Application Studies of Simple Structures Constructed of Bamboo-Woven Concrete in the South Rural of Yunnan

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1. Introduction

Bamboos are important plants among forest resources in the world, which are mainly non-wood forest resources with economical, ecological and social benefits. They are widely distributed in South China. It was in 1999 that there were five biogas digesters successfully constructed of bamboo-woven concrete, which passed the expert teams' appraisal and would be as the demonstration in Jiwu village, Yuping town, Pingbian county, Yunnan Province. Since then the construction technology has been given more attention and spread in the south of Yunnan, China. The costs of traditional structures of biogas digesters are higher for rural peoples, but the costs of the new types constructed of bamboo-woven concrete are so lower that there would be no problem for every family. As the statistics show, there has been up to the amounts of 20,000 biogas digesters in Yunnan. At the same time, some other types such as water-containers, simple houses, grain storage-pots have also been constructed of bamboo-woven concrete in Yunnan.

It was reported that the peculiar plant materials have been applied to the structural engineering such as bridge, town and county house, sewer and canals in Colombia, India, Japan, China, Philippines, Indonesia and other Asia countries. In recent years bamboo structures have also made great progress in many countries.

However, in South China, the bamboo-structures for solving the problems of rural energy construction, which are explored by D R Wu's team, are a kind of innovation with ecological significance. For example, western plowland sent back to forest in China, great diversity of purposes exploration of many species of bamboo. Although the foregoing structures have been commonly used in practice, their mechanical properties and reliability are not very clear. This paper presents that some structural characteristics of Simple Structures Constructed of Bamboo-Woven Concrete are discussed. The conclusion shows that the structures are safe and reliable while spreading in poverty rural, which can not only solve energy problem but also protect forestry bionomics environment and renew vegetation.

2 Types of structures

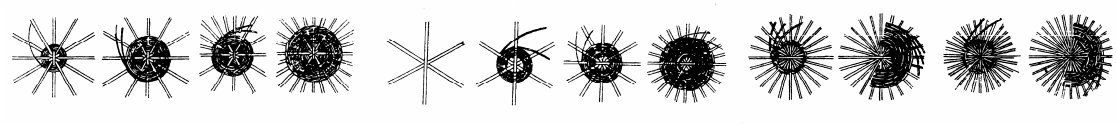
Since the first group of biogas digesters was successfully constructed of bamboo-woven concrete, many other structures such as water-containers, simple houses, grain storage-pots etc., are developed, as fig. 1 and fig. 2 shown. For the construction technology being all the same as biogas digesters and only tiny difference being existed, we might as well give the detailed construction technology of biogas digesters.

A main framework is first woven by using thin bamboo strips, which are prepared by cutting in advance. There are many weaving methods in preparing the main framework, as fig. 3 shown. Then , the framework is put to the place where the dry bamboo frame of biogas digesters should be. Finally, the frame should be mortared to thick of 3~5 centimeters inside and outside with cement mortar, rubbed and maintained for some 20 days before using.


Fig. 1 water-containers and simple house being constructed of bamboo-woven concrete


(a) (b)

Fig.2 (a) Drying biogas digester framework which has been woven; (b) Biogas digester which is rendering with concerete



(a) (b) (c)

Fig. 3 weaving methods for main bamboo framework

The biogas digesters constructed of bamboo-woven concrete is following major characteristics: a) Simple structure: it needs less building material and costs less than that of existing reinforced-concrete biogas digesters. b) High construction efficiency: it speeds up the construction and application of biogas digesters since it doesn't need steel moulding board. c) Strong adaptability: it can be built on the ground, underground or partly underground according to the specific terrain condition. d) Great flexibility: since the frame is woven with thin bamboo strip, it can be changed unrestrained according to the family's demands and built in their spare time. e) Good performance: it guarantees the best conditions to produce methane and simplifies the structure of biogas digesters with the advanced simple-operation stirrer. It reduces the cost and the leakage factors for removing the sealing cover on its top.

