Lower Third of Culm			Middle Third of Culm			Upper Third of Culm		
	1A	1B[a]	1C	2A	2B	2C[a]	3A[a]	3B	3C
LENGTH, in.	36.0	28.5	36.5	36.5	36.3	29.5	30.5	36.3	36.5
WEIGHT, pounds*	7.25	4.98	6.63	5.4	4.8	2.75	3.12	2.4	1.9
NO. OF NODES	5	3	4	4[b]	4[b]	2	3	3	3
NO. OF INTERNODES	4.7[b]	3.2	3.4	4.0[b]	3.2[b]	2.3	2.4	2.7	2.5
MEAN INTERNODAL DISTANCE, in**	7.49	9.0		8.8[b]	11.7[b]	13.2	12.5		14.0
BOTTOM DIAMETER, in.	4.2	4.12	4.2	3.95	3.95	3.31	3.25	2.6	2.5
BOTTOM WALL THICKNESS, in.	.9	0.58	.55	.42	.41	.31	1.19	.27	.25
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), in.	14	13.0	13.5	12.6	12.5	10.75	10.44	9.25	8.25
BOTTOM CIRCUMFERENCE (CALCULATED), in.	13.19	12.94	13.19	10.83	12.40	10.40	10.21	8.32	7.85
TOP DIAMETER, in.	4.05	4.02	4.05	3.85	3.6	3.30	2.95	2.55	2.25
TOP WALL THICKNESS, in.	.6	.55	.45	.4	.37	.29	.25	.25	.25
TOP CIRCUMFERENCE (TAPE MEASUREMENT), in.	13.1	12.87	13.13	12.25	11.75	10.25	9.38	8.25	7.75
TOP CIRCUMFERENCE (CALCULATED), in.	12.72	12.63	12.72	12.09	11.30	10.40	9.27	8.01	7.06
VOLUME, cu. in. ***	1924	1483	1951	1744	1625	1012	921	756	647
WEIGHT PER LINEAR FT.	2.42	2.10	2.18	1.77	1.58	1.12	1.24	.79	.62

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

a. These dimensions were obtained long after the sample was removed from the pressure test. The original sample length was approximately 36 inches. The ends were cut off and sanded to permit proper sealing.

b. Dimensions taken from full size projection of color slide.

APPENDIX 10

TABLE 1B. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974
Guadua angustifolia from Mayaguez, Puerto Rico, cut about July 1, 1974

METRIC UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM								
	Lower Third of Culm			Middle Third of Culm			Upper Third of Culm		
	1A	1B[a]	1C	2A	2B	2C[a]	3A[a]	3B	3C
LENGTH, cm.	91.4	72.4	92.7	92.7	92.2	74.9	77.5	92.2	92.7
WEIGHT, kg.*	3.3	2.3	3.0	2.4	2.2	1.2	1.4	1.1	.7
NO. OF NODES	5	3	4	4[b]	4[b]	2	3	3	3
NO. OF INTERNODES	4.7	3.2	3.4	4.0[b]	3.2[b]	2.3	2.4	2.7	2.5
MEAN INTERNODAL DISTANCE, cm. **	19.0	22.9		22.4[b]	29.7[b]	33.5	31.8		35.6
BOTTOM DIAMETER, cm.	10.7	10.5	10.7	10.0	10.0	8.41	8.3	6.7	6.4
BOTTOM WALL THICKNESS, cm.	2.3	1.5	1.4	1.1	1.0	.8		.7	.6
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), cm.	35.6	33.0	34.3	32.6	31.8	27.3	26.5	23.5	21.0
BOTTOM CIRCUMFERENCE (CALCULATED), cm.	33.5	32.9	32.3	30.7	28.7	26.4	25.9	20.3	17.9
TOP DIAMETER, cm.	10.3	10.2	10.3	9.8	9.1	8.4	7.5	6.5	5.7
TOP WALL THICKNESS, cm.	1.5	1.5	1.1	1.0	0.9	.7	.6	.6	.6
TOP CIRCUMFERENCE (TAPE MEASUREMENT), cm.	33.3	32.7	33.4	31.1	29.8	26.0	23.8	21.0	19.7
TOP CIRCUMFERENCE (CALCULATED), cm.	33.5	32.1	33.5	27.5	31.5	26.4	23.5	21.1	19.9
VOLUME, cc ***	31500	24300	32000	28600	26600	16600	15100	12400	10600
WEIGHT/LINEAR METER, kg.	3.60	3.13	3.24	2.63	2.35	1.67	1.85	1.18	.92

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7
Note: Length dimensions calculated from measurements (English) and rounded to nearest millimeter.

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

a. These dimensions were obtained long after the sample was removed from the pressure test. The original sample length was approximately 91 cm. The ends were cut off and sanded to permit proper sealing.

b. Dimensions taken from full size projection of color slide.

