ANALYSIS AND DESIGN OF BAMBOO BASED COWSHED

Submitted By:

Deepti Chauhan

(2008CE10260)

Under supervision of

Dr. Suresh Bhalla

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Department of Civil Engineering

Indian Institute of Technology, Delhi

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CERTIFICATE

I do certify that this report explains the work carried out by me in the Course CED 412 - Project Part 2 under the overall supervision of Dr. Suresh Bhalla. The contents of the report including text, figures, tables, computer programs, etc. have not been reproduced from other sources such as books, journals, reports, manuals, websites, etc. Wherever limited reproduction from another source had been made the source had been duly acknowledged at that point and also listed in the References.

Deepti Chauhan

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This is to certify that the report submitted by Deepti Chauhan (2008CE10260) describes the work carried out by her in the course Course CED 412 - Project Part 2 under my overall supervision.

Dr. Suresh Bhalla

(Supervisor)

Date: 30 Apr, 2012

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Deepti Chauhan

ABSTRACT

The main objective of this project was to design shed type structures using bamboo, and arrive at the optimum design. Data for wind loads and dead loads has been obtained from IS 875 Part 2 & 3. Since no standard code is available for bamboo, Steel code (IS 800, 1984) has been adapted wherever necessary. Further, a comparison with the arched roof shed has proved pitched roof shed to be more economical and better has been carried out.

For the structure, the design of columns, base plate, inclined and top members, foundation and joints of the structure have been carried out. For the design of joints, the experimental testing of bamboo joints has been carried out in the Universal Testing Machine in the Concrete Laboratory. The manual analysis of the forces and moments has been validated using STAAD Pro.

The culmination of the project has resulted in complete design details for bamboo frame of span 6m. The design details have been depicted with figures and labelled.

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Chapter 1 BUILDINGS

1.1 INTRODUCTION

High rise steel buildings account for a very small percentage of the total number of structures that are built around the world. The majority of steel structures being built are low rise buildings, which are generally of one storey only. Industrial buildings, a subset of low-rise buildings are normally used for steel plants, automobile industries, utility and process industries, thermal power stations, warehouses, assembly plants, stores, garages, small scale industries, etc. These buildings require large column free areas. Hence interior columns, walls, and partitions are often eliminated or kept to a minimum. Most of these buildings may require adequate head room for the use of an overhead travelling crane.

1.2 DIFFERENT COMPONENTS OF A BUILDING

The structural engineer has to consider the following points during the planning and design of buildings:

i. Selection of Roofing and wall material
ii. Selection of bay width
iii. Selection of structural framing system
iv. Roof trusses
v. Purlins, grits and sag rods
vi. Bracing systems to resist lateral loads
vii. Gantry girders, columns, base plates, and foundations

1.2.1 Roofing and wall material

In India, corrugated galvanized iron (GI) sheets are usually adopted as coverings for roofs and sides of industrial buildings. Light gauge cold-formed ribbed steel or aluminium decking can also be used. Sometimes asbestos cement (AC) sheets are also provided as roof coverings owing top their superior insulating properties.

1.2.2 Bay width

In most cases, the bay width may be indicated by owner requirements. Gravity loads generally control the bay size. Based on both strength and stiffness (L/180) requirements, the maximum economical span is 9m.

1.2.3 Structural Framing

For the purpose of structural analysis and design, industrial buildings are classified as:

- Braced frames
- Unbraced frames

In braced buildings, the trusses rest on columns with hinge type of connections and the stability is provided by bracings in the three mutually perpendicular planes. These bracings are identified as follows:

a. Bracings in the vertical plane in the end bays in the longitudinal direction
b. Bracings in the horizontal plane at bottom chord level of the roof truss
c. Bracings in the plane of upper chords of the roof truss
d. Bracings in the vertical plane in the end cross sections usually at the gable ends.

1.2.4 Purlins, Girts and Eave strut

Secondary structural members such as purlins and girts span the distance between the primary building structures portal frames or truss-column system). They support the roof and wall covering and distribute the external load to the main frames or trusses. Purlins form a part of the roof bracing system and girts are a part of the wall bracing system of the building. The third type of secondary structural member is the Eave strut. This member is located at the intersection of the roof and the exterior wall and hence acts as both the first purlin and the last (highest) girt. The building s eave height is measured to the top of this member.

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1.2.5 Spacing of Purlins

The spacing of the purlins largely depends on the maximum safe span of the roof covering and glazing sheets. Hence they should be less than or equal to their safe spans when they are directly placed on purlins.

1.2.6 Plane Trusses

A structure that is composed of a number of line members pin-connected at the ends to form a triangulated framework is called a truss. In a truss, the members are so arranged that all the loads and reactions occur only at the joints (intersection point of the members). For common trusses with vertically acting loads, compressive forces are usually developed in the top chord members and tensile forces in the bottom chord members. However, it is often necessary to design the various members of a truss both for tension and compression and select the member size based on the critical force.

1.2.7 Spacing of trusses

The spacing of trusses is mostly determined by the spacing of supporting columns which in turn is determined by the functional requirements. When there are no functional requirements, the spacing should be such that the cost of the roof is minimized. It can be shown that an economic system is obtained when the cost of trusses is equal to the cost of roof covering plus twice the cost of purlins. i.e.

$$C_t = C_r + 2C_p \qquad \text{...... (1.1)}$$

where

C_t = Cost of the trusses/unit area

C_r = Cost of the roof coverings/unit area

C_p = Cost of the purlins/unit area

1.3 LOAD COMBINATIONS FOR DESIGN

For shed type buildings, the following combinations of loads are considered when there is no crane load:

1. Dead loads + imposed loads (live loads)

2 Dead loads + wind loads (wind direction being normal to ridge or parallel to ridge whichever is severe)

4. Dead loads + imposed loads + wind loads (which may not be critical in most of the cases).

The 3rd combination is considered with internal positive air pressure and internal suction air pressure separately to determine the worst combination of wind load.

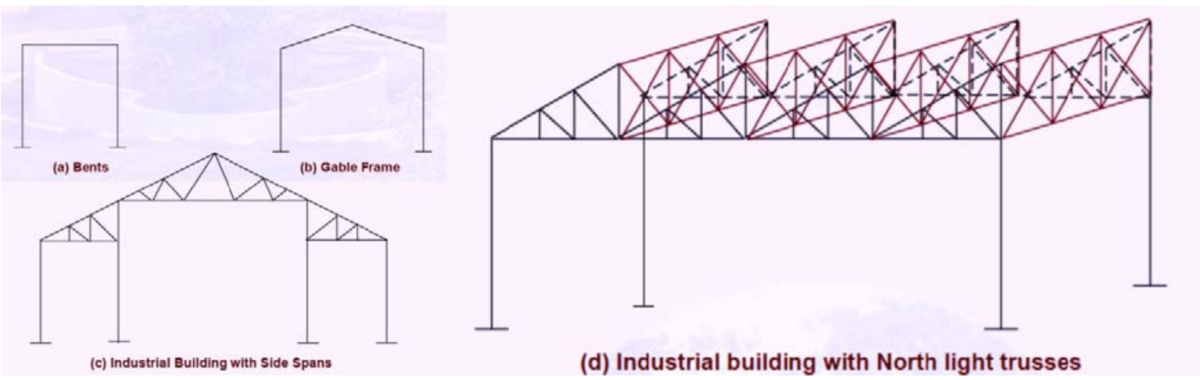


Figure 1.1 Different Components of an Industrial Building

1.4 WHY BAMBOO AS A CONSTRUCTION MATERIAL?

Construction industry is one of the most polluting industries in the world. Production of both concrete and steel causes considerable deterioration of the environment. Cement, the main constituent of concrete, requires heating limestone and other ingredients to over 1,400^{O}C by burning fossil fuels. Producing every ton of cement results in the emission of at least one ton of carbon dioxide (CO_2) (CS Monitor, 2008). Roughly 5 to 10 percent of global CO_2 emissions are related to the manufacture and transportation of cement (Scientific American, 2008). Similarly, production of every ton of steel is accompanied with the release of over two tons of CO_2 in the atmosphere (Ghavami, 2007).

