Mini Project Report on

SHED TYPE STRUCTURES – STEEL VS BAMBOO

Submitted By:-

Moti Baba

(2006CE10270)

Under supervision of

Dr. Suresh Bhalla

Department of Civil Engineering

Indian Institute of Technology, Delhi

May 2009

CERTIFICATE

"I do certify that this report explains the work carried out by me in the course CED310, Mini Project, under the overall supervision of Dr. Suresh Bhalla. The contents of the report including text, figures, tables 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."

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Date: May 4th, 2009

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This is to certify that the report submitted by Mr. Moti Baba describes the work carried out by him in the course CED-310 (Mini Project), under my overall supervision.

Dr. Suresh Bhalla

(Supervisor)

Date: May 4th, 2009

ACKNOWLEDGEMENT

I would like to express my sincere thanks and gratitude to Dr. Suresh Bhalla for his continuous and unfailing support, guidance and help, which have been invaluable during the course of this project. His knowledge, insight and constant motivation at each step of the project has been instrumental in its completion.

Moti Baba

ABSTRACT

The main objective of this project was the design of industrial buildings (shed type structures) using bamboo, evolve at a sound approach for developing design subroutines using MATLAB 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) has been adapted wherever necessary. Two industrial buildings of different dimensions have been designed, both manually and using the computer program to check the correctness of the program. Foundations for the two buildings have also been designed manually.

The program obtains the input data for the dimensions of the building etc. from the user and the output is in the form of design of sections required for the different components of the building. For the optimization of design, the program has been executed several times for different span lengths and a graphical plot has been obtained between the spacing of the columns and the total quantity of the bamboo required for the building (which is directly proportional to the cost of the structure). It is found that for a 25m×6m×4.5m bamboo industrial building, 4.16m is the optimum frame spacing using arch and bambcrete column components.

Table Of Contents

List of Figures

List of Tables

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 AN INDUSTRIAL BUILDING

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

    i.   Selection of Roofing and wall material

   ii.   Selection of bay width

  iii.   Selection of structural framing system

   iv.   Roof trusses

    v.   Purlins, girts 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.

1.2.5 Spacing of Purlin

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.

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

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 + snow loads

3. 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.
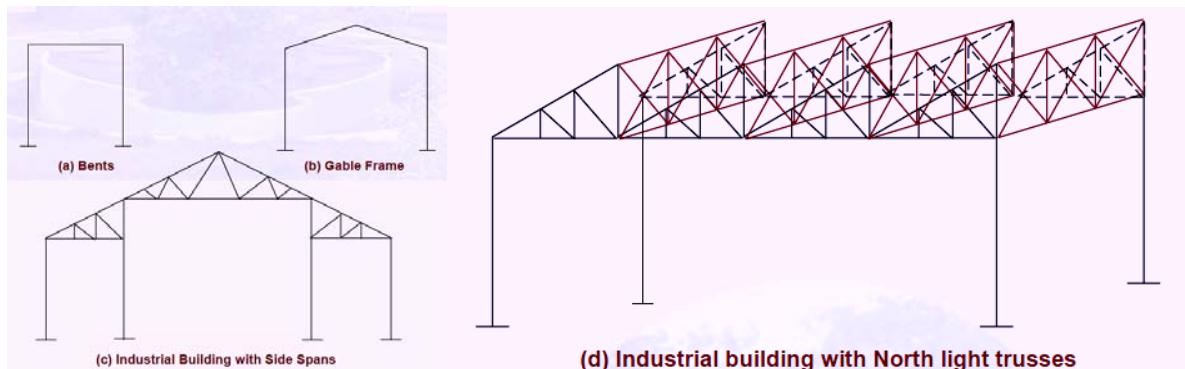
Figure 1.1 Different Components of an Industrial Building

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 700 kg/m^3, results in much higher strength to weight ratio as compared to steel (density = 7800 kg/m^3) 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×10m

in plan and 6.7m 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, of the type shown in Fig. 2.2, where

bamboo elements serve as struts and ferrocement bands as battens. The steel roof truss shall be

replaced by bamboo tied arch of the type shown in Fig. 2.3. The arch has a crown height of 1.7m

and span of 10m. Both the columns and the bamboo arch are classified as 'bambcrete' elements,

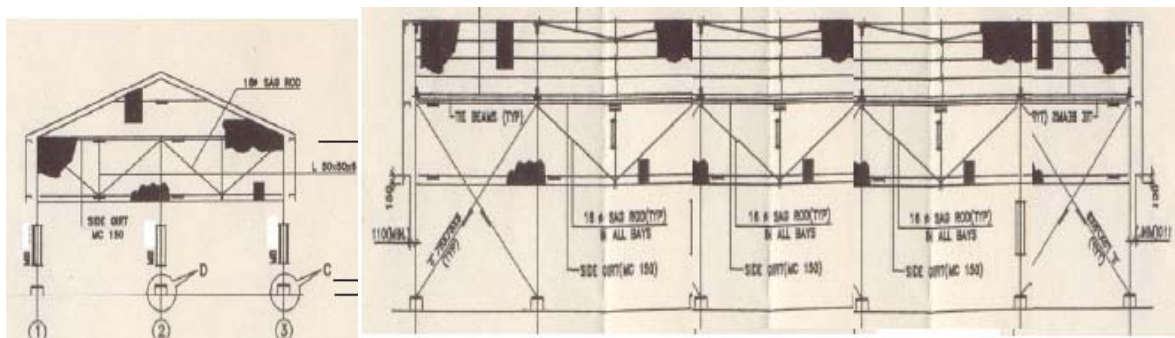to signify the combination of bamboo with concrete.