APPENDIX 10

TABLE 2A. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES, AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974

Unknown Species from Tela, Honduras[c, e]

ENGLISH UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM							
	Lower Third of Culm			Middle Third of Culm			Upper Third of Culm	
	1A	1B	1C	2A	2B	2C	3A	3B
LENGTH, in.	37.5	36.0	36.0	35.5	36.0	36.0	36.0	35.7
WEIGHT, pounds*	12.06	4.84	3.91	2.72	3.50	2.08	2.42	1.45
NO. OF NODES	5	4	4	2	3	2	2	3
NO. OF INTERNODES	4.0	3.8	3.8	1.5	2.0	1.6	1.5	2.0
MEAN INTERNODAL DISTANCE**	8.6	9.2	3.4	23.0	16.9	22.3	22.0	17.2
BOTTOM DIAMETER, in.	4.00	3.75	3.56	2.25	2.30	2.28	2.25	2.00
BOTTOM WALL THICKNESS, in.	.89	.50	.31	.25	.69	.31	.30	.23
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), in.	12.88	12.38	11.50	7.62	7.75	7.56	7.00	6.12
BOTTOM CIRCUMFERENCE (CALCULATED), in.	12.57	11.78	11.18	7.07	7.23	7.16	7.07	6.28
TOP DIAMETER, in.	4.12	3.60	3.25	2.12	2.25	2.12	2.14	1.69
TOP WALL THICKNESS, in.	.75	.25	.25	.37	.42	.20	.32	.19
TOP CIRCUMFERENCE (TAPE MEASUREMENT), in.	13.50	11.50	10.40	7.50	7.44	6.88	7.00	5.63
TOP CIRCUMFERENCE (CALCULATED), in.	12.94	11.30	10.20	6.66	7.07	6.66	6.73	5.31
VOLUME, cu. in.***	494.	429.	394.	268.	273.	276.	252.	210.
WEIGHT PER LINEAR FT. LBS/FT.	4.02	1.61	1.30	.91	1.17	.70	.81	.49

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

c. Sample obtained from the former United Fruit Company golf course, Tela, Honduras. The clump was very tall. Color of the culm, greyish green. Sheaths from the ground up. Thorny. Reputedly from India.

d. Determined from a coupon cut at a location away from node in a very dry sample.

e. All sections of culms except the lower portion of culm section 1A split on drying and were not suitable for pressure testing.

APPENDIX 10

TABLE 2B. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES, AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974
Unknown Species from Tela, Honduras[c, e]

METRIC UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM							
	Lower Third of Culm			Middle Third of Culm			Upper Third of Culm	
	1A	1B	1C	2A	2B	2C	3A	3B
LENGTH, cm.	95.2	91.4	91.4	90.2	91.4	91.4	91.4	90.8
WEIGHT, kg. *	5.5	2.2	1.8	1.2	1.6	.9	1.1	.7
NO. OF NODES	5	4	4	2	3	2	2	3
NO. OF INTERNODES	4.0	3.8	3.8	1.5	2.0	1.6	1.5	2.0
MEAN INTERNODAL DISTANCE, cm.**	21.8	23.4	8.6	58.4	42.9	56.6	55.9	43.7
BOTTOM DIAMETER, cm.	10.2	9.5	9.0	5.7	5.8	5.8	5.7	5.1
BOTTOM WALL THICKNESS, cm.	2.3	1.3	.8	.6	1.8	.8	.8	.6[d]
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), cm.	32.7	31.4	29.2	19.4	19.7	19.2	17.8	15.5
BOTTOM CIRCUMFERENCE (CALCULATED), cm.	31.9	29.9	28.4	18.0	18.4	18.2	18.0	16.0
TOP DIAMETER, cm.	10.5	9.1	8.3	5.4	5.7	5.4	5.4	4.3
TOP WALL THICKNESS, cm.	1.9	.6	.6	.9	1.1	.50	.8	.5[d]
TOP CIRCUMFERENCE (TAPE MEASUREMENT), cm.	34.3	29.2	26.4	19.0	18.9	17.5	17.8	14.3
TOP CIRCUMFERENCE (CALCULATED), cm.	32.9	28.7	25.9	16.9	18.0	16.9	17.1	13.5
VOLUME, cc.***	8095.2	7030	6456.5	4391.7	4473.6	4522.8	4129.5	3441.3
WEIGHT PER LINEAR METER, kg.	5.98	2.40	1.93	1.35	1.74	1.04	1.21	.73

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7
Note: Length dimensions calculated from measurements (English) and rounded to nearest millimeter.

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

c. Sample obtained from the former United Fruit Company golf course, Tela, Honduras. The clump was very tall. Color of the culm, greyish green. Sheaths from the ground up. Thorny. Reputedly from India.

d. Determined from a coupon cut at a location away from node in a very dry sample.

e. All sections of culms except the lower portion of culm section 1A split on drying and were not suitable for pressure testing.