The project presents the possible replacement of concrete and steel by eco-friendly bamboo as a modern engineering construction material. In fact, growth of every ton of bamboo consumes nearly a ton of carbon dioxide besides releasing fresh oxygen into the atmosphere. In this project, through structural analysis and design principles, it is demonstrated ‘as to how’ modern engineered structures can be a real possibility using bamboo. A detailed structural analysis and design of a typical bamboo shed structure is presented in accordance with the Indian standard codes of practice. The columns are designed as battened columns with concrete bands as the ties. The roof is designed as a bamboo “parabolic tied arch” resting on the battened bambcrete columns. Other elements such as purlins and bracings are also bamboo based. Not only the proposed structure is capable of withstanding the loads as prescribed in the codes of practice, its cost is several times less than the so called modern structures constructed using concrete and steel. The details presented in this project set aside the conventional belief that only concrete and steel structures can be engineered. Modern structural analysis and design practices can be suitably applied upon bamboo elements for rational engineering design of buildings and other structures.

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. 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 200 GPa. Concrete has much lower strength than those of bamboo reported here. In addition, the low density of bamboo, which is typically 700kg/m^3, results in much higher strength to weight ratio as compare to steel (density = 7800 kg/m3) and concrete (density = 2400 kg/m^3). The only shortcoming with raw bamboo is susceptibility to termite attack which can be set aside by suitable chemical treatment.

Chapter 2 DESIGN PHILOSOPHY

2.1 STRUCTURAL DETAILS AND BASIC BAMBOO ELEMENTS

At present, no book or code of practice is available for design of bamboo structures on scientific lines. The first attempt in this direction was made by Bhalla et al. (2008). In order to explain the design procedure, two shed type structures, 25m×6m in plan and 4.5m in height, and 25m×8m in plan and 5.5m in height have been designed using engineered bamboo. The structure is assumed to be situated in Delhi region. Fig. 2.1 shows the front and the side elevations of a conventional industrial shed made of steel. In the alternative design presented here, the steel columns shall be replaced by battened bamboo columns, where bamboo elements serve as struts embedded in a steel base plate. The steel roof truss shall be replaced by bamboo pitched roof. The pitched roof has a height of 2.5 m and span of 8m. Both the columns and the pitched roof will be constructed with the combination of bamboo and steel elements.

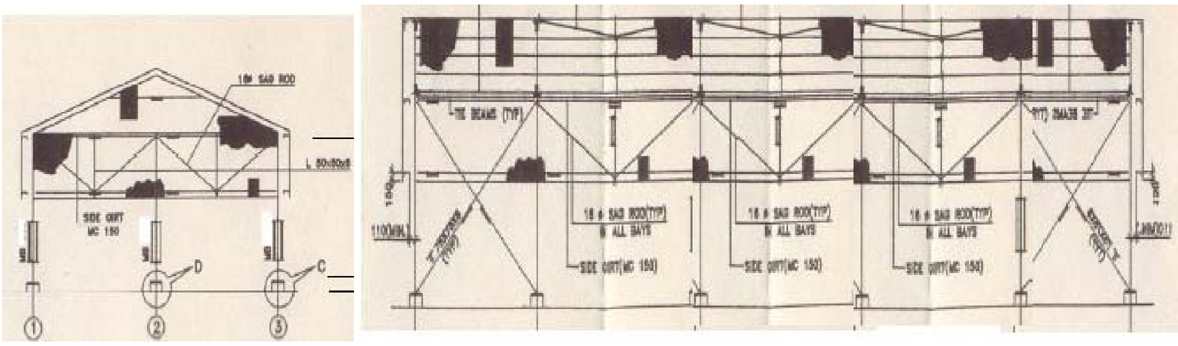


Figure 2.1 A conventional shed structure made of steel

2.2 DESIGN PHILOSOPHY AND ALLOWABLE STRESSES

The design covered in this project is assumed to use the species *dendrocallamus giganteus* (DG) of bamboo, for which the tensile strength and the compressive strengths are reported as 121.5MPa and 55.55 MPa respectively (Ghavami, 2007). However, the recent tests carried out in the laboratory have resulted in an increased compressive strength of 61 MPa (Shaw A., 2012). The proposed approach follows the working stress design method and assumes that bamboo behaves linearly elastic in the working stress range. Being natural product, and expecting a large variation of strength characteristics, a large factor of safety of 3.5 is considered in the proposed approach. According to IS 800 (1984), the permissible stress in tension works out to be 16 MPa. For compression, by taking the factor of safety and the elastic critical stress, the allowable compressive stress works out to be 11 MPa for a slenderness ratio of 80. Each bamboo element is considered to have an external diameter of 40mm and a wall thickness of 10mm.

