Mini Project Report on

"TENSEGRITY BASED POULTRY SHED"

Submitted by:

NIKHIL VYAS

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Under Supervision of:

DR. SURESH BHALLA

Department of Civil Engineering

Indian Institute of Technology, Delhi

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CERTIFICATE

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Nikhil Vyas

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Dr. Suresh Bhalla
Assistant professor
Department of Civil Engineering
Indian Institute of Technology Delhi
Date: April 24th 2009

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ABSTRACT

Tensegrity is a developing and relatively new system which creates amazing, lightweight and adaptable structures, giving the impression of a cluster of struts floating in the air. They are a special class of light-weight space truss structures, where the tensile elements are made of cables. They are easy to construct and are light in weight. Another main advantage is that they can be folded. Thus they will prove useful in coming years when structures which are space efficient will be required.

Bamboo is a non characterized and non validated material which is readily available in rural areas in India and has great scope as a building material.

The combination of the concept of tensegrity and bamboo as a building material has a vast potential to result in eco-friendly, economical, structurally optimal structures which are light-weight, earthquake resistant, transportable and storable. Thus we can have shelters or even permanent structures made at a fraction of existing costs and still be more eco-friendly.

The objective of this project was to fabricate a “TENSEGRITY BASED POULTRY SHED” structure using bamboo struts and jute ropes and the basics in tensegrity. Main emphasis was on light weight quick fabrication, ease in folding and dismountability. The individual elements were separately tested in the lab, and found suitable to resist likely loads

The complete structure was displayed in Open House’2009.

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CHAPTER 1

INTRODUCTION

1.1 DEFINITION OF TENSEGRITY AND TENSEGRITY STRUCTURES

"The word 'tensegrity' is new invention and contraction of the phrase 'tensional integrity.' Tensegrity describes a structural-relationship principle in which structural shape is guaranteed by the finitely closed, comprehensively continuous, tensional behaviours of the system and not by the discontinuous and exclusively local compressional member behaviours. Tensegrity provides to the structure ability to yield increasingly without ultimately breaking or coming asunder"

Fig 1.1. Needle Tower by Kenneth Snelson (1968)

Tensegrity structures are three-dimensional space structures built of struts and cables attached to the ends of the struts. The struts can resist the compressive force; the cables resist the tensile forces. Most-strut-cable configuration which one might conceive is not in equilibrium, and if actually constructed will collapse to a different shape, only strut-cable configuration in a stable equilibrium will be called tensegrity structures.

1.2 PRINCIPLE OF TENSEGRITY STRUCTURES

Tensegrity structures are structures based on the combination of a few simple but subtle and deep design patterns:

- loading members only in pure compression or pure tension, meaning the structure will only fail if the cables yield or the struts buckle (the struts would have to be an exceptionally weak material with a very large diameter to yield before they buckle or the cables yield)
- preload, which allows cables to be rigid in compression
- minimal over constraint which reduces stress localization
- mechanical stability, which allows the members to remain in tension/compression as stress on the structure increases

Because of these patterns, no members experience a bending moment. This produces exceptionally rigid structures for their mass and for their cross section.

1.3 PROPERTIES OF TENSEGRITY STRUCTURES

The tensegrity concept can be defined in terms of push and pull, where push is provided by struts and pull is provide by cables have a win-win relationship with each other. Pull is continuous and push is discontinuous. The two balance each other producing the integrity of tension and compression. Tensegrity structures consists only compression struts and tension cable members. These fundamental phenomena do not oppose, but rather complement each other. Tensegrity is the name for a synergy between a co-existing pairs of fundamental physical laws of push and pull, or compression and tension, or repulsion and attraction.

Thus a tensegrity is any balanced system composed of two elements, a continuous pull balanced by discontinuous push. When these two forces are in balance, a stabilized system results that is maximally strong

"The tension-bearing members in these structures – whether Fuller's domes or Snelson's sculptures – map out the shortest paths between adjacent members (and are therefore, by definition, arranged geodesically) Tensional forces naturally transmit themselves over the shortest distance between two points, so the members of a tensegrity structure are precisely positioned to best withstand stress. For this reason, tensegrity structures offer a maximum amount of strength."- Ingber

1.4 ADVANTAGES AND DISADVANTAGES OF TENSEGRITY STRUCTURES

Tensegrity structures have specific advantages that merit their consideration for use as Engineering structures and mechanisms (Kumar, 2007)-

1. Tensegrity structures are form finding and deployable. This means that for a structure with flexible (cable) tension members, as the last cable is shortened, the structure will automatically deploy (i.e. rise from its initial collapsed state to the stable tensegrity position). This aspect makes tensegrity structures attractive when pre-use storage space is at a premium or for compact transportation. Additionally, by using elastic, tensegrity structures can be self-erecting or self deployable. The potential energy in the elastic cables is used to deploy the structure into its stable configuration.