APPENDIX 10

TABLE 3A. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES, AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974
Bambusa vulgaris from La Lima
Honduras

ENGLISH UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM: Lower Third of Culm	Middle Third of Culm	Upper Third of Culm
LENGTH, in.	36.62	36.25	36.00
WEIGHT, pounds*	6.06	4.76	1.22
NO. OF NODES	4	3	4
NO. OF INTERNODES	3.5	3.0	3.3
MEAN INTERNODAL DISTANCE, in.**	8.9	12.3	10.3
BOTTOM DIAMETER, in.	3.06	3.02	1.75
BOTTOM WALL THICKNESS, in.	.34	.48	.20
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), in.	10.38	10.25	5.88
BOTTOM CIRCUMFERENCE (CALCULATED), in.	9.61	9.49	5.50
TOP DIAMETER, in.	2.88	3.00	1.30
TOP WALL THICKNESS, in.	.50	.36	.20
TOP CIRCUMFERENCE (TAPE MEASUREMENT), in.	9.13	9.44	4.50
TOP CIRCUMFERENCE (CALCULATED), in.	9.05	9.42	4.08
VOLUME, cu. in.***	357.	356.	186.
WEIGHT PER LINEAR FT, lb/ft	1.98	1.57	.41

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

APPENDIX 10

TABLE 3B. PHYSICAL DIMENSIONS OF BAMBOO SAMPLES, AS RECEIVED AT THE UNIVERSITY OF MASSACHUSETTS, SUMMER, 1974
Bambusa vulgaris from La Lima
Honduras

METRIC UNITS

DIMENSION	LOCATION OF SPECIMEN ON CULM		
	Lower Third of Culm	Middle Third of Culm	Upper Third of Culm
LENGTH, cm.	93.0	92.1	91.4
WEIGHT, kg.*	2.7	2.2	.6
NO. OF NODES	4	3	4
NO. OF INTERNODES	3.5	3.0	3.3
MEAN INTERNODAL DISTANCE, cm.**	22.6	31.2	26.2
BOTTOM DIAMETER, cm.	7.8	7.7	4.4
BOTTOM WALL THICKNESS, cm.	.9	1.2	.5
BOTTOM CIRCUMFERENCE (TAPE MEASUREMENT), cm.	26.4	26.0	14.9
BOTTOM CIRCUMFERENCE (CALCULATED), cm.	24.4	24.1	14.0
TOP DIAMETER, cm.	7.3	7.6	3.3
TOP WALL THICKNESS, cm.	1.3	.9	.50
TOP CIRCUMFERENCE (TAPE MEASUREMENT), cm.	23.2	24.0	11.4
TOP CIRCUMFERENCE (CALCULATED), cm.	23.0	23.9	10.4
VOLUME , cc***	5850.1	5823.8	3048
WEIGHT , kg/m	2.95	2.34	.61

*Weights measured during summer, after uncontrolled drying period. Humidity and temperature control facilities were not available until October-November 1974. See P.K. Whitehouse report, Appendix 7

**This figure includes full internodes plus partial internodes. Pressure seals were applied to cuts between nodes.

***External dimensions used.

APPENDIX 11

PROGRESS REPORTS

The progress reports made during the contract period are included in order to give a sense of the continuity of the investigation.

PROGRESS REPORT

FEASIBILITY STUDY ON THE USE OF BAMBOO PIPES IN PRESSURIZED WATER SYSTEMS

(WHO FILE REFERENCE W2/181/17)

University of Massachusetts

October 30, 1974

Stanley Lippert
Principal Investigator
Department of Industrial Engineering
and Operations Research
University of Massachusetts

The contract for this study was received April 23, 1974. The work accomplished thus far is described briefly below.

May, 1974. A report "Feasibility Study on the Use of Bamboo in Pressurized Water Systems" by Eulogio O. Herrera discussed some of the findings of a trip to Colombia in December, 1973-January, 1974 taken by Lippert and Herrera. A copy of record is enclosed.

June, 1974. Shipment of bamboo samples received from Honduras. The samples were from plantings specified by Lippert during a trip to Honduras in January, 1974. No technical specialists were located to identify the specimens. One set was from the vicinity of LaLima, the other from Tela.Later, one set was identified as Bambusa vulgaris Schrader ex Wendland.

June, 1974. Lippert travelled to Smithsonian Institution, Washington, D.C. The Botany Section has, reputedly, the best collection of literature on bamboo. F.A. McClure left his collection of documents, together with his index and cross-index cards, with the Smithsonian Institution. A suggestion to arrange for a computerized access to the documents has been carried out in part. It would be of interest to continue this work, especially if feasibility is demonstrated. Dr. Thomas Soderstrom of the Smithsonian was especially helpful in responding to inquiries.

July, 1974. A shipment of Guadua angustifolia was received from the United States Agricultural Experiment Station in Mayaguez, Puerto Rico. Narciso Almeda made the arrangements. In December, 1973 he had conducted Lippert on a tour of various bamboo plantings at the station. There was an active interest in bamboo in Puerto Rico some years ago, not now.

July and
August, 1974. Home visits were made by two students, Ricardo Chaparro and Rafael Dammert, to Peru. Inquiries were made in anticipation of working on the project during the fall semester, as noted below.

REPORT ON TRIP TO LIMA — RAFAEL G. DAMMERT

Made contact with Director of CEPIS*, Ing. Odyer Sperandio and set up interview with him. He was very receptive and offered full cooperation. He showed a lot of enthusiasm about the pressurized bamboo pipe project.

Had an interview with Ingeniero Ricardo Chaparro M., Manager of Economics Dept., ESAL (Empresa de Saneamiento De Lima) (State-owned water supply system of Lima), who offered full cooperation and good contacts within the ESAL. The General Manager of ESAL was contacted too, and was interested in project. We were given a tour of the facilities.