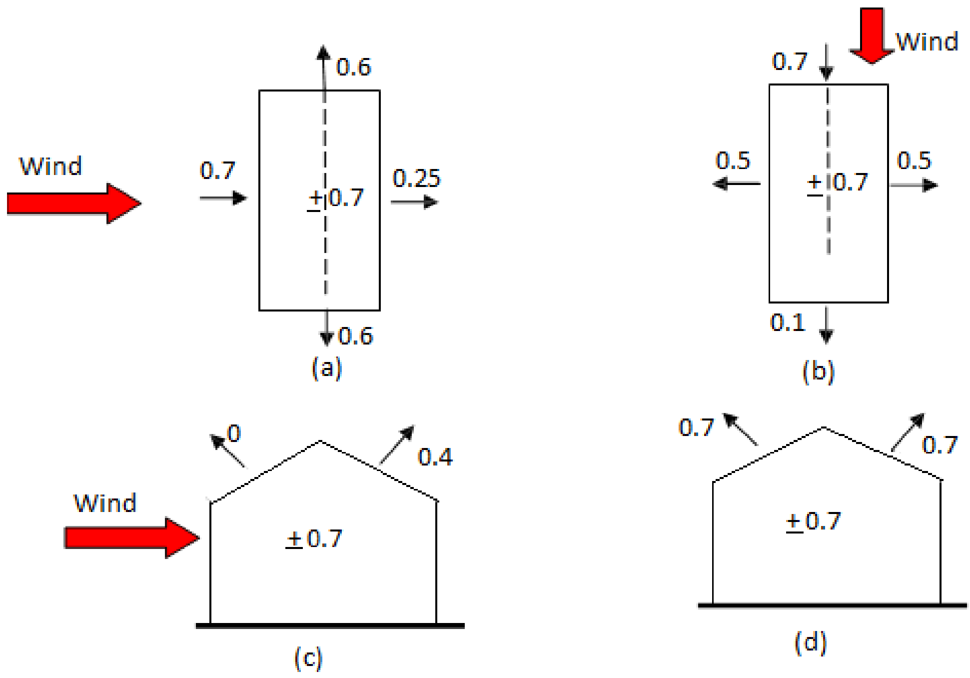
2.3 DEAD LOADS AND IMPOSED LOADS

Dead load and imposed load analysis of the structure are straightforward since these loads do not induce any moment on the column due to flexible connection of the bamboo arch with the columns. For dead loads, the roof has been considered to be covered by galvanized iron (GI) sheeting. These are considered to impose a dead load of $0.25kN/m^2$. The density of bamboo is assumed to be equal to $7kN/m^3$. In accordance with IS 875 part 2, an imposed load of $0.75kN/m^2$ has been considered for the roof.

2.4 WIND LOADS

In this study, the structure is analyzed for wind forces in accordance with IS: 875 Part 3. For Delhi region, this code recommends a basic wind speed V_b of 47m/s. This study has considered the value of the probability factor (risk coefficient) k_1 as1.0 assuming a mean probable life of 50 years. The terrain, height and size factor k_2 of 1.0 has been considered since the proposed structure belongs to class A and category 2 as per IS 875 part 3. Finally, the topography factor k_3 has been chosen as 1.0. These factors result in a design wind speed V_Z $(= k_1\ k_2\ k_3\ V_b\ )$ of 47m/s , thereby resulting in a design wind pressure of 1.325 kN/m^2 $(= 0.6V_z^2)$. The external and internal pressure coefficients on the wall and roof in accordance with IS 875 Part 3 are shown in Fig. 2.2 for two wind directions - normal to the ridge and parallel to the ridge. An internal wind pressure of ±0.7 has been considered. In overall, following wind cases have been analyzed:

1. Wind normal to ridge, inside suction.
2. Wind normal to ridge, inside pressure.
3. Wind along ridge, inside suction.
4. Wind along ridge, inside pressure.



(a) Walls: Wind normal to ridge. (b) Walls: Wind along ridge
(c) Roof: Wind normal to ridge (d) Roof: Wind along ridge

Figure 2.2 Wind pressure coefficients in accordance with IS 875 part 3

Fig. 2.3 shows the steps involved in the analysis of a typical transverse frame, which supports the wind load on a tributary length of 5m of the building, for the case of wind load normal to ridge with pressure inside. The structure is analyzed as the superposition of two cases- (A) and (B), shown in the figure. The columns are idealized as propped cantilevers for case (A).

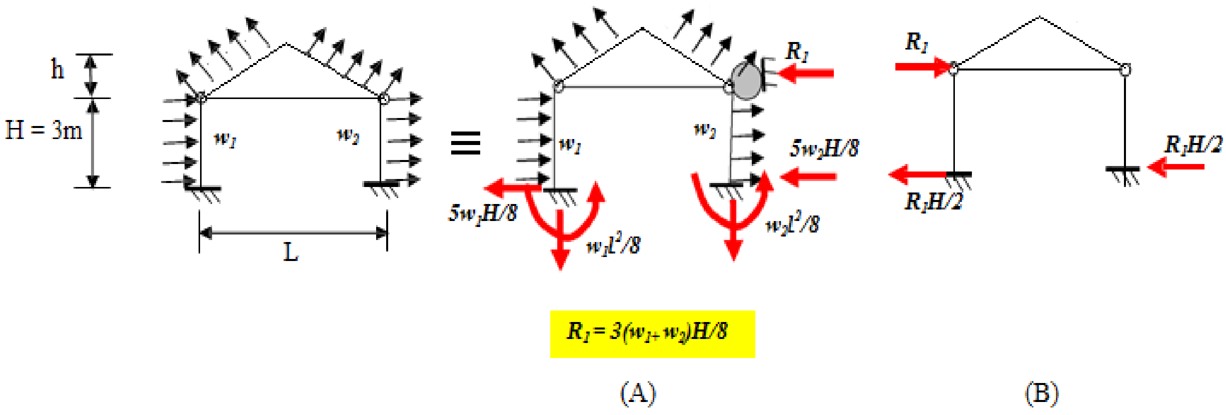


Figure 2.3 Analysis of transverse frame for wind normal to ridge, inside pressure

2.5 DESIGN OF COLUMNS

For the design of Columns, the moment acting at the base of the columns is considered as a couple of forces, compressive and tensile. The total load (dead + imposed) acting on each column is calculated and the net compressive and tensile force acting on the column is calculated, and then the column is designed for the critical force. The number of bamboo struts may also be governed by the slenderness ratio (which is limited to 200 for all the compression members for bamboo). The local slenderness ratio is kept limited to 80 by having stirrups at regular distances. The column, thus designed, is using bamboo struts and the formula:

$$\sigma = P/A \pm M/Z \qquad \text{... (2.1)}$$

2.6 DESIGN OF BASE PLATE

The base plate has been designed assuming stiff connection between the bamboo struts and the base plate. The moment from the bamboo struts is transferred to the base plate using gusset plates and joints. The base plate has been designed assuming M30 concrete foundation. With calculations for forces and moments, the size of the base plate and the number of bolts required has been calculated. The following equations were used for calculating the thickness of the base plate

$$P + T = 0.36\, f_{ck}\, b\, x_u \qquad \text{... (2.2)}$$

$$P{*}d + M = 0.36\, f_{ck}\, b\, x_u\, (L/2 + d - 0.416\, x_u) \qquad \text{... (2.3)}$$

2.7 DESIGN OF FOUNDATION

The foundation has been designed as isolated footings of reinforced concrete (RC). Usual design principles followed for footing design (considering the bending moment, one-way shear and two- way shear) have been used. The footing has been designed assuming M30 concrete. The allowable load has been calculated for the footing using:

Under normal conditions: $q_{all,\ gross} = q_{all,\ net} + q$ ... (2.4)

Under wind/earthquake: $q_{all,gross} = 1.25\ q_{all,net} + q$ ... (2.5)

Then the total load and moment for the footing are calculated:

$$P_t = P + \text{Overburden} \quad \text{... (2.6)}$$

$$M_t = M + H^*(\text{Footing thickness}) \quad \text{... (2.7)}$$

Thereafter, the stress requirements are checked:

$$\sigma_{max} = P_t/A + M_t/Z \quad \text{... (2.8)}$$

$$\sigma_{min} = P_t/A - M_t/Z \quad \text{... (2.9)}$$

The moment for the foundation is calculated and reinforcement is calculated. Also, the footing is then checked for one way, two way shear, sliding and overturning.