Figure 2.1 A conventional shed structure made of steel

Figure 2.2 A typical Bambcrete Column   **Figure 2.3 A typical Bambcrete Arch**

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). 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 four is considered in the proposed approach. Hence, the allowable stress in tension works out to be 30 MPa. For compression, taking the factor of safety as well as elastic critical load analysis, the allowable compressive stress works out to be 13 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 0.15kN/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. 2.4 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

Fig. 2.5 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). The wind force acting on the walls induces moment on the columns while that on the roof simply result in axial force.
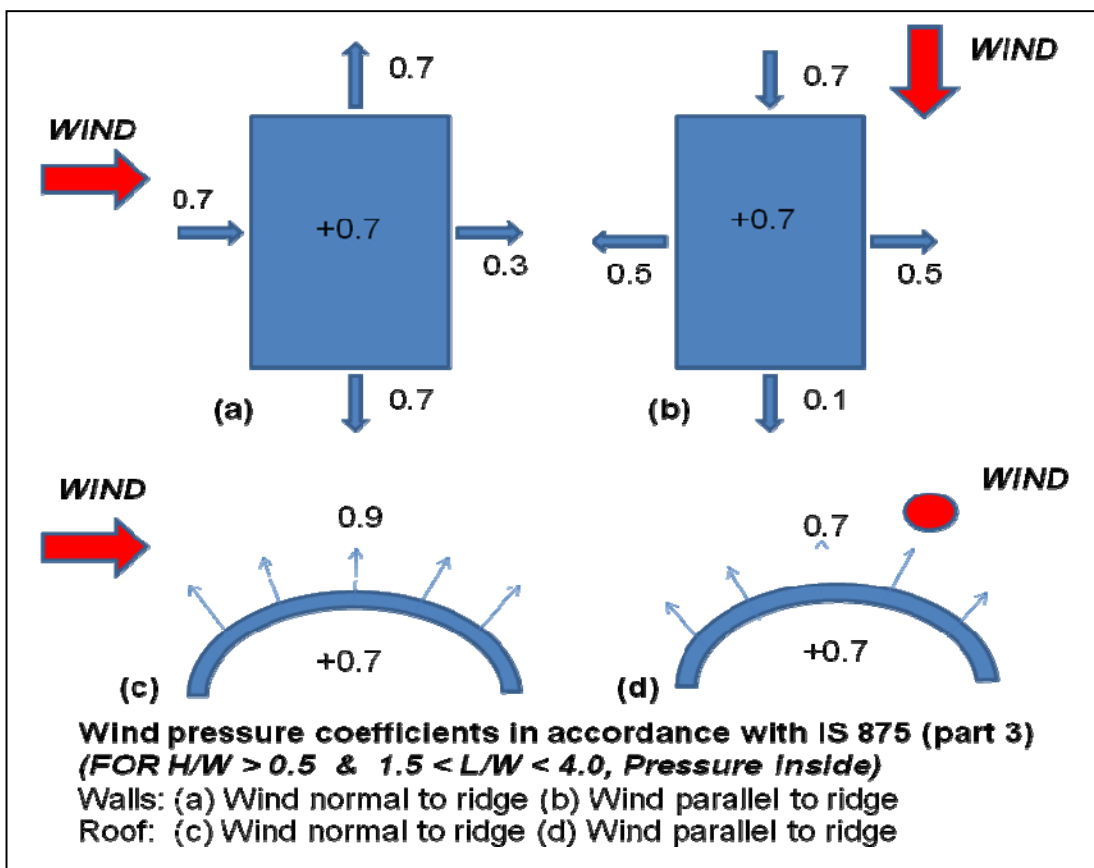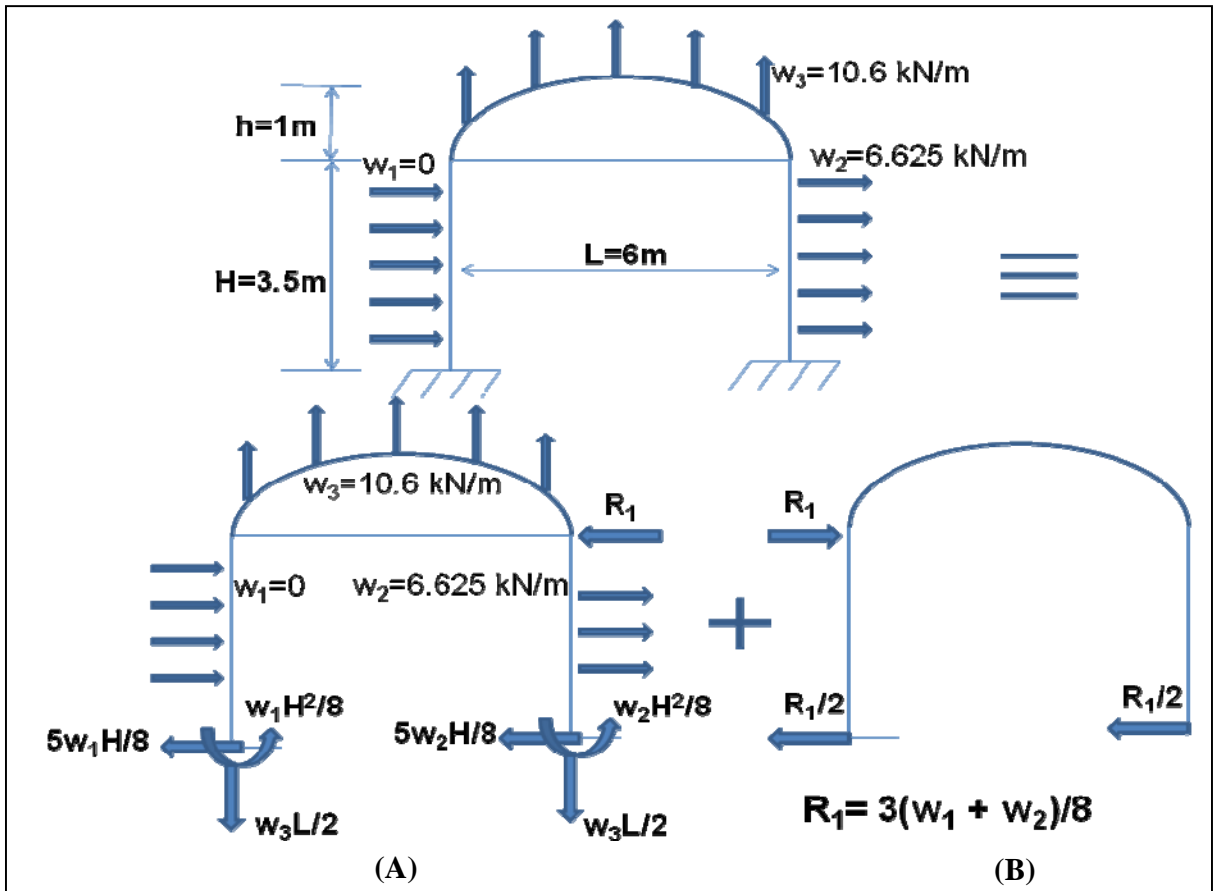