2. One of the greatest benefits of tensegrity structures is that forces are purely axial and predominantly tension. The tension-only members are not subject to compressive

forces that cause buckling and can take advantage of materials that are strong in tension. This feature results in material efficiencies and low structure weight.

3. Tension members also self stabilize and become more stable the larger the load as the tension pulls the structure towards the equilibrium position.
4. The fact that these structures vibrate readily means that they are transferring loads very rapidly, so the loads cannot become local. This is very useful in terms of absorption of shocks and seismic vibrations. Thus, they would be desirable in areas where earthquakes are a problem.
5. For large tensegrity constructions, the fabrication process would be relatively easy to carry out, since the structure is self-scaffolding.

There are also several disadvantages that must be overcome to make tensegrity structures useful (Kumar, 2007)-

1. Tensegrity structures are not conventionally rigid; they always exhibit an infinitesimal flex and must be prestressed to resist deformation in the direction of the flex.
2. Tensegrity arrangements need to solve the problem of bar congestion. As some designs become larger (thus, the arc length of a strut decreases), the struts start running into each other.
3. Spherical and domical structures are complex, which can lead to problems in production.
4. In order to support critical loads, the pre-stress forces should be high enough, which could be difficult in larger-size constructions.

1.5 APPLICATIONS OF TENSEGRITY

I. The qualities of tensegrity structures which make the technology attractive for human use are their resilience and their ability to use materials in a very economical way. These structures very effectively capitalize on the ever increasing tensile performance modern engineering has been able to extract from construction materials.

II. In tensegrity structures, the ethereal (yet strong) tensile members predominate, while the more material-intensive compression members are minimized. Thus, the construction of buildings, bridges and other structures using tensegrity principles could make them highly resilient and very economical at the same time.

III. In a domical configuration, this technology could allow the fabrication of very large-scale structures. When constructed over cities, these structures could serve as frameworks for environmental control, energy transformation and food production. They could be useful in situations where large-scale electrical or electromagnetic shielding is necessary or in extra-terrestrial situations where micrometeorite protection is necessary. And, they could provide for the exclusion or containment of flying animals over large areas, or contain debris from explosions.

IV. These domes could encompass very large areas with only minimal support at their perimeters. Suspending structures above the earth on such minimal foundations would allow the suspended structures to escape terrestrial confines in areas where this is useful. Examples of such areas are congested or dangerous areas, urban areas and delicate or rugged terrains.

V. In a spherical configuration, tensegrity designs could be useful in an outer-space context as superstructures for space stations.

VI. Their extreme resilience makes tensegrity structures able to withstand large structural shocks like earthquakes. Thus, they could be desirable in areas where earthquakes are a problem.

1.6 BAMBOO AS A BUILDING MATERIAL: NEED AND ADVANTAGES

There has been a furious construction activity in the developing world, especially India and China, for the last one and a half decades. Although not directly visible, construction industry is one of the most polluting industries in the world. Production of both concrete and steel cause considerable deterioration of the environment.

Producing every ton of cement results in the emission of at least one ton of carbon dioxide (CO2). Roughly 5 to 10 percent of global CO_2 emissions are related to the manufacture and transportation of cement. Similarly, production of every ton of steel is accompanied with the release of over two tons of CO_2 in the atmosphere.

The developing economies need millions of houses for their growing population, a big part of which is homeless, the fast growth rate necessitates infrastructure development in the form of suitable space for offices and industries. While acknowledging the need for building more structures, it is also most important to keep the environmental issues at the forefront.

It is here that engineered bamboo can be of great value to civil engineers owing to several noteworthy features.(Bhalla et al. ,2008)

- From environmental consideration, production of every ton of bamboo consumes about a ton of the atmospheric CO2, in addition to releasing fresh oxygen into the atmosphere.
- From structural engineering point of view, bamboo has competitive strength characteristics. Typically, species like dendrocallamus giganteus (DG) have tensile strength of about 120 MPa, compressive strength of 55 MPa and Young’s modulus of 14

GPa. These figures do not compare badly with mild steel which has an ultimate strength of 410 MPa, yield strength of 250 MPa and Young's modulus of 20 GPa.

- Concrete has much lower strength than those of bamboo reported here. In addition, the low density of bamboo, which is typically 700 kg/m3, results in much higher strength to weight ratio as compared to steel (density = 7800 kg/m3) and concrete (density= 2400 kg/m3).