2.8 DESIGN OF INCLINED MEMBERS AND TOP CHORD

The design of inclined chord members is similar to that of the columns. It is calculated using the total force and moment acting on the member and is distributed among the various bamboo members. First of all, the load intensity due to dead loads (w1) has been calculated and then the calculation of load intensity due to wind loads (w2) has been done. After calculating the load intensities, the load intensity w1 has been resolved in two directions, one parallel to axis of member and another normal to it. After computation of the maximum moment, a suitable section of the bamboo struts is considered and the sectional properties (I, Z) of the section are calculated. Similarly, the top horizontal chord of the structure is designed. Spliced sections of bamboo are used. Again, the design of the member is governed by the slenderness ratio criteria.

2.9 DESIGN OF JOINTS

The joints for the base of the columns are designed to transfer forces and moments to the base plate and the footing. The joints are designed with clamps on either side tightened to hold the bamboo strut. The base joints are designed to make use of the shear and friction bearing capacity of the bamboo strut. Further, the various joints are connected to the base plate and connected with each other through welding. The formula used for calculating the weld size for the base plate is as follows:

$$f_e = \sqrt{(f_a^2 + 3q^2)} \leq f_u/((\sqrt{3})\gamma_{mw}) \quad \text{... (2.10)}$$

Further, apart from the joints at the base, the joints on top of the column and at the roof are designed to be pin joints. Bamboo struts at the top of the column are connected together using a gusset plate and then the gusset plate is connected to the inclined members using I-bolts joints.

Figure 2.4 I-bolt joint

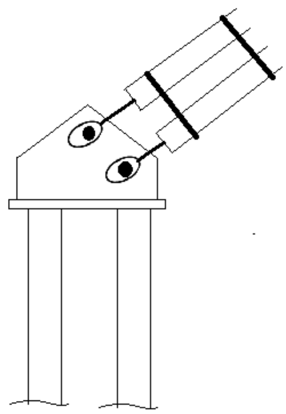


Figure 2.5 Joint connection with I-bolt joint and gusset plate

2.10 COMPARISON OF PITCHED AND ARCHED ROOF

Previous work has also been carried in the same field (Korde, 2012). Analysis and design was carried out on such structural frame of Bamboo structure with an arched roof.

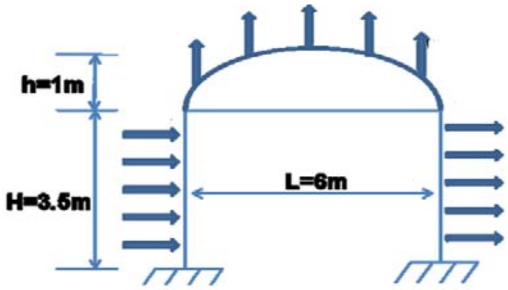


Figure 2.6 Arched-roof Bamboo shed

However, the forces are much higher in the case of arched roof as compared to that of the present analysis with a pitched roof. The comparison of the forces for a bamboo frame of 6m span is given in Table 2.1.

TABLE 2.1 Comparison of design forces in Arched Roof and Pitched Roof Frame

	Tensile (KN)		**Moment (KNm)**		**Horizontal (KN)**	
	Arch	Pitched	Arch	Pitched	Arch	Pitched
Case 1						
Wind normal, inside pressure	31.81	14.78	25.37	19.2	18.85	18.92
Case 2						
Wind normal, inside suction	3.98	-8.25	29.43	16.67	24.64	19.47
Case 3						
Wind along, inside pressure	27.83	23.09	12.18	8.49	17.4	14.91
Case 4						
Wind along, inside suction	0	0	20.3	1.49	2.9	2.48

It can be seen that the forces and moments in the pitched-roof frame are less than those in the arched-roof frame. Hence, the pitched roof structure is economical and better than the arched-roof structure.

The complete design of two bamboo sheds has been manually done. The plan area for the two buildings was taken as 25m×6m and 25m×8m. The total height of the two buildings has been considered as 5m (3m column height and 2m pitched roof height) and 5.5m (3m column height and 2.5m pitched roof height) respectively. The frame spacing has been taken as 5m for both the buildings.

3.1 RESULTS FOR BUILDING A (25M×6M×4M) :

3.1.1 Forces in Column

The summary of forces at the bottom of column for the four different wind conditions as computed for building A is displayed in Table 3.1:

TABLE 3.1 Summary of forces at base of column

S.No.	Wind Case	Tensile Force (KN)	Moment (KN-m)	Horizontal Force (KN)
1	Wind Normal to ridge, inside suction	-3.25	16.67	19.47
2	Wind Normal to ridge, inside pressure	14.28	19.2	18.92
3	Wind parallel to ridge, inside suction	0	1.49	2.48
4	Wind parallel to ridge, inside pressure	23.09	8.49	14.91

3.1.2 Design forces in columns:

Using Table 3.1, design forces in columns have been calculated for two different cases.

TABLE 3.2 Summary of design forces in column

S.No.	Load Combination	Bending Moment (KN-m)	Axial Force (KN)
1	Dead Load + Wind Case 1	16.67	18.25 (C)
2	Dead Load + Wind Case 2	19.2	0.22 (C)
3	Dead Load + Wind Case 3	1.49	15 (C)
4	Dead Load + Wind Case 4	8.49	8.09 (T)

3.1.3 Design of columns of building A:

Based on the design forces on the columns and the allowable stress for bamboo, the columns have been designed. Here, the concentric circles represent the bamboo struts. For example, Figure 3.1 shows that a section of 400mm×400mm consisting of six bamboo struts is suitable for the column.

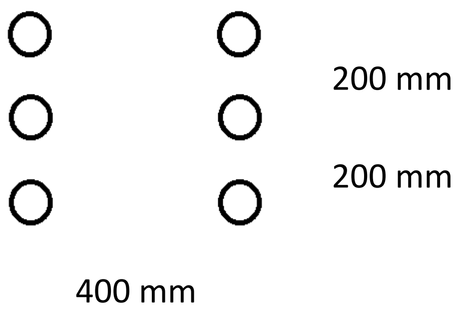


Figure 3.1 Cross sections of column component of building A

A similar column on the same lines has been constructed at IIT Delhi with 4 bamboo struts. Figure 3.2 shows a sample column constructed at IIT Delhi and then tested at Trinity College, Dublin, Ireland.

Figure 3.2 Sample column for testing constructed using 4 bamboo struts

3.1.4 Design of Base Plate for Building A

The base plate for Building A is designed for 6 bamboo strut columns. The bamboo struts are further connected with each other with the use of gusset plates. Further the joints are welded to each other. The various joints of bamboo struts are welded together and the calculated weld size is 8 mm.