Figure 2.4

Figure 2.5 Analysis of a typical Transverse frame
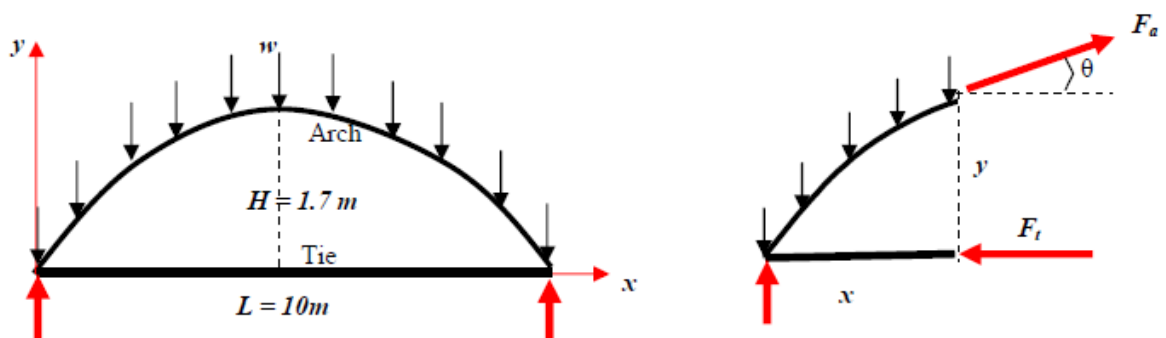
2.5 DESIGN OF BAMBOO TIED ARCH

Figure 2.6 Idealized Model of Bamboo tied Arch.

Fig. 2.6 shows the idealized model of the bamboo tied arch. The arch is assumed to follow a parabolic profile as given by

$$y = 4H(Lx - x^2)/L^2$$

`   ...2.1

where H is the crown height and L the span of the arch. In general, under a uniformly distributed load w (acting downwards), the force in the arch (Fa) and the tie element (Ft) can be derived, using equilibrium of forces, as

$$F_a = w\sqrt{L^4 + 16\,H^2(L-2x)^2}\,/8H \quad (C)$$

...2.2

$$F_t = wL^2/8H \quad (T)$$

...2.3

2.6 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 80 for all the compression members for bamboo). The local slenderness ratio is also kept limited to 80 by having ferrocement bands at a spacing of 1200mm everywhere.

2.7 DESIGN OF SIDE BRACINGS

X type side bracings have been provided at the two end bays of the building. For the design of side bracings, the total force acting on the face perpendicular to the ridge is calculated. The force

is divided equally among all the corners of the bracings at the two end bays and the force acting in the tension member of the bracing is calculated using equilibrium of forces as shown in Fig. 2.7. The force acting in the compression member is neglected during the computation of the tensile force, which leads to a conservative design. The design of the bracing may ultimately be governed by the strength criteria or the slenderness ratio. Here the check for slenderness ratio is to be done for both in-plane and out-of-plane buckling with different effective length.