Met with Ing. Javier Bacigalupo, Chief of Rural Aqueducts in Peru, Ministerio De Salud (Jefe De Acueductos Rurales En El Peru--

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Ministerio De Salud). He said they were satisfied with a pressure criterion of 105.0 psi. He showed interest and offered help with the project.

Ing. Augusto Navarro, Director Del Programo Academico De Ingenieria Sanitaria, Universidad Nacional De Ingenieria was on a trip to Mexico, we were not able to interview him.

We were not able to contact Ing. Carlos Ruiz Altuna, Researcher, Universidad Nacional De Ingenieria.

*CEPIS = Centro Panamericano De Ingenieria Sanitaria.
Ing. = Ingeniero

September, 1974. Steven Lord, a Senior Mechanical Engineering student, began tests on bursting strength. The basic approach was to fit the ends of the test specimens into polyester body filler mixed inside heavy cast iron caps. One cap was drilled and threaded for hydraulic fittings. This short specimen had no nodes. It was made from the unknown species collected in Honduras from a heavy basal portion of the culm. A pressure of 400 p.s.i. (pounds per square inch) was sustained momentarily. The purpose of the test was to develop a suitable procedure for bursting strength tests of bamboo.

September, 1974. A prototype tool for coring culms was built by Peter Blake. Mr. Blake is a Mechanical Engineering student at the University of Massachusetts who works full time as a tool designer in industry. He receives no credit for his work and no pay. He does his work on his own time at the place of his employment. Performance of the first tool was not satisfactory. Increase in number of blades is the next development step. The principle of the tool is that the diameter of the cutting edges can be adjusted through a fair range of sizes, and that the flexible blades, within a given setting, can accommodate to taper and out of round variation, in cross section.

October, 1974. Two heavy sections of Guadua angustifolia, each 3 feet long, tested for bursting strength. Two findings: (1) Leaks at the ends developed. End seal method requires improvement. (2) Larger hydraulic pump required when testing large volume samples.

October, 1974. Two tests performed on samples from the upper half of the culm of Guadua angustifolia. A modified method of end sealing was tested. No end leakage occurred. At about 40 p.s.i., pressure was lost due to hairline cracks (presumably from drying history of the bamboo).

October, 1974. Revised coring tool with extra blades requires further work:
(1) larger screw diameter.
(2) guide for setting blade at correct position and cutting angle.

(3) increased cup size for blade holder.
(4) Mr. Lord has different concept for the tool.

October, 1974. Sr. Oscar Hidalgo, an architect from Colombia, was invited to talk to the group working on bamboo pipe. Sr. Hidalgo has just had a book published on uses of bamboo, a comprehensive treatment with many photographs and diagrams by the author. Sr. Hidalgo is especially interested in low cost housing using bamboo. The book,

"Bambu
Su Cultivo y applicaciones en:
Fabricacion de Panel
Construccion Arquitectura Ingenieria Artesani

is published by Estudios Tecnicos Colombianos Limitada, Apartado Aereo 7289, Cali, Colombia, 1974.

October, 1974. Two students from the Wood Technology Department of the University will assist on tests requiring wood technology methods. Of special interest at this time are chemical treatment of bamboo, and reinforcement to increase bursting strength. In addition, a visiting wood technology specialist, Sr. Carlos Wiessel B., from Costa Rica will be observing the bamboo tests. There may be an opportunity to arrange for field tests in the future.

PROGRESS REPORT

FEASIBILITY STUDY ON THE USE OF BAMBOO PIPES IN PRESSURIZED WATER SYSTEMS

(WHO FILE REFERENCE W2/181/17)

University of Massachusetts

May 30, 1975

Stanley Lippert
Principal Investigator
Department of Industrial Engineering
and Operations Research
University of Massachusetts

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November, 1974. Professor Richard Trueswell, Head of the Department of Industrial Engineering and Operations Research, suggested a new method for sealing the ends of the bamboo samples for the pressure tests.

His suggestion was followed. The new apparatus consisted of a heavy steel plate into which a threaded steel rod was placed. The threaded rod ran through the section of bamboo culm to be tested and through a second steel plate, which constituted the bottom of the apparatus. A heavy nut below the lower plate was used to press the two plates together. A heavy rubber gasket was placed between the steel plates and the ends of the sample to create the seal. In addition to the clamping action of the threaded rod, one clamp was used on each of the four edges of the steel plates.

This new arrangement worked very well. An hydraulic pump and a pressure gauge appropriate to the test requirements of bamboo was purchased. It was possible to test two specimens in one afternoon with less trouble than it took for one specimen by the original method. The major pressure testing experiments were performed in November.

December, 1974. Steven Lord, the mechanical engineering student who performed the major testing operations, completed his work for his bachelor's degree at the University of Massachusetts, and moved to the Massachusetts Institute of Technology.

Edmund N. Beliekewicz, a student from Wood Technology who assisted in the experiments and in the preparation of specimens for testing, left the project at the end of the semester. He prepared a report on the project for the advisor in his department.

The intact specimens suitable for pressure testing were used up by this time. Sample coupons for tensile tests were planned for matching tests. The end of the semester followed by the Christmas recess, diminishing funds, and the graduation of some students put an end to major testing for pressure.

A proposal for a continuation of the feasibilty study was transmitted to W.H.O.