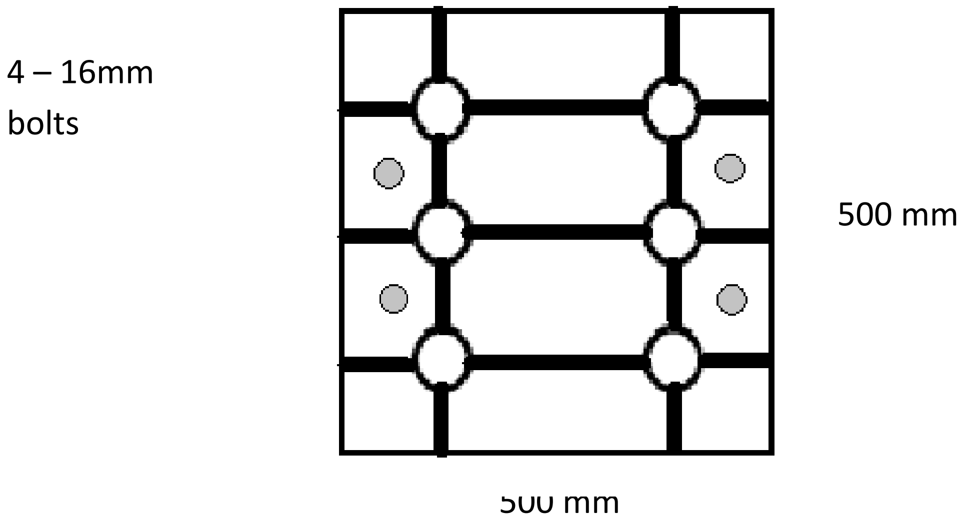


Figure 3.3 Base plate of column for building A

3.1.4 Design of Foundation for Building A

The foundation has been designed as isolated footings of reinforced concrete (RC). Usual design principles followed for footing design (considering the bending moment, one-way shear and two- way shear) have been used. The foundation layout plan for the whole building is in Figure 3.3.

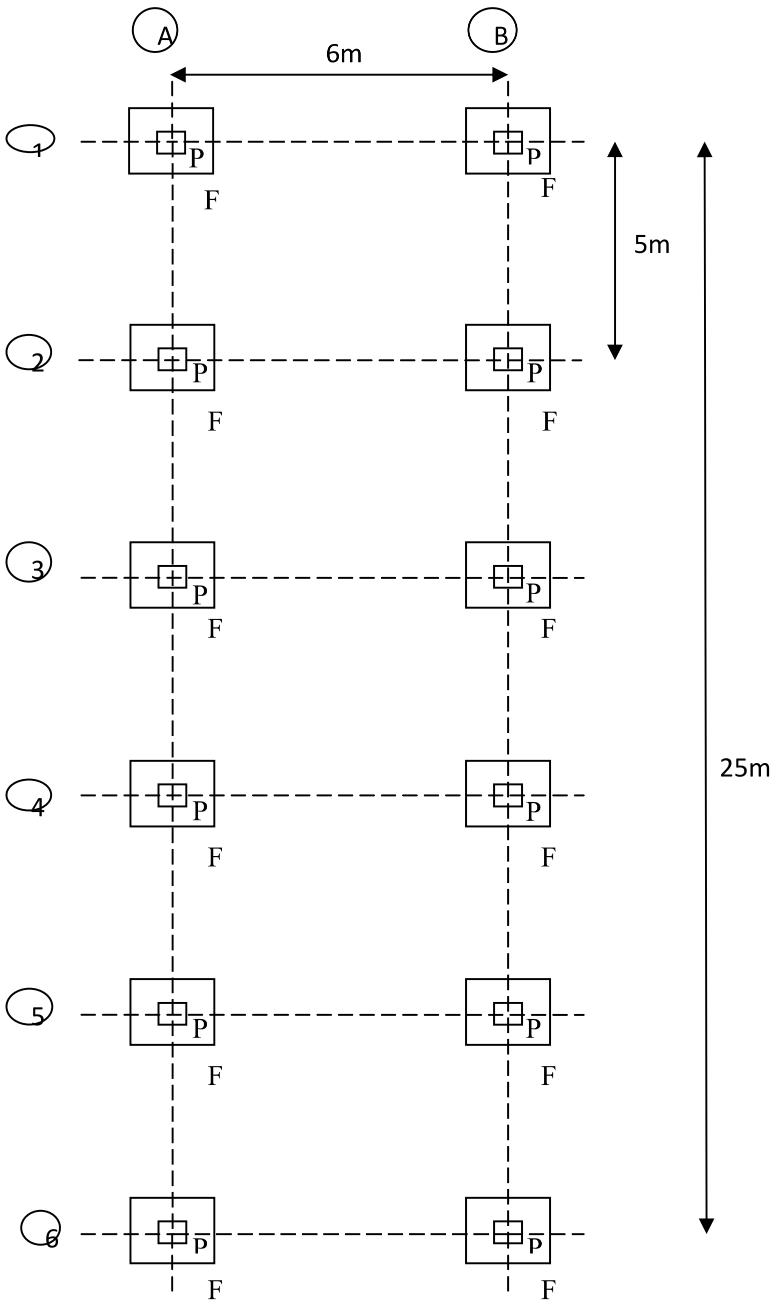


Figure 3.4 Foundation Layout Plan for Building A

Figure 3.5 and Figure 3.6 shows the Foundation Details in plan for the footing and the pedestal with the details of the reinforcement also given.

2

750 mm

1

500 mm

1500 mm

750 mm

500 mm

750 mm

750 mm

1500 mm

Figure 3.5 Foundation Details for Building A in Plan

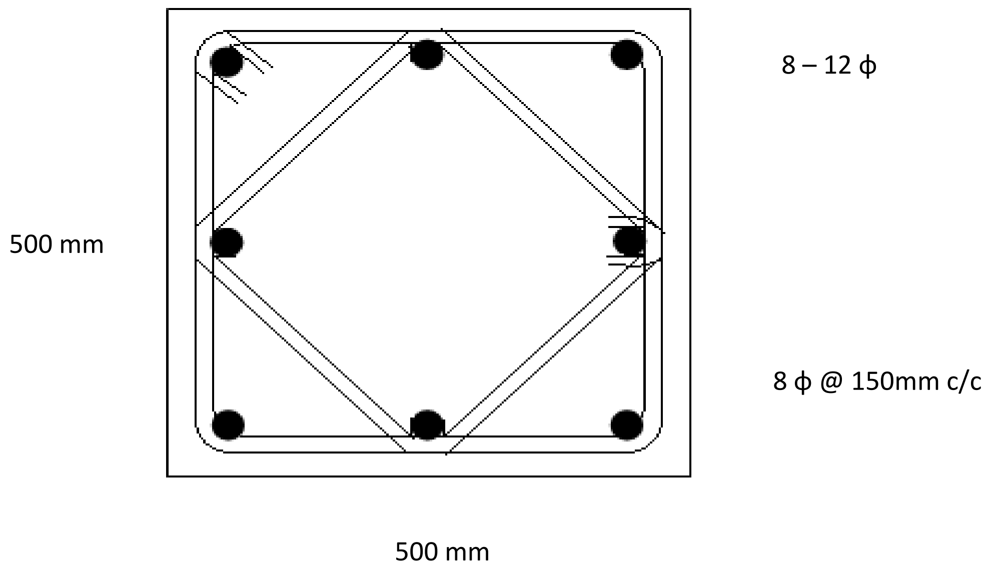


Figure 3.6 Reinforcement Details for Pedestal of Building A in Plan

Figure 3.7 gives the reinforcement details of the foundation in elevation.