$$F_b = F \times \sqrt{H^2 + L^2} / (8L)$$

[Tensile]
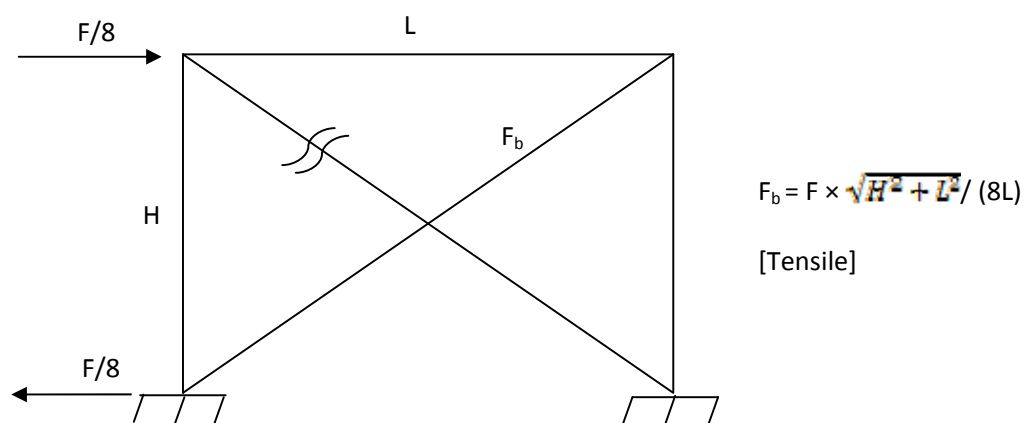
Figure 2.7 Design of Side Bracings

(side view of end span of the building)

2.8 DESIGN OF TOP AND BOTTOM CHORD MEMBER

The design of bottom chord members is also similar to the design of bracings. The total force acting on the face of the building (perpendicular to the ridge) is calculated and approximately half of the force is supposed to act at the centre of the bottom bracing. Again, the members carrying the compressive force are neglected and the force acting on the tension members is

calculated through simple force equilibrium. Again, the design of the member is governed by the slenderness ratio criteria. The section thus obtained for the Bottom Chord member is also applied to the Top Chord member as it is.
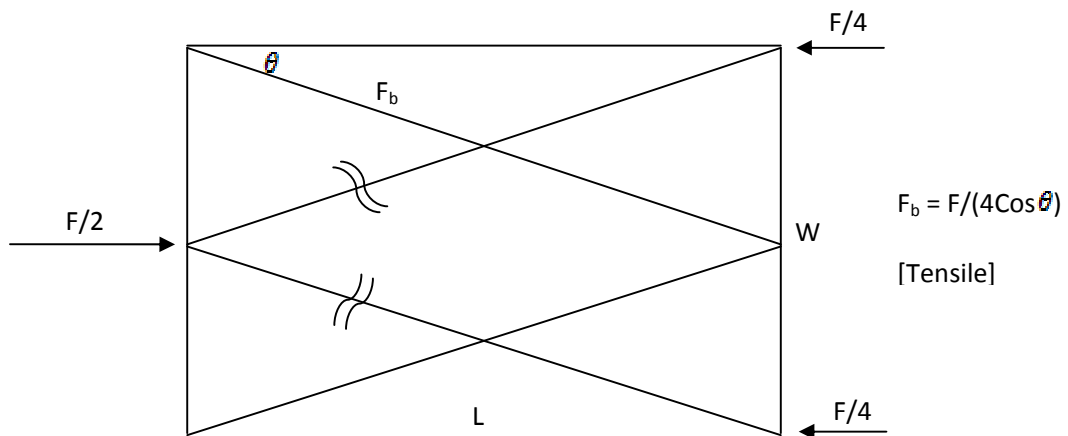
Figure 2.8 Design of Bottom Chord Member

(Top view of end span of the building)

2.9 DESIGN OF PURLINS

For the design of purlins, biaxial moments are to be considered. 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 purlin and another normal to it. The maximum bending moment in the two directions is calculated using the formula:

$$M = wL^2/10 \hspace{3cm} \textbf{...2.4}$$

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. The section taken is considered ok for the design only if $\sigma_r \leq \sigma_{all}$.

where

$$\sigma_r = \frac{M_x}{Z_x} + \frac{M_y}{Z_y} \qquad \qquad ...2.5$$

σ_{all} = Allowable stress

= 13 N/mm^2 (lower of the compressive and tensile stress)

The section selected is also checked for the slenderness ratio (l/r should be less than 200).

In all the above cases, the bamboo struts are tied by concrete bands at a regular spacing of 1200mm in order to limit the local slenderness ratio to 80, as mentioned earlier.

2.10 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 complete design of two industrial buildings has been manually done. The plan area for the two buildings was taken as 25m×10m and 25m×6m. The total height of the two buildings has been considered as 6.7m (5m column height and 1.7m crown height) and 4.5m (3.5m column height and 1m crown height) respectively. The frame spacing has been taken as 5m for both the buildings.

3.1 RESULTS FOR BUILDING A (25M×6M×4.5M) :

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	3.976	29.428	24.644
2	Wind Normal to ridge, inside pressure	31.81	25.369	18.846

3	Wind parallel to ridge, inside suction	0	20.300	2.899
4	Wind parallel to ridge, inside pressure	27.833	12.177	17.396

3.1.2 Analysis of the arch-tie component:

The forces in the arch-tie component have been calculated for two different cases in Table 3.2.

Wind case 2 has been considered since it is the most critical case.

TABLE 3.2 Summary of forces in the arch-tie member

S.no	Load Combination	Force in Arch (kN)	Force in Tie (kN)
1	Dead loads + Wind loads (case 2)	52.208 (T)	43.439 (C)
2	Dead loads + Live loads	25.419 (C)	21.150 (T)

3.1.3 Design forces in columns:

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

TABLE 3.3 Summary of design forces in column

S.no	Load Combination	Bending Moment (kN-m)	Axial Force (kN)
1	Dead loads + Wind Case 1	29.428	1.133 (T)
2	Dead loads + Wind Case 2	25.369	28.967 (T)

3.1.4 Cross - sections of different components of building A:

After the execution of the MATLAB program, the following sections were considered suitable for the different components of building A.