According to using condition in the field, the biogas digesters can be divided into such 3 kinds as 6, 8 and 10 m^3, and there are the same structures as water-containers, grain storage-pots etc.

For simple houses constructed of bamboo-woven concrete, the beams and columns should be paid more attention to, which belong to mainly carrying-loads structures. To solve this problem, many bamboo strips can often be used to form one beam or column by cementing or bundling. Then they are mortared to thick of 3~5 centimeters with cement mortar as protection layer. The other plates or slabs could be woven with thin bamboo strips and be mortared with cement between two sides.

According to studies, it should be taken into account whether the surface of structures except simple house is smooth or not like arch curve surface, which could mainly carry compressive forces and bear negligible tensile forces. In an ideal structure, concrete is proved to be a mainly carrying-loads member, and bamboo frame is equivalent to steel moulding board in practice, not a bearing member. Based on Chinese building Codes, concrete should be kept at least 40 years durability and safety. In fact, the structures built in 1999 have been well in function for 6 years.

3 Analysis of structural mechanical properties

Any structure should be designed to support loads without danger of overall collapse or failure of the components. One basic way to assure the safety of the structure is to ascertain that stresses and strains produced by loads less than those allowed by established design codes. For the bamboo-woven concrete structures, however, there are not established design codes. In order to understand the mechanical properties of the structures, tests in the fields and modelling simulation of biogas digesters are adopted based on the principles of structural design and analysis.

As Fig.2 shows, the new-type biogas digesters is made up of the upper arched shell and the lower columnar frame. The lower columnar frame is strengthened specially by increasing its thickness or its part underground yet bears the soil pressure. According to analysis of structural mechanics, we can know that since the hoop effect gives the upper part enough horizontal thrust, the upper arched shell can bear enough load. So it can be concluded that the new-type biogas digesters is safe unless upper arched shell is not smooth curved surface.

Based on structural design principle, it is necessary to consider how many loads the structure can bear, how much the reasonable thickness of cement mortar is and what curved surface is the best for the structure of biogas digesters which is buried underground. To explore and solve these problems well would play a positive role for popularizing the new-type biogas digesters.

Simple tests in the fields were firstly done. Several typical biogas digesters constructed of bamboo-woven concrete were selected in the south of Yunnan province. An instrument for strain gauge was used to measure the strain and stress of the structures. According to the actual loading condition on the upper arched shell, we selected a meridian and three points numbered from 1 to 3 along it, and named them as A,B and C. Before carrying out the testing, partial area around point 1,2 and 3 should be polished, then strain gauges were pasted. Finally , we connected the wire to the strain gauge instrument. Because of the special circumstances around the biogas digesters where even the soil should be excavated, it was impossible for us to load it accurately. We loaded it with some sacks of cement per sack weigh 50 kilogramme in the fields, and got the deformation data of two different biogas digesterss just as Table 1 shows.

Fig. 4 Testing field of structural deformation of biogas digester constructed of bamboo-woven concrete

Table 1 Two Groups of Results of the Testing in the fields

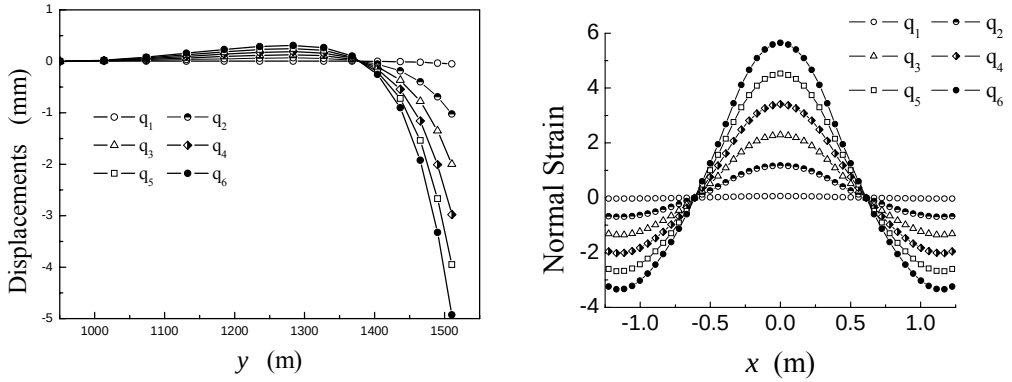
Test serial number	Load (kg)	strain ($\mu\varepsilon$)
biogas digesters A measure point 1	600	10
biogas digesters B measure point 1	700	7
biogas digesters A measure point 2	600	12
Biogas digesters B measure point 2	700	5
biogas digesters A measure point 3	600	−16
biogas digesters B measure point 3	700	−23