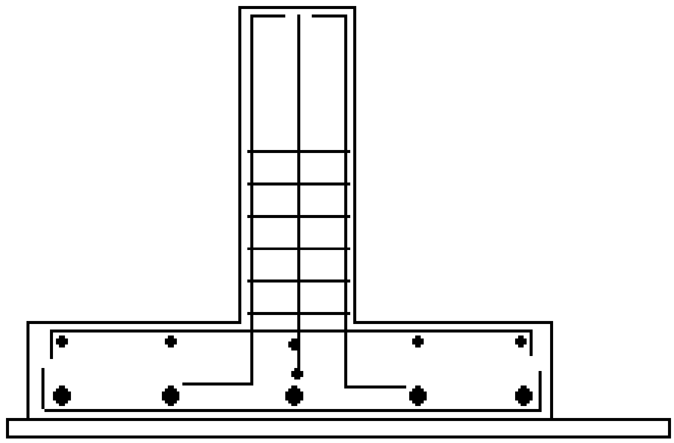


Figure 3.7 Foundation details of Building A in Elevation

Figure 3.8 shows the bolts designed to connect the base plate to the foundation. 4-16mm bolts are to be used with the length of around 560mm in the pedestal.

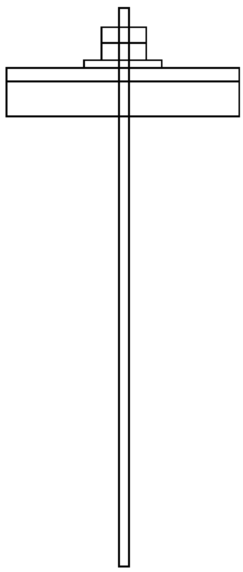


Figure 3.8 Details of Bolt for Pedestal of Building A

3.1.5 Design of Inclined & Top members for Building A

For the inclined members, the bamboo struts are tied by stirrups at a regular spacing of 500mm in order to limit the local slenderness ratio to 80, as mentioned earlier. The inclined members constitute of 4 bamboo struts each at a distance of 300mm. Similarly, the top horizontal chord of the structure is designed. Spliced sections of bamboo are used.

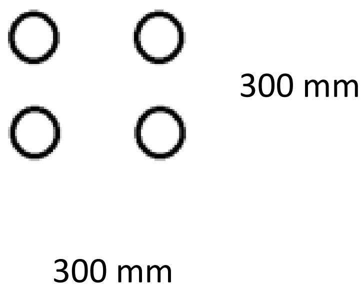


Figure 3.9 Cross section of inclined member of Building A

3.1.6 Design of joints for Building A

Apart from the I-bolt joints discussed for the pin joint connections, the joints at the base are designed with clamps on either side tightened to hold the bamboo strut. The base joints are designed to make use of the shear and friction bearing capacity of the bamboo strut.

Figure 3.10 Joints connecting base of column and base plate

3.2 RESULTS FOR BUILDING B (25M×8M×4.5M) :

The results for Building B include the forces in the columns and the design of column and the base plate. These are just some preliminary calculations and further designs for the structure have been carried out for the bamboo frame with 6m span.

3.2.1 Forces in Column

The summary of forces at the bottom of column for the four different wind conditions as computed for building B is displayed in Table 3.3 as follows:

TABLE 3.3 Summary of forces at base of column

S.No.	Wind Case	Tensile Force (KN)	Moment (KN-m)	Horizontal Force (KN)
1	Wind Normal to ridge, inside suction	-5.38	15.59	19.11
2	Wind Normal to ridge, inside pressure	19.8	18.01	18.53
3	Wind parallel to ridge, inside suction	0	1.49	2.48
4	Wind parallel to ridge, inside pressure	30.79	8.49	14.91

3.2.2 Design forces in columns:

Using Table 3.4, design forces in columns have been calculated for two different cases.

TABLE 3.4 Summary of design forces in column

S.No.	Load Combination	Bending Moment (KN-m)	Axial Force (KN)
1	Dead Load + Wind Case 1	16.67	18.25 (C)
2	Dead Load + Wind Case 2	19.2	0.22 (C)
3	Dead Load + Wind Case 3	1.49	15 (C)
4	Dead Load + Wind Case 4	8.49	8.09 (T)

3.2.3 Cross - sections of different components of building B:

Based on the design forces on the columns and the allowable stress for bamboo, the columns have been designed. Here, the concentric circles represent the bamboo struts. For example, Figure 3.3 shows that a section of 400mm×400mm consisting of ten bamboo struts is suitable for the column.

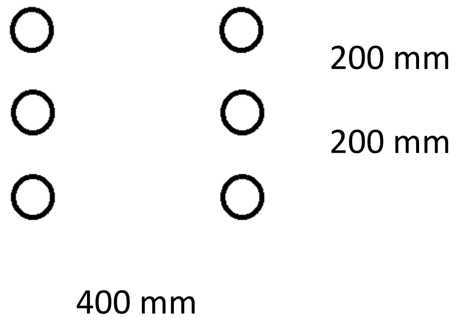


Figure 3.11 Cross sections of column of building B

3.2.4 Design of Base Plate for Building B

The base plate for Building A is designed for 6 bamboo strut columns. The bamboo struts are further connected with each other with the use of gusset plates. Further the joints are welded to each other. The various joints of bamboo struts are welded together and the calculated weld size is 8 mm.

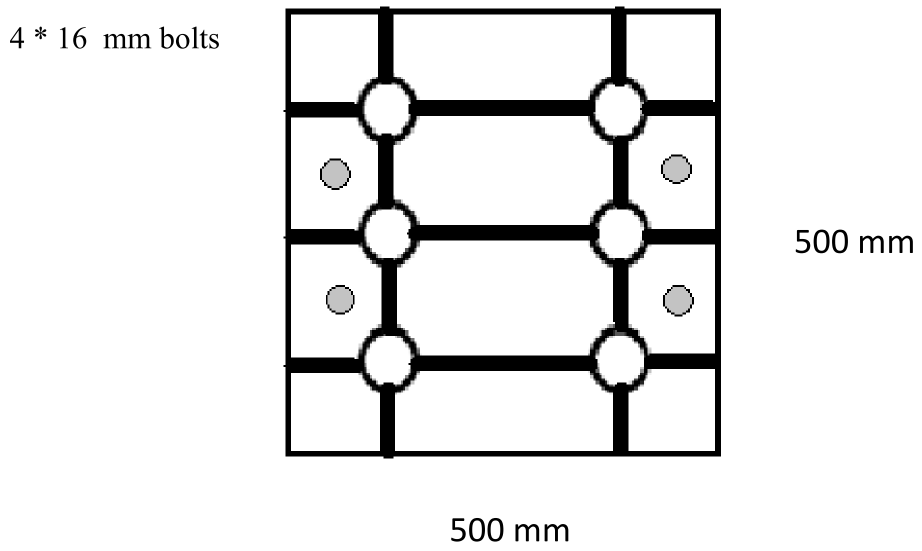


Figure 3.12 Base plate of column for building B

Chapter 4 ANALYSIS VALIDATION USING STAAD

The manual analysis carried out for the force and moments of the structural bamboo frame is validated by analysing the frame using STAAD Pro. The frame dimensions have been taken to be 4m in height (with 3m column height and 1m inclined member height) and a span of 6m. The supports at the base of the columns are fixed joints. The material specified for the analysis is steel as the results would be similar and the assumptions that bamboo behaves in an elastic manner as steel holds good.