January, 1975. S.Lippert visited the ORVIS Company, Inc. in Manchester, Vermont. This company has been making bamboo fishing rods since the last century. The factory is in new quarters. The entire process from receiving of raw stock from mainland China, to the finished rod was inspected. The operations are extremely clean and precise. Milling of bamboo to an accuracy of 0.00025 inches is done, on tapered triangular sections.

The factory manager reproduced a copy of a 1944 report by F. A. McClure, "Western Hemisphere Bamboos as Substitutes for oriental bamboos for the Manufacture of Ski Pole Shafts" for the use of our feasibility study. Specimens which the Bureau of Standards of the United States then tested. (The other company which prepared specimens for the Bureau of Standards was located only a few miles from the University of Massachusetts. It is now out of business).

(2)

McClure's report is first rate. The Orvis process it describes is practically identical to the process used today, except that better machinery and the newer plant are used today.

This report was copied at reduced size at the University so that eventually, interested cooperators in the bamboo feasibility study would be able to have access to the information.

February, 1975. Variability of the physical properties of bamboo ski poles was calculated, based on McClure's (1944) report. The purpose of this exercise was to determine variability in a highly controlled product made from hand selected parts at every stage of the manufacturing operation where there is considerable labor per pound of material produced. An upper limit of control superior to the field conditions anticipated in developing pressurized pipes from bamboo.

Microfiche of cultural materials of the Human Relations Area Files were examined for Latin America on five subject headings related to water systems and water uses. Approximately half of all ethnic communities on which information is available was brought together, but not analyzed. This exercise was intended to determine if information useful to engineers from outside a particular cultural area can be found prior to field work. The most extensive returns from the search were from articles on the Incas. The book "Drawers of Water" by Gilbert F. White, David J. Bradley and Anne U. White (University of Chicago Press, Chicago, 1972) contains recent observations on customary attitudes toward water in Kenya and Uganda. It would be of interest to investigate whether or not these kinds of observations could have been predicted in part by utilization of the Human Area Resources Files.

March, 1975. Microfiche photocopies of Human Relations Area Files materials of poor quality were retyped on cards for greater ease of reading and reference.

W.H.O. reported funding not adequate for continuation of the proposal. A limited proposal was invited. This was submitted.

April, 1975. Special coupons were cut for determining tensile strength of bamboo perpendicular to the fibers. These tests are related to hoop strength of bamboo.

May, 1975. A contract for continuation of studies until the end of 1975 was approved. Field work in Costa Rica authorized. One potential joining method for bamboo pipes was tested. Since all intact bamboos had been used up, two pieces of cast-iron sewer pipe, 4 inches in diameter, were used to simulate the bamboo. The pieces were turned on a lathe to give a smooth cylindrical external wall. The joined pipes were installed in the bamboo pressure testing apparatus and tested at 200 PSI for two minutes. There was no leakage.

A second test was run on the strength of the joint in tension. No slippage occurence until 900 pounds of tension was applied.

(3)

Ing. Augusto A. Navarro Palma of the National University of Engineering in Lima, Peru indicated his interest in cooperating on the bamboo feasibility project (this was a response to our December, 1974 proposal).

Paul Whitehouse submitted his report on tensile strength of bamboo coupons, perpendicular (tension at right angles to the fiber).

Preparations begun for field trip to Centro Agronomico Tropical de Investigacion y Enseñanza, Turrialba, Costa Rica.

PROGRESS REPORT

FEASIBILITY STUDY ON THE USE OF BAMBOO PIPES IN PRESSURIZED WATER SYSTEMS

(WHO FILE REFERENCE W2/181/17)

University of Massachusetts

September 2, 1975

Stanley Lippert
Principal Investigator
Department of Industrial Engineering
and Operations Research
University of Massachusetts

TRIP TO COSTA RICA

June, 1975

Thomas L. Prunier, a volunteer worker, who graduated in May from the University of Massachusetts in Wood Technology, and S. Lippert travelled to Miami, Florida by automobile. This was done to reduce air freight costs on the hydraulic pump, pressure testing machine, and supplies. The trip began the morning of Tuesday, June 10, 1975. En route, Lippert visited Dr. Tom Soderstrom, Botany Department of Smithsonian Institution. Dr. Soderstrom is trying to get sponsorship for a Bamboo Institute, which will try to encourage information exchanges between workers interested in bamboo, including applications as well as botanical information.

On Monday, June 16, Lippert and Prunier travelled by air from Miami to San Jose, Costa Rica.

On Tuesday, June 17, visited the Forest Products Laboratory at the University of Costa Rica. Michael Krones, Chief in charge, whose offer of cooperation provided the impetus for the trip, discussed the work situation. A garden on the University campus contained several species of bamboo. A culm of Bambusa vulgaris was cut for specimens of culm sections.

In the afternoon, a visit was made to a large furniture factory, Urgelles y Peron. The plant manager, Augustin Peron, is a graduate of the University of Massachusetts who majored in Wood Technology.

Wednesday, June 18, at the University of Costa Rica, Prunier and Lippert demonstrated and photographed pipe coupling using the No-Hub couplers on short lengths of Bambusa vulgaris and prepared a sketch for a go-no-go pipe diameter gauge. Met Mr. J. L. Whitmore at the Forest Products Laboratory in the afternnon.