Here, the concentric circles represent the bamboo struts. For example, Figure 3.1 (a) shows that a section of 100mm×100mm consisting of four bamboo struts is suitable for the arch member.
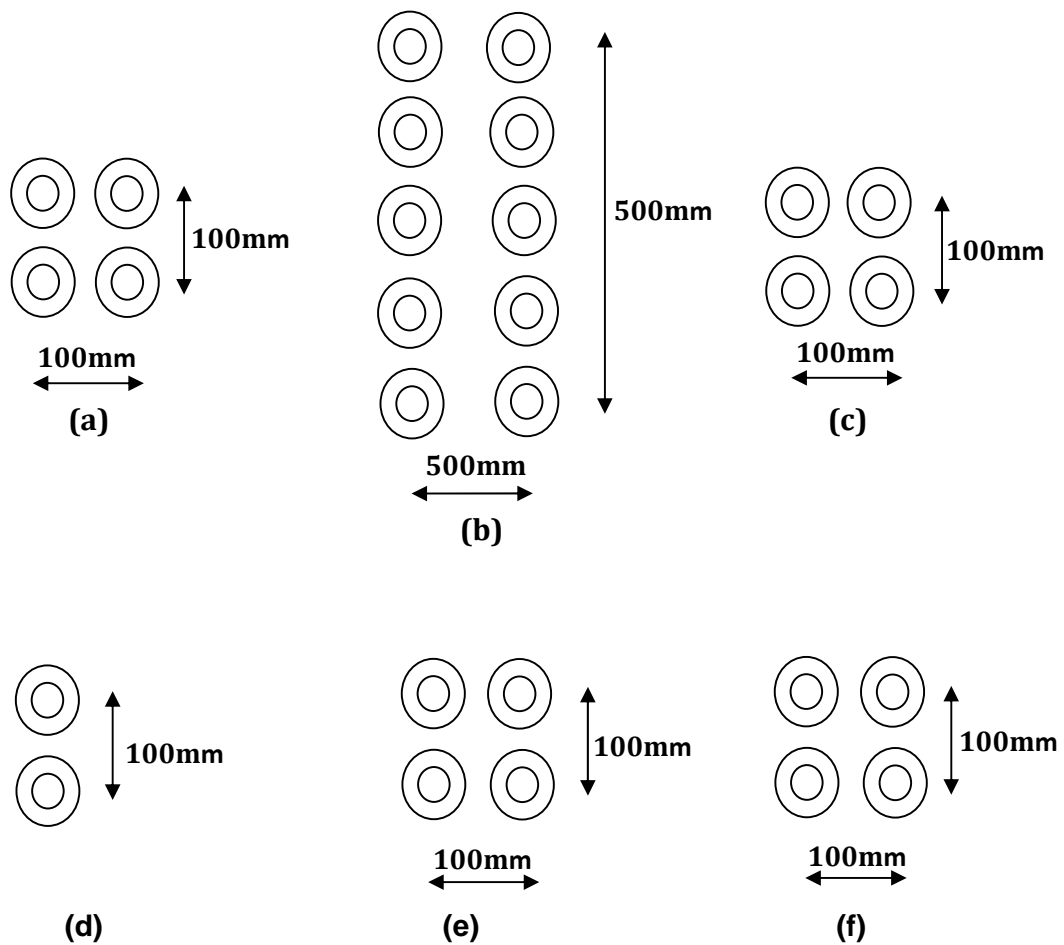

Figure 3.1 Cross sections of different components of building A

(a) Arch   (b) Column   (c) Tie
(d) Bottom/Top Chord member   (e) Side bracings   (f) Purlin

3.1.5 Foundation

After doing the calculations, it was determined that an isolated footing of size 2m×2m×.3m of RCC is safe for the structure. The reinforcement details for the footing have been shown in Figure 3.2.
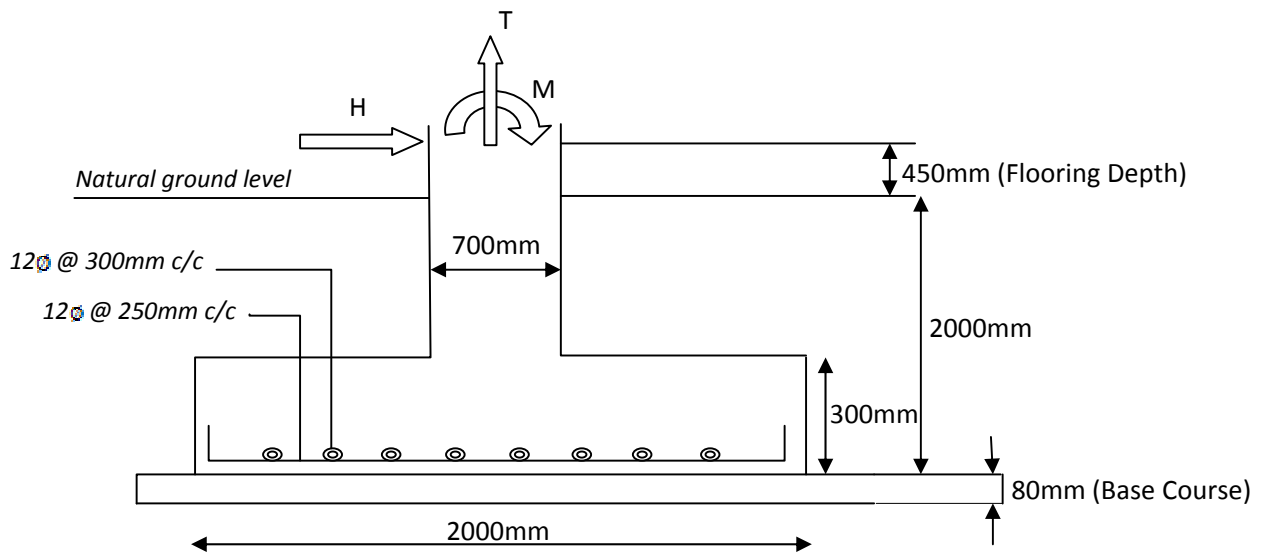