  The only shortcoming with raw bamboo is susceptibility to termite attack which can be set aside by suitable chemical treatment

1.7 UNITS FABRICATED

A. SIMPLEX UNIT

Simplest tensegrity structure is the "Simplex". Also known as "Elementary Equilibrium" or "Three-Struts T-Prism". Fig 1.2 represents the top view of the simplex unit. Here dark dash line represent strut whereas solid line represents wires in lower and upper plane. Green line represents cable joining the two planes. All dimensions shown are actual lengths not projected lengths and are in cm. Three struts which join column and roof are not shown in this diagram.

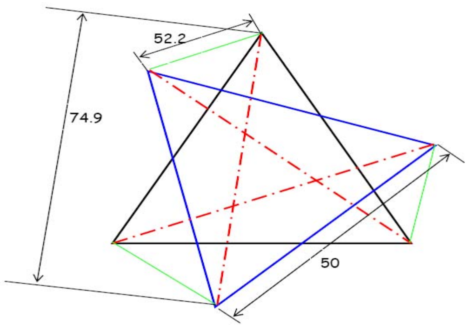

Fig 1.2. Top view of simplex column

B. HALF-CUBOCTAHEDRON STRUCTURE

A cuboctahedron is a polyhedron with eight triangular faces and six square faces.

Half- cuboctahedron structure is shown in Fig. 1.3.

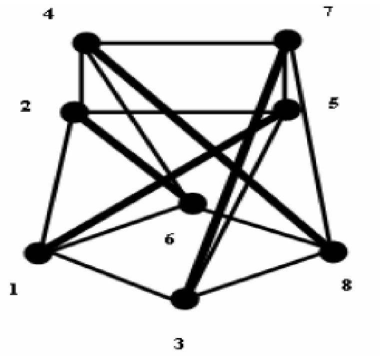

Fig 1.3. Half-cuboctahedron structure

CHAPTER 2

FABRICATION METHODOLOGY

2.1 COLUMN FABRICATION

2.1.1 STAGE 1: JOINT FABRICATION FOR COLUMN

Bamboo struts of length 66cm each for the simplex units and struts of length 59 cm for struts joining column to roof were procured from the Micromodel Lab, IIT Delhi. Hooks of diameter 10 mm (with fasteners) were procured from the local markets. The bamboo rod length was cut keeping in mind the increase in length of strut due to insertion of hooks at both the ends (approximately 4 cm increase on one side).

2.1.1.1 Joints used at base

Fig 2.1 shows typical joint at base. Three such joints were fabricated per column

Fig 2.1 Joint used at base

For this type of joint, first the hole at the end of the bamboo was filled with epoxy adhesive. The epoxy was prepared by mixing the components- hardener and resin, as shown in Fig 2.2. Then, a single hook end was inserted into the bamboo hole and the fastener was expanded using pliers till it expanded equal to the hole diameter. The hook was then pushed in after application of epoxy to the washer to ensure against leakage of adhesive. Then they were kept for 24 hours as epoxy takes time to cure.

Fig 2.2 Epoxy and hardener

2.1.1.2 Joints used in the middle

Fig 2.3 shows a typical middle joint

Fig 2.3 Joint used in the middle

For this type of joint, two hooks were first connected to each other. This was done by bending one of the hooks and then inserting the other hook into it. After this, one hook was inserted into a bamboo which either had a base joint or joint connecting to roof at opposite end and another hook was inserted into a bamboo with middle joint at the opposite end. The joint fabrication procedure was as above. They were then left to cure for 24 hours.

2.1.1.3 Joints used for connecting to roof

These joints shown in Fig 2.4 were situated at the top of column. One such joint was fabricated per column.

Fig 2.4 Joint used for connecting column to roof

For this type of joint three hooks were connected to each other. This was done by bending one of the hooks and then inserting another hook into it and repeating this for one more hook. After this, the hooks were inserted into a bamboo which had a middle joint at opposite end. The joint fabrication procedure was as above. They were then left to cure for 24 hours.

2.1.2 STAGE 2: CABLE FABRICATION FOR COLUMN

Ropes of length 58 cm were cut for the base and top triangle of the simplex unit. This was done keeping 5 cm on each side to tie knots. Side length was supposed to be 50 cm but actual length was kept 48 cm as the rope elongates when put under tension and elongation was found to be around 2 cm. Similarly ropes of length 60.2 cm were cut to connect base to top of simplex unit.

2.1.3 STAGE 3: FINAL COLUMN FABRICATION

Finally, struts were joined with cables to give one unit of simplex as shown in the Fig 2.5, which were then joined to produce one column as shown in the Fig 2.6. Similarly, three other units were fabricated. Height of each simplex module was 0.5 m and total height of a column was 1.6m.