Thursday, June 19, Lippert and Prunier travelled independently to CATIE in Turrialba. A clump of bamboo sighted in Tres Rios near the railroad track.

Consulted with Whitmore, and were briefed by Arnold Ericson, Secretary of Research, CATIE. Inspected two bamboo sites on CATIE campus. The larger one, at the location called CAVERIA, close by the CATIE entrance nearest Turrialba, appeared most promising, because of a wide lawn workspace, several species of bamboo and healthy specimens. Shop facilities at CATIE were inspected. Returned to San Jose.

Friday, June 20, shopped in hardware stores for cutting tool and miscellaneous plumbing items needed for field work.

Saturday, June 21, travelled by train to Punta Arenas. Returned to San Jose by bus. Only insignificant bamboo plantings visible from route.

Sunday, June 22, no bamboo activity.

Monday, June 23, Lippert and Prunier with tools and testing equipment travelled to CATIE. Mr. Whitmore provided his personal station wagon. Lippert and Prunier with helper, cut and measured two bamboo culms from Caveria from one unidentified species and one from Bambusa vulgaris. Located 5/8 inch steel rod in Turrialba hardware store for drill shaft.

In morning, Lippert and Prunier to Turrialba with Whitmore. Cut and measured bamboo. Photographs at Caveria site, CATIE, in morning.

In afternoon, picked up steel rod in Turrialba, cut a few culms of green bamboo at Caveria (not B. vulgaris).

In evening, met Ted Pasca, Editor, UNASYLVA (FAO, Rome) and Hester Burres, FAO (Rome) assigned to CATIE.

Mr. Pasca would be receptive to an article for UNASYLVA on bamboo.

June 24 - In morning, Prunier arranged for 15-foot bar steel to be welded to flat wood drill at CATIE shop.

Lippert travelled with Whitmore and others to observe insect repellent effects of chemicals placed at the foot of young Spanish cedars. Wes McConnell, (University of Oregon), who is doing this study suggested checking the possible benefit to increased strength of bamboo by linking fibers by suffusing, under pressure, bamboo sections with formaldehyde, a low cost chemical. This effect is observed in wood.

Whitmore showed a possible test site for a bamboo pipe system at Quinta Elizabeth, about 4 km. from Siouirres.

Parallel to the road is a flat area, then a slope, that appears to be a fill from road construction. Below the slope is another flat area which leads to a steep descent to the Rio Siqurres, a small stream whose source is a few miles away. The stream seemed to Lippert to be over one-hundred feet below the lower flat shelf (later measured at a little under 90 feet) through shoulder-high shade plants. A narrow path led back and forth across the slope to the stream bed. A gravity flow system from up-stream would not be feasible. This site would require pumping from stream up to the level area.

In the afternoon, tried without success to reach Hacienda Atirro (Arturo Rojas or Oscar Rojas) by telephone from CATIE. Contact had been made by telephone from San Jose Friday, June 20. Atirro is a few miles from Turrialba. A site inspection was desired.

Rio Reventazon, which runs along the edge of the CATIE grounds, is a much larger river than the Siquirres. We were advised that access was not easy in this area. The lift up the very steep banks or cliffs in this area would require a larger pump than the Rio Siquirres site.

In the afternoon, Prunier, Lippert and two workers from CATIE visited the Caveria site at CATIE. Culms of two species previously cut were sized using a wooden template go-no go gauge with 2-inch, 3-inch and 4-inch circular holes. Standardization was on outside diameter, not length. The job was accomplished quickly and easily. The stock of pipe lengths was brought back to the main CATIE area.

Lippert returned to San Jose. Prunier remained in Turrialba.

Wednesday, June 25 - Lippert made progress report to Miguel Krones and Eugenia Vargas of the Forest Products Laboratory at the University of Costa Rica, and Rodrigo Orozco, Dean of the Faculty of Engineering. Mr. David Donaldson, Engineer at the Pan American Health Organization in Washington, D.C., had suggested that Dean Orozco be contacted. The Forest Products Laboratory of CATIE is associated with the Faculty of Engineering. Dean Orozco is interested in engineering applications. Student projects such as the bamboo pipeline study are desirable but represent only a fraction of potential engineering areas of interest. Dean Orozco would like to see interdisciplinary work,(engineering and architecture, for example), to broaden student capabilities. Support for such activities is needed.

Thursday, June 26. Lippert and Krones travelled from San Jose to Turrialba. Met with Whitmore and Prunier--discussed possible proposals for establishing a small bamboo plantation. Whitmore suggested transplants from Mayaguez, Puerto Rico. Only one man has a detailed knowledge of the bamboo work, Mr. Narciso Almeyda of the Federal Experiment Station.

Later in the morning, Prunier set up hydraulic test of specimens cut from culms taken from the Caveria section of CATIE with the assistance of a mechanic at CATIE. A sample taken 30 feet above the base of the culm of a large green, unidentified specimen burst at 35 pounds per square inch. Three Bambusa vulgaris specimens burst at 125 psi, 75 psi, and 70 psi for samples cut 1 foot, 7 feet and 10 feet above the base of the culm, respectively.