Notes: 1. The measure points were numbered from top to bottom;
2. Since the results came from two different biogas digesterss, the coordinates of these measure points were not the same.

In order to make a complete study on the new-type biogas digesters, the same bamboo-woven frames were selected in the fields, around which cement mortar was poured in mould boards. Then they were cut into standard test samples after maintenance, and the standard mechanics of materials test was done to obtain such elasticity parameters as elastic modulus and Poisson's ratio by using of the universal testing machine. Two different methods were put to use while constructing standard test samples, one of which

was to pouring cement mortar around the bamboo-woven frame, and another one of which was to weaving the frame with the strips of wrapping paper and pouring cement mortar around them. Experiment results show that the bamboo-woven frame could bear some tensile forces.

By means of the above measure data, the average of elastic modulus is about 20×10^3 MPa and the average of Poisson's ratio is about 0.18. All these results were identical with the ordinary cement concrete on the whole.



(a) (b)

Fig. 5 (a) Vertical displacements of shell structure subjected to various distributed loads along meridian(unit: mm); (b) The normal strain of two dimensional structures caused by various distributed loads (unit: $\mu\varepsilon$).All results are while the thichness is 5 cm

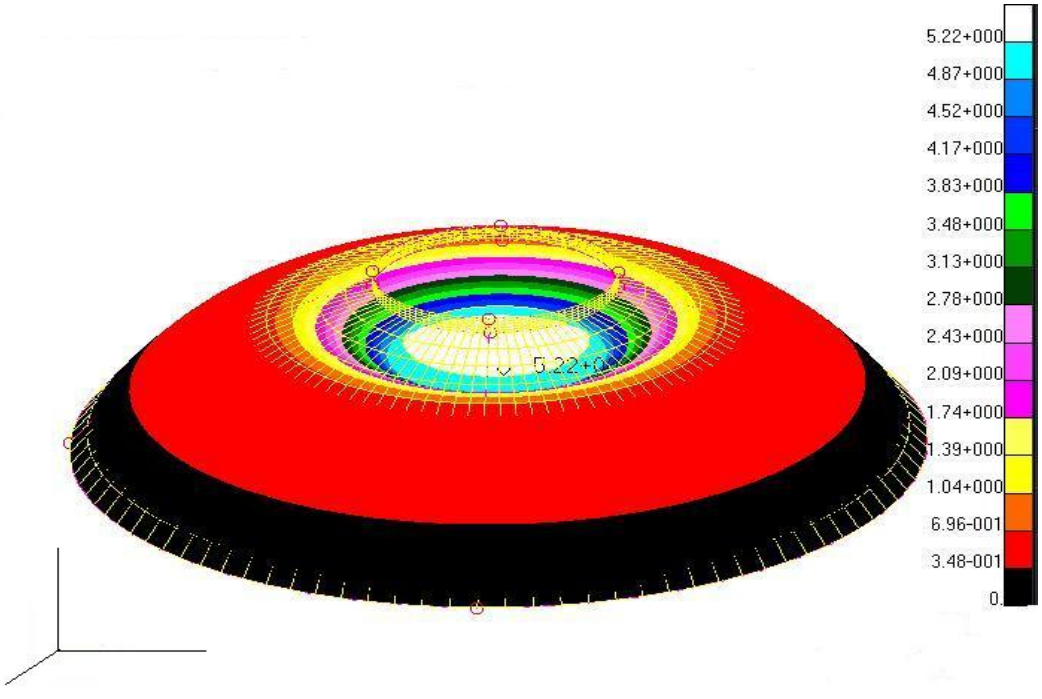


Fig . 6 Displacements of three dimensional shell model under uniform loads(unit: mm)

Using the elasticity parameters gotten, the theoretical models are established and analyzed. Different models are adopted to simulate the structure, for example, three dimensional arched shell model whose computational results are shown in fig.5(a) and fig.6, two dimensional arched curve model whose computational results are shown in fig.5(b). All these results were basically consistent with the field testing while some errors are considered.