Fig 2.5 Simplex Unit

Fig 2.6. Complete column

2.2 ROOF FABRICATION

2.2.1 STAGE 1: JOINT FABRICATION FOR ROOF

Bamboo rods of length 90cm each were procured from the Micromodel Lab, IIT Delhi.

Hooks of diameter 10 mm (with fasteners) were procured from the local markets. The bamboo rod length was cut keeping in mind the increase in length of strut due to insertion of hooks at both the ends (approximately 4 cm increase on one side).

2.2.1.1 Joints used at top of roof

These joints, shown in Fig 2.7, were used at top of roof. Sixteen such joints were fabricated for the roof

Fig 2.7. Joints used at top of roof

For this type of joint, first the hole at the end of the bamboo was filled with epoxy adhesive. Then, a single hook end was inserted into the bamboo hole and the fastener was expanded using pliers till it expanded equal to the hole diameter. The hook was then pushed in after application of epoxy to the washer to ensure against leakage of adhesive. Then they were kept for 24 hours for curing.

2.2.1.2 Joints used in the middle of the roof base

These joints as shown in Fig 2.8, were used in the middle. Four such joints were fabricated per for the roof.

Fig 2.8. Joints used in the middle of the roof base

For this type of joint, two hooks were first connected to each other. This was done by bending one of the hooks and then inserting the other hook into it. After this, one hook was inserted into a bamboo which had a roof top joint at the opposite end. The joint fabrication procedure was as above. They were then left to cure for 24 hours.

2.2.1.3 Joints used at centre of roof

These joints as shown in Fig 2.9 , were used at the centre of the roof. One such joint was fabricated for the roof.

Fig 2.9. Joints used at centre of roof

For this type of joint four hooks were connected to each other. This was done by bending one of the hooks and then inserting another hook into it and repeating this for two more hooks. After this, the hook was inserted into a bamboo which had a roof top joint at the opposite end. The joint fabrication procedure was as above. They were then left to cure for 24 hours.

2.2.1.3 Joints used for connecting to column

These joints, shown in Fig 2.10 , were at the four corners of the roof. Four such joints were fabricated for the roof.

Fig 2.10. Joints used for connecting to column

For this type of joint first the hole at the end of the bamboo was filled with epoxy adhesive. . Then a single hook end (which had already been bent open) was inserted into a bamboo which had a roof top joint at the other end. The joint fabrication procedure was as above. They were then left to cure for 24 hours.

2.2.2 STAGE 2: CABLE FABRICATION FOR ROOF

Ropes of length 85 cm were cut for the base and of length 47.5cm for the top square of the Half-cuboctahedron unit. This was done keeping 5 cm on each side to tie knots. Side length was supposed to be 75 cm but actual length was kept 83 cm as the rope elongates when put under tension and elongation was found to be around 2 cm.

Similarly ropes of length 70.5 cm were cut to connect base to top of Half-cuboctahedron unit.

2.2.3 STAGE 3: FINAL ROOF FABRICATION

Finally, struts were joined with cables to form one half-cuboctahedron unit as in Fig 2.11 which were joined to form the roof as shown in the Fig 2.12. The roof has square dimensions of 1.5m x1.5m and a height of 0.5m.

Fig.2.11.Half Cuboctahedron Unit

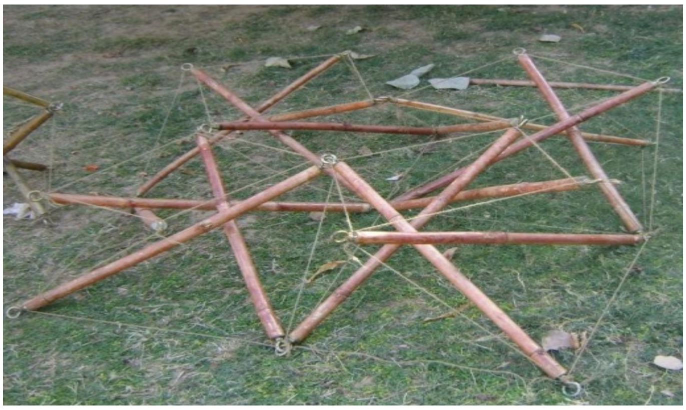

Fig 2.12.Complete Roof

2.3 JOINING OF COLUMS WITH ROOF TO COMPLETE FINAL STRUCTURE

In the end the roof was joined with the four columns at the four corners as shown in the Fig 2.13. This was done by inserting the open hooks at the four base corner joints of the roof into the topmost joints of the column and then securing the joint by tying it with rope.