In the afternoon Lippert visited Margarita Bonilla, assistant to Hugo Cáceres, Head of Documentation, Centro Interamericano de Documentacion Agricola (CIDIA) which is Centro del Instituto Interamericano de Ciencias Agricola de OEA (IICA). Cáceres was out of the country at this time. A quick check of their bamboo holdings showed only a few references and lists of references, quite inadequate for serious bamboo work. Lippert left the Center several technical reports which contained over one thousand references.

Lippert spoke to Mr. Orlando Arboleda Sepulveda of the Information Service at the Document Center (CIDIA). The Canadian Government supports preparation of documentation of articles for the Food and Agriculture Organization (FAO) which then prints the information. The documentation provides

(1) A six-digit accession number

(2) The title of the document

(3) A listing by major classification

(4) The reference number in the back, plus an author list terms.

(5) About 125 major reference terms.

The Documentation Center prepares a KWIK index (Key Work In Context) of some of its materials.

Lippert returned to San Jose. Prunier stayed on at Turrialba to continue field preparations for laying pipe.

Friday, June 27. Lippert located topographical maps of the Turrialba and Siquirres regions. The Universal Bookstore on Avenida Central has some maps. For complete files, it is necessary to go to

Edificio Administracion
Ministerio de Obras Publicas y Transportes
Direccion de Geodesia y Cartografia
Servicio Geodesica Interamericano
Avenida 20, Calle 9-11
Phone 26-10-96

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Lippert telephoned Eugenia Vargas to arrange for surveyors from University. Prunier prepared pipe lengths at CATIE for installation at Siquirres, then returned to San Jose.

Saturday, June 28. Lippert and Prunier checked hardware stores and rental agencies to determine purchase costs and rental possibilities.

Sunday, June 29. Bus trip to Volcano Poas. Observed several clumps of bamboo on way up the road to Poas. Species not known. Clumps small.

Monday, June 30. Lippert and Prunier to LACSA to inquire about excess baggage charges and to arrange for July 4 departure. Bussed to Turrialba and checked stores for pump rentals. Rentals not available in Turrialba. To CATIE a few hours, then taxied to Hacienda Attiro. Were fortunate in finding Arturo Rojas and Otto Rojas. The sugar mill at Attiro is run by the Rojas family. Had a quick tour of the sugar mill, which is powered by steam. The bagasse is used as fuel for the furnace. Inspected a clump of very tall bamboo. Guesses were that the clumps were about 20 years old and had come from Brazil.

Lippert back to San Jose, Prunier stayed on in Turrialba. Plans made to visit Quinta Elizabeth near Siquirres on Wednesday, July 2.

July, 1975

Tuesday, July 1. Lippert to Forest Products Laboratory. On this day, Srta. Eugenia Vargas takes over as Chief of the Forest Products Laboratory. Michael Krones resigned as of June 30. Dean Orozco made letter request to LACSA for reduction of excess baggage. Lippert and Krones made firm arrangements with INTACO-COSTA, RICA, S.A. for rental of 3 horsepower pump for one day. Motor checked and running. Minor plumbing changes requested in galvanized iron pipe fittings. The Forest Products Laboratory would like to have Prunier stay on until Peace Corps assignment comes through. Peace Corps assignment not expected until end of year, at which time an indoctrination period would take place. There is no money in the W.H.O. budget to carry Prunier through to end of year and firm commitment to Prunier before departure within the week is unlikely.

Wednesday, July 2. Prunier and helpers from CATIE loaded pre-cut bamboo pipes, couplings, tools and a CATIE pump of unknown specifications on to a CATIE truck and set off for Quinta Elizabeth near Siquirres. The load was carried from the flat area near the road to the lower flat area, and the pump was carried down to stream level.

Michael Krones picked up Lippert, a small rented pump as a backup, and three "observers" in San Jose and transported the lot to Turrialba. A surveying team recruited from students of the Faculty of Engineering by Eugenia Vargas, travelled in their own vehicle to CATIE. The Krones party and the students travelled in their own vehicles to Quinta Elizabeth, reaching it about noon. A total of eleven men were now at the site:

2 CATIE employees

3 student surveyors (employed for the day)

1 former head of the Forest Products Laboratory, whose resignation had been effective two days earlier, and therefore, technically a volunteer on the project

3 "observers"

2 volunteer workers from the University of Massachusetts.

Everyone got into the act. The observers became volunteers, and in about two hours, the pipeline of Bambusa vulgaris was laid, supported on forked limbs at shoulder height above the ground. Attempts to start the CATIE pump failed. The intake hose was rotten. The end was cut off and fastened, by means of a No Hub coupler, to the bamboo pipe. After a variety of efforts, the big pump was set aside and the smaller and more portable pump that had been rented for a backup was started. The motor ran, but no success was achieved in getting pumping action on a steady basis. Different priming methods were tried. Had there been a water supply topside, the pipe could have been stoppered at the bottom and filled from the top, thus getting a static test. By this time, the CATIE employees were already past their usual field work hours, and more than an hour from Turrialba.

Thursday, July 3. In the morning, Lippert and Krones returned the rented pump and proceeded to the University. In the afternoon, Prunier returned to San Jose, not feeling well. A doctor diagnosed appendicitis, prescribed medicine, delayed departure and diagnostic tests. Surveyors delivered map in evening.