Figure 3.2 Details of the foundation for building A

3.2 RESULTS FOR BUILDING B (25M×10M×6.7M) :

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 3.4 as follows:

TABLE 3.4 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	6.627	60.057	35.206
2	Wind Normal to ridge, inside pressure	53.016	51.773	26.922
3	Wind parallel to ridge, inside suction	0	4.142	4.142
4	Wind parallel to ridge, inside pressure	46.389	24.851	24.851

3.2.2 Analysis of the arch-tie component:

The forces in the arch-tie component have been calculated for two different cases in Table 3.5. Wind case 2 has been considered since it is the most critical case.

TABLE 3.5 Summary of forces in the arch-tie member

S.no	Load Combination	Force in Arch (kN)	Force in Tie (kN)
1	Dead loads + Live loads	41.792 (C)	34.559 (T)
2	Dead loads + Wind loads	85.835 (T)	70.979 (C)

3.2.3 Design forces in columns:

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

TABLE 3.6 Summary of design forces in column

S.no	Load Combination	Bending Moment (kN-m)	Axial Force (kN)
1	Dead loads + Wind Case 1	60.057	1.575 (T)
2	Dead loads + Wind Case 2	51.773	47.964 (T)

3.2.4 Cross - sections of different components of building A:

After the execution of the MATLAB program, the following sections were considered suitable for the different components of building B.
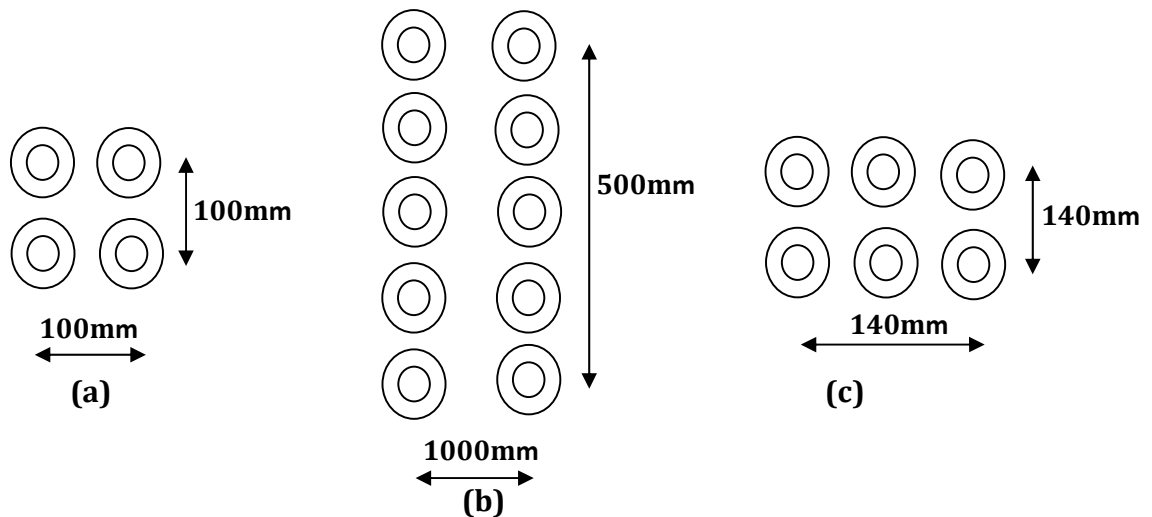

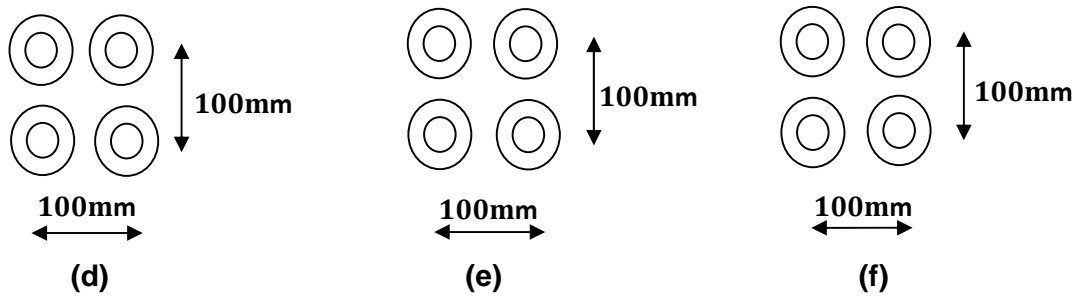**Figure 3.3 Cross sections of different components of building B**

Figure 3.3 Cross sections of different components of building B (contd.)