Under the forgoing circumstance were only uniform live loads considered and dead loads (weight of structure) omitted. But the uniform live loads have been amplified many times from q_1 to q_6, so the most dangerous case, which is not existed in practice, is also considered.

4 Analysis of structural safety and durability

The bamboo-concrete structure deforms under loads in an elastic manner. Although its elastic modulus is one tenth that of steel and similar deformation will result since its strength is also about one tenth that of steel, concrete is classically a kind of compressive material.

From the mechanics performance point of view merely, bamboo has distinct orthotropic characteristic that its strength is apparently influenced by the direction of its fiber. Under the condition of tension and compression, if the force's direction is consistent with the fiber's, bamboo's strength is great relatively. Under the condition of static and dynamic bending, if the force's direction is vertical with the fiber's, bamboo's strength is also great relatively. If the force's direction deviates from above-mentioned direction, strength will cut down quickly and regularly. Since the bamboo-wove biogas digesters is woven crisscross, it can be concluded that the bamboo-woven biogas digesters has isotropic characteristic as a whole.

Although several presumptions have been made such as the material is isotropic and uniform, the upper part is smooth entirely and the displacement is one-dimensional etc., the results of testing and analysis are enough to prove that the bamboo-wove biogas digesters is reasonable basically for the structure design and safe enough under ordinary load. It is suggested that during building process, it should be tried as far as possible to maintain the smoothness of curved surface and the shape of arched shell in order to reduce artificial exceptional bending moment.

Analyzing the material of bamboo-woven concrete, it is known that before the cement mortar is destroyed, the bamboo doesn't bear load, only after the cement mortar is destroyed, the bamboo begins to bear load. According to the results of field testing, the new-type biogas digesters can bear load over 1 ton, which is actually born by the cement mortar alone. Thus we conclude that biogas digesters is safe enough even if the bamboo has rotted as long as its thickness of its protection layers is over 3 cm.

Besides, the disgusted-oxygen microorganism environment in biogas digesters plays a big part in protecting it and improving its durability.

5 Possible faults

The concrete used in the above structures is a mixtures of water,sand and portland cement. The mechanical properties of fine gravel concrete are mainly dependent to variation in the mixture of the components, so a particular combination of these ingredients must be carefully considered. As the concrete hardens, it releases some excess water over a period of time and shrinks. As a result of the shrinks, fine cracks often develop. In order to minimize these shrinkage cracks, some particular treatments could be applied, for example, covering the inside- and-outside surface with waterpfoof materials or mixing some resin with concrete, keeping the structure moist for at least 5 days.

6 Conclusion

Bamboo is regarded as a good natural construction material,and probably,one of the oldest known materials used in construction. Based on extensive and systematic testing in the fields and theoretical studies, the structures constructed of Bamboo-Woven Concrete are considered as being safe and reliable. Further work, such as simple design standard codes, should be done for the structures constructed of Bamboo-Woven Concrete.

For structural design of digesters constructed of in practice, the following should be noted: (1) to ensure that the structures possess the surface design demands, a kind of simple construction equipment should be explored for form and weave framework. (2) if possible, prefabricated bamboo framework should be given such more attention that the structure could be spread in more regions. (3) It is necessary to continue to improve construction technology so that the structure will more safe and reliable.

In a word, the fact that the above structures are being spread is very significance with overall ecological, forest ecological environment, environment pollution, sustainable development, building harmony society between Man and nature.

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