The results of the STAAD analysis are in accordance with the manual analysis. The resultant reactions at the base of the columns have been found to be similar to that of the manual results. The reactions found out have been shown in Table 4.1.

TABLE 4.1 Comparison of design forces in column

Wind along, inside pressure

Column 1					
Tensile		**Moment**		**Horizontal**	
Manual	STAAD	Manual	STAAD	Manual	STAAD
23.09	21.014	-8.49	-6.651	-14.91	-12.614
Column 2					
Tensile		**Moment**		**Horizontal**	
Manual	STAAD	Manual	STAAD	Manual	STAAD
23.09	21.014	8.49	6.651	14.91	12.614

The construction of the structural frame for a bamboo shed of a span of 6m is based on the designs and analysis done. After the design of all the components of the structure: foundation, base plate, columns, inclined and top members, joints; the construction of the structural frame can be carried out. Figure 5.1 shows a sketch of the constructed bamboo frame.

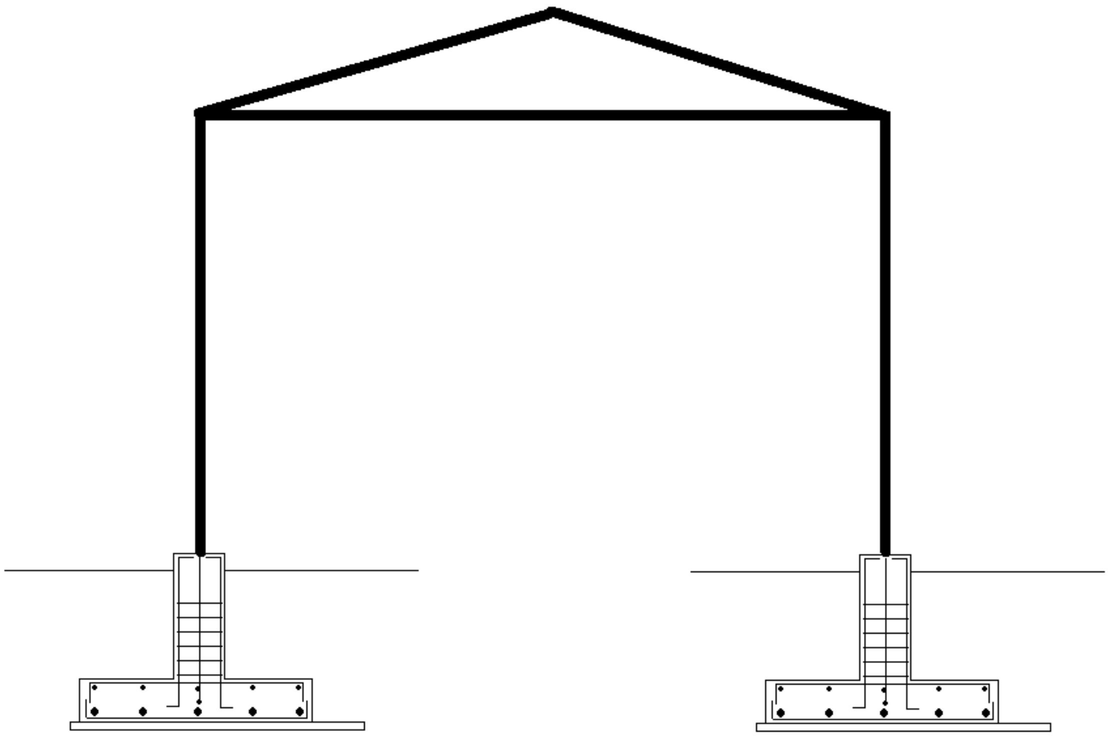


Figure 5.1 Sketch for Construction of Bamboo Frame

Apart from the tensile and compressive capacity of bamboo, the friction bearing capacity of the bamboo is another important property to be considered during the construction of bamboo shed structures. Hence, tests were carried out with bamboo samples and various friction agents to calculate the friction capacity of bamboo elements. The test was carried out on the Universal Testing Machine in the Concrete Laboratory.

6.1 TEST 1: PLAIN BAMBOO SAMPLE

Figure 6.1 Simple Bamboo sample

Figure 6.2 Friction Joint of Bamboo sample

Figure 6.3 Testing of Simple Bamboo sample

Figure 6.4 Failure of Simple Bamboo sample

6.2 TEST 2: TYRE-TUBE RUBBER BAMBOO SAMPLE

Figure 6.5 Failure of Tube-Tyre Rubber Bamboo sample

6.3 TEST 3: ARALDITE BAMBOO SAMPLE

Figure 6.6 Friction Joint of Araldite Bamboo sample

Figure 6.7 Testing of Araldite Bamboo sample

Figure 6.8 Failure of Araldite Bamboo sample

6.4 TEST RESULTS

External diameter for all the samples = 35 mm

TABLE 6.1 Load taken by the test samples

S.No.	Sample	Load taken (kg)
1	Plain Bamboo Sample	800
2	Tube tyre on Bamboo Sample	1000
3	Araldite Bamboo Sample	1500

It can be concluded from the test results, the friction capacity of the bamboo increases with various agents such as tube tyre rubber and araldite. The increase in the load taken is around 200 kg for tyre tube rubber with respect to plain bamboo sample. The increase in the load with use of araldite is about 700 kg with respect to the plain bamboo sample.

After the previous tests, more tests have been carried out wherein the rubber coating was in contact with bamboo with the help of araldite. The results of the tests are given in Table 4.2 (Shaw, 2012) . However, further tests need to be carried out to achieve accurate and reliable results.

TABLE 6.2 Load taken by the new test samples

Test Number	Load (Kg)
1	1600
2	1200

Chapter 7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

This project has covered the analysis and the conceptual design of a typical bamboo based shed structure under various loads and their combinations. Wind loads have been considered as per IS 875 part 3 and the structure analyzed in a simple fashion, by considering the behavior of a typical frame in the transverse direction. The roof is supported by bamboo pitched roof structure and the columns are designed as battened bamboo members. The proposed structure aims to provide an alternative environment friendly construction for a steel industrial 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 better and more economically viable than the arched roof structure and thus, several times cheaper and eco friendly.

The design developed for the bamboo shed structure gives satisfactory results for the computation of forces and cross-sections of all the components. The design of the various components have been carried out in accordance with the IS codes and the experimental results. Further, the manual analysis has been verified with analysis using STAAD Pro. Also, the experimental tests for the friction capacity joints have been carried out for various bamboo samples. From the results, it has been verified that the joints designed for the structure are safe and feasible.

The culmination of the project has resulted in the complete design detail for the bamboo shed frame structure with detailed design of the foundation, base plate, columns, inclined and top members and joints.