(a) **Arch**   (b) **Column**   (c) **Tie**
(d) **Bottom/Top Chord member**   (e) **Side bracings**   (f) **Purlin**

3.2.5 Foundation

After doing the calculations, it was determined that an isolated footing of size 2.5m×2.5m×.3m of RCC is safe for the structure. The reinforcement details for the footing have been shown in Figure 3.4.
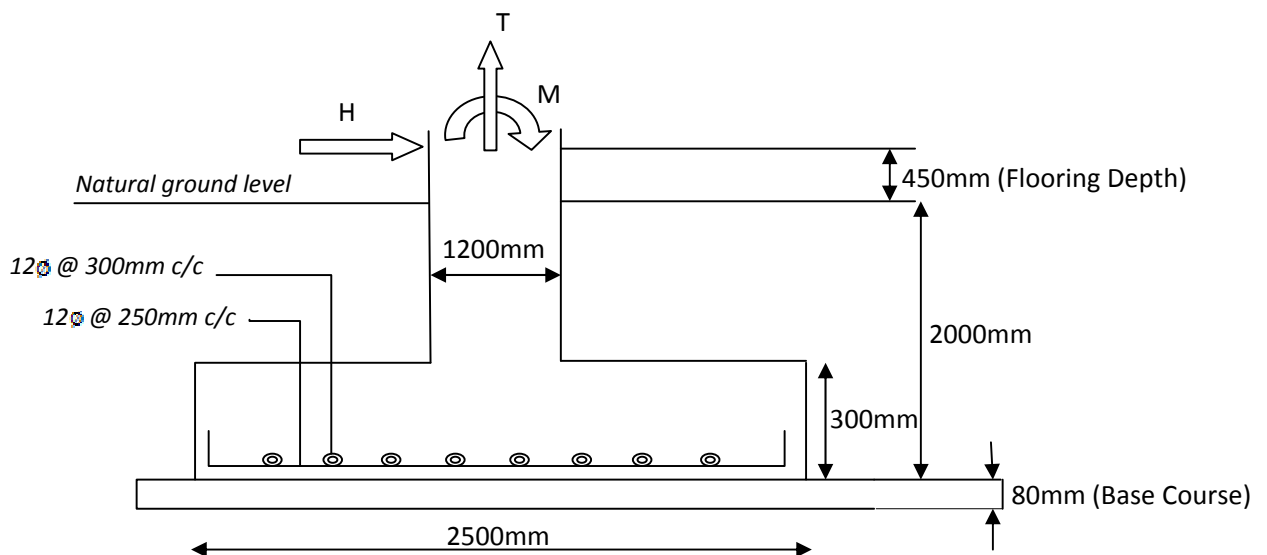

Figure 3.4 Details of the foundation for building B

3.3 OPTIMIZATION OF BUILDING 'A' AND 'B'

The optimization of Building A and B was carried out by finding out the total weight of bamboo required for the complete building. The design was carried out using the computer program for different frame spacings (e.g 5m initially) and the total weight of bamboo required was found out every time. The frame spacing which gave the minimum weight was selected as the most optimum spacing and the corresponding design as the most optimum design.

A graph has been plotted for the weight of bamboo for the entire building vs. the frame spacing of the building for both A and B. The minima of the curve represents the optimum frame spacing and hence the optimum design of the two buildings.