Fig 2.13.Final Shed Structure

Chapter 3

Preliminary Analysis

3.1. TESTING OF CABLES AND STRUTS

3.1.1.Testing of Bamboo Struts

The Bamboo struts were tested for compression in the UTM as shown in Fig 3.1.Bamboo specimens of 18cm (L/R<10) were tested and the average compressive strength from several tests came out to be 57.5 MPa.

Fig 3.1.UTM used for testing bamboo Struts

3.1.1. Testing of jute ropes

The jute rope was tested for tensile strength by tying it to a spring balance and suspending weights from the other end as shown in Fig 3.2.The average tensile strength came out to be 122.5N

Fig 3.2.Spring Balance used for testing jute rope

3.2. CHECK FOR ADEQUACY OF MEMBERS

Typical forces in a tensegrity based shed structure similar to the one fabricated are (Singh, R.P., 2009) in the range of 90 to 120 N for normal wind conditions and in the range of 700 N for worst cases.

Thus we can observe that the members have strengths that are more than required for normal wind conditions and thus we can conclude that the structure has an adequate factor of safety.

However for the worst case scenario the loads are of the range 700N, therefore we should use much stronger elements (mainly cables) in case we are expecting worst case conditions.

CHAPTER 4

COMPARISON WITH PREVIOUS WORK

4.1 COMPARISON WITH PREVIOUS WORK

Previously, metal struts i.e. either steel or aluminium were used (Fig 4.1 to 4.4). In the newly fabricated structure bamboo struts were used which had only to be cut from long bamboo sticks and no grooving or hammering was required. Cables and wires were replaced by ropes.

Previously used joints (Fig 4.1 to 4.4) either required welding or processing of metal sheets and nuts and bolts arrangement whereas the newly fabricated joints (Fig 4.5 to 4.7) required a single hook.

Fig 4.1: Previously used Circular-plate joint Source: K. Vijay Kumar(2007)

Fig 4.2:Previously used central roof Joint Source: Goyal A(2008)

Fig 4.3: Previously used joint in the middle of Roof base
Source: Goyal A (2008)

Fig 4.4: Previously used column base joint
Source: Mittal A (2008)

Fig 4.5.Newly Fabricated Central Roof Joint

Fig 4.6.Newly Fabricated joint used in the middle of the roof base

Fig 4.7 Newly Fabricated Column base joint

Some of the advantages of the new structure over previous ones are listed below

1. Minimum processing of struts required.
2. No welding or nuts and bolts arrangement required in fabrication.
3. More flexible than previous structures.
4. Dismountable and easily storable.
5. No complex procedure when connecting cables as only a knot has to be tied.
6. Structure much lighter than some of the previous structures.
7. Much more environment friendly as compared to any of the previous structures and much more viable for rural areas.
8. More economical.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The main conclusions drawn from the project are-

There is great potential of the combination of bamboo and tensegrity in the construction industry.The fabricated structure aims to provide an alternative environment friendly construction for a steel poultry shed. It can serve multiple purposes, such as workshop for a cottage industry, warehouse, and other medium industries. Not only is the structure light compared to conventional steel, it is at the same time several times cheaper and eco friendly. Such structures can pave way for sustainable industrialization of the rural sector in India and other developing nations.

5.2. RECOMMENDATIONS

Some of the recommendations for further research in fabrication of bamboo based tensegrity sheds are-

1. Instead of jute rope nylon rope should be used as cable. This is due to the fact that jute ropes are not very durable and break easily after they come in contact with water i.e. after it rains. Another problem with jute ropes is their high and variable elasticity.
2. Bamboo of the lightest type available should be used so as to keep the dead load on structure small.

REFERENCES

Goyal A(2008), Fabrication of Prototype Dismountable Half-Cuboctohedron Roof for Shed Structures, Mini Project Report, Department of Civil Engineering, IIT Delhi

Bhalla et al.(2008), Bamboo As Green Alternative To Concrete And Steel For Modern Structures

Mittal A(2008), Fabrication of Prototype Dismountable Simplex Column for Shed Structures, Mini Project Report, Department of Civil Engineering, IIT Delhi

Kumar K V(2007), Dynamic Characterization of Tensegrity Structures, M.Tech Project Thesis, Department of Civil Engineering, IIT Delhi

Singh, R.P.(2009), Health Monitoring of Structures using Piezo-Transducers, M.Tech Project Thesis, Department of Civil Engineering, IIT Delhi

Online Resources:

Snelson, K.(2009)

http://www.kennethsnelson.net/, accessed January 2009-May 2009