7.2 RECOMMENDATIONS FOR FUTURE WORK

Some of the recommendations for future work in the project are as follows:

1. The joints for the bamboo structure can be designed to be more strong and effective. New design for stronger and lighter joints for connecting the pitched roof structure and the columns of the bamboo shed structure can be designed.
2. The cost of construction of the bamboo frame has scope of reduction. With proper substitute materials and further optimization of the design, it would result in decrease of the cost for the structure. Also, as stated the improvement in the design of joints would lead to a great decrease in the cost of the structure.
3. The construction of the whole bamboo shed should be carried out with the calculations and design for the walls and the roof of the shed.
4. The design of the bamboo shed can be further optimized by calculating the most optimum span length which results in the minimum forces due to wind load and dead load.

7.3 SOURCES OF ERROR

The calculations also involve some approximations which might lead to some error in the computation of the forces and the critical sections. Some of these approximations are:

1. Since no standard codes of practice are available for bamboo, steel code (IS 800, 1984) has been used wherever required, which might have lead to some error in the design.
2. While computing the force on the bamboo structure, the joints have been assumed to be pin joints with negligible friction. This approximation might have lead to some error in calculation of wind loads and moments.

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APPENDIX

CALCULATIONS FOR BUILDING A

Total length	25m
Spacing	5m
Bay Width	6m
Height (max)	3+2=5m
Roof slope	18.5 degrees
Height above ground	3m

Velocity Vb =		47	m/s	
k1		1		Class A structure
k2		1		Terrain category 2 structure
k3		1		
Vz		47	m/s	
Pz		1325.4	N/m2	
Cpi	0.7	-0.7		

External Pressure Coefiicients for h/w = 0.5

	Wind angle	
portion of roof	0	90
E	0	-0.7
F	0	-0.6
G	-0.4	-0.7
H	-0.4	-0.6

External Pressure Coefiicients for h/w = 0.5 & l/w= 4.17

	Wind angle	
	0	90
A	0.7	-0.5
B	-0.25	-0.5
C	-0.6	0.7
D	-0.6	-0.1

CALCULATIONS FOR BUILDING B

Total length	25m
Spacing	5m
Bay Width	8m
Height (max)	3+2.5=5.5m
Roof slope	32 degrees
Height above ground	3m

Velocity Vb = 47 m/s

k1		1	Class A structure
k2		1	Terrain category 2 structure
k3		1	
Vz		47	m/s
Pz		1325.4	N/m2
Cpi	0.7	-0.7	

External Pressure Coefiicients for h/w <= 0.5

portion of roof	Wind angle 0	90
E	0	-0.7
F	0	-0.6
G	-0.4	-0.7
H	-0.4	-0.6

Ext. Pressure Coeff for h/w <= 0.5 & l/w= 3.125

	Wind angle 0	90
A	0.7	-0.5
B	-0.25	-0.5
C	-0.6	0.7
D	-0.6	-0.1

	a	roof1	roof2	b
Case 1	0	0.7	1.1	0.95
	0	4.6375	7.2875	6.29375
Case 2	1.4	-0.7	-0.3	-0.45
	9.275	-4.6375	-1.9875	-2.98125
Case 3	-1.2	-1.4	-1.4	-1.2
	-7.95	-9.275	-9.275	-7.95

Wind case		Column 1			Column 2	
	Tensile	Moment	Horizontal	Tensile	Moment	Horizontal
Case 1	19.8	8.62	2.88	19.8	18.01	18.53
Wind normal, inside pressure						
Case 2	-11.01	15.59	19.11	-11.01	1.81	-3.87
Wind normal, inside suction						
Case 3	30.79	-8.49	-14.91	30.79	8.49	14.91
Wind along, inside pressure				.		
Case 4	0	1.49	2.48	0	-1.49	-2.48
Wind along, inside suction						

FORCES ON COLUMNS FOR BUILDING A & B

Wind case	Column 1						Column 2					
	Tensile		Moment		Horizontal		Tensile		Moment		Horizontal	
	6m	8m	6m	8m	6m	8m	6m	8m	6m	8m	6m	8m
Case 1 Wind normal, inside pressure	14.78	19.8	9.81	8.62	3.27	2.88	14.78	19.8	19.2	18	18.92	18.53
Case 2 Wind normal, inside suction	-8.25	-11	16.67	15.59	19.47	19.1	-8.25	-11	2.89	1.81	-3.51	-3.87
Case 3 Wind along, inside pressure	23.09	30.8	-8.49	-8.49	-14.91	-14.9	23.09	30.8	8.49	8.49	14.91	14.91
Case 4 Wind along, inside suction	0	0	1.49	1.49	2.48	2.48	0	0	-1.49	-1.5	-2.48	-2.48

CALCULATIONS FOR ALLOWABLE STRESS IN BAMBOO

COMPRESSIVE

Yield stress, fy	55	Mpa	15.71	S.F. = 3.5
Elastic Modulus	14	Gpa		
slenderness ratio	80			
fcc	21.56788	Mpa		
n	1.4			
permissible stress	11.02736	Mpa		

TENSILE

Yield stress, fy	120	Mpa	34.29	S.F. = 3.5
Elastic Modulus	14	Gpa		
slenderness ratio	80			
fcc	21.6	Mpa		
n	1.4			
permissible stress	16	Mpa		

Bamboo with 40mm dia and 10mm wall thickness

Cross sectional area=	942	mm2
	9E-	m2

04

Permissible load=	10.3877 7	KN	(Compression)	Permissible load=	15	KN	(tension)

CALCULATIONS FOR BASE PLATE

l/2 =	225	mm
a =	175	mm
esu =	0.001091	
xul =	304.3478	
P=	8.1	KN
M=	19.2	KNm
fck =	30	N/mm2
b =	450	mm
xu =	10.72	mm

Check: xu < xul

T =	50.22	KN
A (bolts)=	230.175	mm2
	68509.09	

s	8	mm	A	14000	mm2
t	5.6	mm			
fu	410				
gamma	1.25		I	354214635	mm4
fwn	189.3709	n/mm2	y	250	mm
			z	1416858.5	mm3

fn	4.34	
	-7.6	
fq	1.07	
fe	7.86	n/mm2
	4.72	n/mm2

CALCULATIONS FOR FOUNDATION

P=	-23.09	size	1.5	1.5	0.3	area	2.25
							0.56
M=	-8.49					z	3
H=	14.91	depth	1.5				
soil							
gamma	18	d	0.24				
q all	180						

				17.2964			
q gross	207		sigma max	4			
q all				31.5791			
wind	252		sigma min	1			
P total	54.985						
			26.3421333				
M total	-4.017	M	3		V	28.63	
		x	0.55			0.31	
			6.76846438				
		Mu	9			14	
		Mu/bd		0.07833			0.03
		2	78.3387082	9	N/mm2	38.88	9

P=	-23.09	14.78						
						d'		
M=	8.49	-19.2	d=		1.2	=	60	
H=	14.91	18.92				D=	500	
		M30					0.12	60
		Fe 415						
			Mux	26.382	3.504			
			M/fbd					
			2	0.0206	0.003			
			Pu/fbd	-0.007	0.005			

				stirrup s	8mm	200 c/c
p/fck	0.005 375	0.15				
	628	8	10 mm			

bolts on pedestal

base plate = 12mm	12
grout thickness = 25mm	25

T=	68	development length/dia		35	56 0
P=	95				
		Total length =	655		