The optimization of building A and B has been done as an illustration to show the usefulness of the program as a time and money saver. As can be seen from Figure 3.5 and 3.6, a frame spacing of 25/6m (i.e. **having a total of six spans in the building**) gives the minimum weight of the building A and a frame spacing of 25/8m (i.e. **having a total of eight spans in the building)** gives the minimum weight of building B and hence the most optimum design for the two buildings..
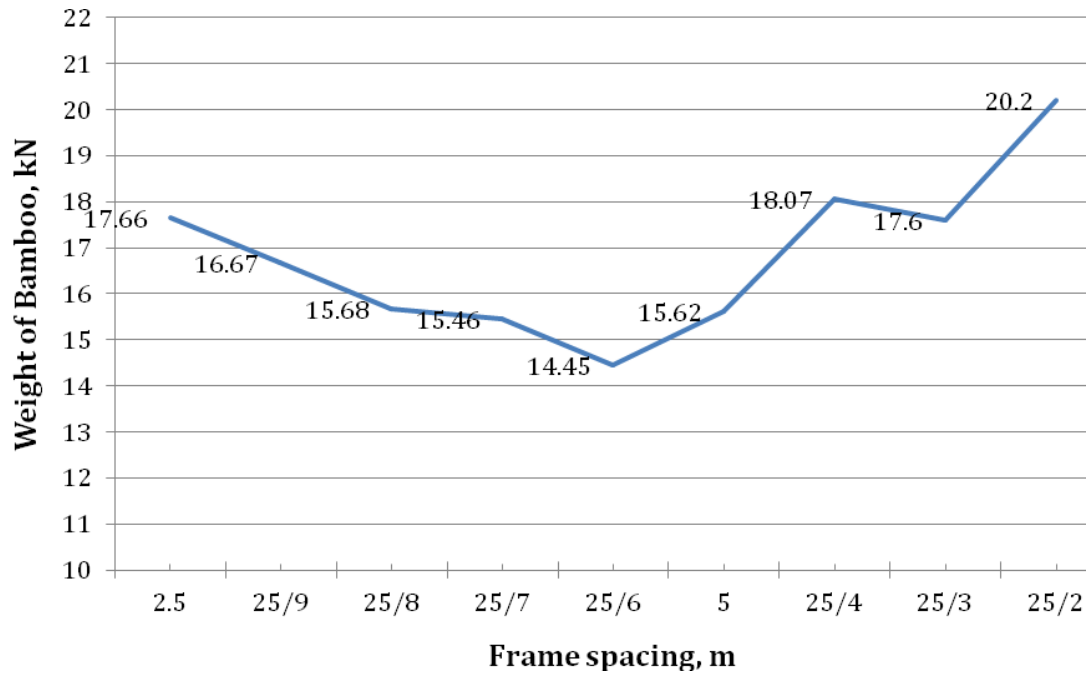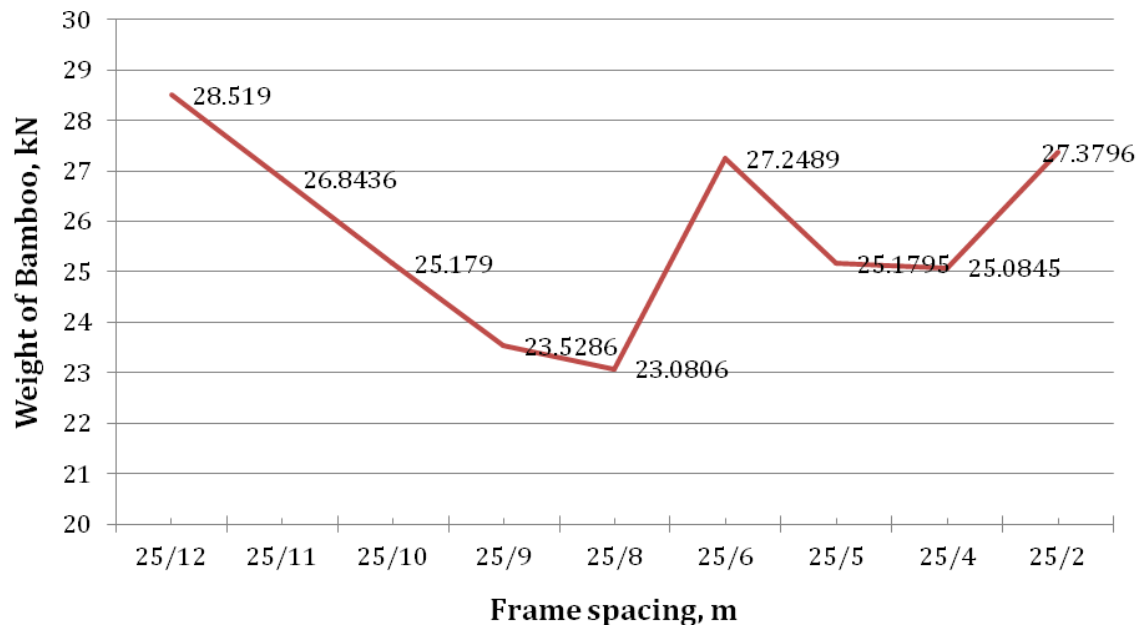
Figure 3.5 Optimization of building A

Figure 3.6 Optimization of building B

Chapter 4   *CONCLUSIONS AND RECOMMENDATIONS*

4.1 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 tied arches and the columns are designed as battened bamboo members tied by ferrocement ties. 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 several times cheaper and eco friendly.

The program developed for the design of the bamboo industrial building gives satisfactory results for the computation of forces and cross – sections of all the components as was seen by comparing manual results with those obtained by executing the program. The determination of optimum spacing was also carried out successfully for the two buildings. Hence, the effectiveness of the program to be used as a preliminary design tool for bamboo industrial buildings has been confirmed.

4.2 RECOMMENDATIONS

Although the program gives satisfactory results, there is scope for improvement in the program. Some of the recommendations for improvement of the program are as follows:

1. The program takes a lot of input from the user which is time consuming. The user has to consult IS 875 Part 3 for the determination of suitable wind coefficients. The program can be designed more extensively so that the user is not required to consult IS 875.

2. The program doesn't design the foundation of the building since the scope was currently limited to bamboo components only, which can surely be integrated with the program.

3. The program doesn't optimize the design automatically. It has to be done manually by changing the span length every time the program is run and finding out the corresponding weight of bamboo required. It would be highly efficient if the optimization could be done automatically as it would considerably reduce the time and effort required for optimization.

4. The program doesn't have a very effective GUI (Graphical user interface) i.e. the different sections given by the program cannot be easily understood due to the lack of a dynamic drawing/animation. It is recommended that some animation tools be integrated with the program in order to have an easy understanding of the results.

5. The program does not display any error message if some incorrect (or incompatible) input is given. This limitation can be overcome by integrating some error messages with the program.

4.3 SOURCES OF ERROR

The program also involves 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) has been used wherever required, which might have lead to some error in the design.

2. The program approximates the parabolic arch as a triangle while computing the forces on the purlins, which might lead to some error in the final section of the purlin.

3. While computing the force on the face perpendicular to the ridge, the area under the parabolic arch has been approximated as a rectangle. Although this approximation leads to conservative design, it might lead to a higher cost of construction of the building .

4. While computing the moment of inertia of a section, the moment of inertia of the individual bamboo struts about their own axis has been neglected, which leads to underestimation of the stiffness of the section.

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