Friday, July 4. Prunier felt comfortable and was in condition to walk to the laboratory. In the afternoon, the doctor gave him permission to travel.

Saturday, July 5. Took early flight to Miami. Picked up car, had dinner, and started drive home.

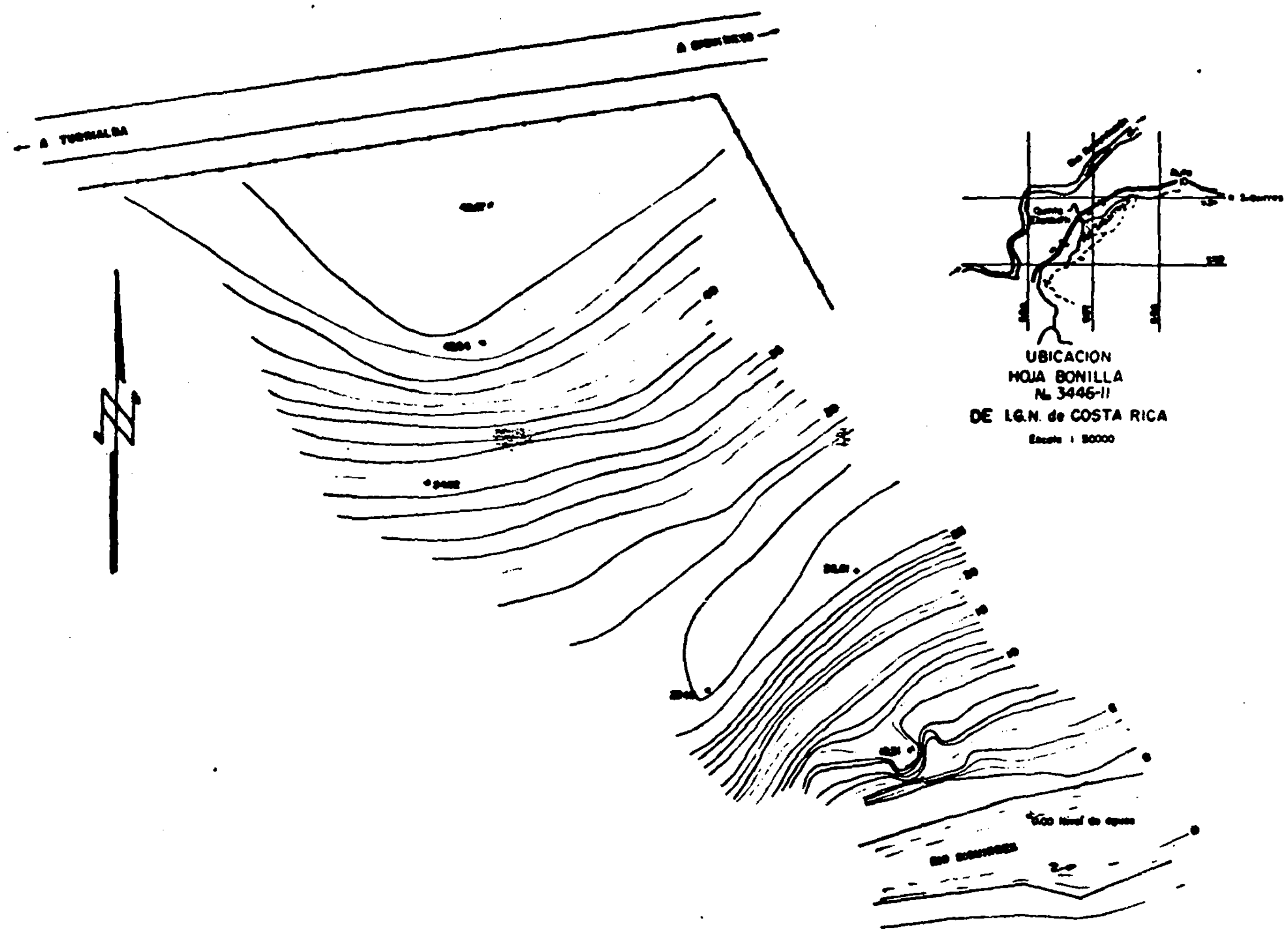
Monday, July 8. Prunier was feeling well enough to do most of the driving from Florida. Trip ended in early evening.

Trip Recapitulation

Round trip from Amherst, 29 days

In Costa Rica, 19½ days.

July 9 to July 31. Prunier in hosptial for appendectomy and out. Lippert worked on trip expenses for University of Massachusetts and began organizing slides made on trip. Prunier did literature search and began write-up of field data.



Levantamiento de curvas de nivel
en franja de QUINTA ELIZABETH
para estudios de
INSTALACION CAÑERIA BAMBU

Levantó Jorge A. Hernández O. Apartado Postal 8-4780
Juan C. Saporta Z. San José, Costa Rica

RECEIVED JULY 3, 1975

August, 1975 Prunier continued write-up of technical aspects of trip. Some color reproductions for the final report were processed. Made arrangements for typing assistance after the beginning of the fall semester.

Received letter from Mr. Michael G. McGarry, Program Office, Population and Health Sciences, International Development Research Centre expressing interest in bamboo project and requesting draft proposals. Lippert replied by telephone, contacting Mr. David Henry. Several exploratory letters were sent out.