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# Seismic Performance of Traditional Bamboo-Stilted House of Flood Plains in Assam

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**Abstract**

This work studies the performance of a typical single storey, environmentally sustainable bamboo-stilted house located in the flood plain of Assam. Field study is done at the Nimatighat area of Jorhat, Assam, India, for collection of the building configuration and details of, material, structural, and foundation of a typical bamboo-stilted house. Modeling is done in SAP 2000®. The model has the most accurate representation of the structure including spring elements to account for soil-structure interaction. Based on the modal analysis results the best suitable model is finalized. The bamboo species found in the site is Bambusa balcooa (Botanical name). The physical and mechanical properties are as per IS 15912:2012. The geometrical properties of the bamboo elements are based on field study. Spring stiffness for footing is obtained using formulations from established literature as appropriate for the soil-type found in the site. The seismic performance of the finalized model is evaluated using the response spectrum method of IS 1893(Part 1):2016.

*Keywords*: Seismic performance, bamboo, modeling, soil-structure interaction, response spectrum method

## 1. Introduction

Bamboo is the gift of nature given to mankind. Bamboo is an excellent building material. It has the potential to be used to make an eco-friendly building with the highest GRIHA rating. P.sharma, K. Dhanwantri and S.Mehta (2014) [1] studied the utilization of bamboo as a building material. Because of the favorable relationship between load-bearing capacity and weight, bamboo can be used for construction even for very tall structures. However, bamboo being strong, versatile, and resilient is capable of resisting the considerable forces generated by wind and roof coverings. Due to its lightweight in nature and favorable elastic properties, buildings made from it are very good at resisting earthquakes. Ayesha Syeda and Jayesh Kumar (2014) studied [2] that bamboo can be used as a green building material. Bamboo has a high strength/weight ratio and hence it is a good alternative for roof framing. The fire resistance of bamboo is very good because of the high content of silica acid. Moreover, the enormous elasticity of bamboo makes it a very useful material in areas with a high risk of earthquake Bamboo as a building material has high compressive strength and low weight has been one of the most used building materials as support for concrete, especially in those locations where it is found in abundance. Mayank Desai (2018) [3] studied that bamboo has very convincing structural properties. His study showed that bamboo has comparable properties to steel. The tensile strength of bamboo and steel falls in the same range while the compressive strength of bamboo is slightly lesser than steel. Thus, he concluded that bamboo is a suitable structural element for a building, and with the proper use of technology, it can be used for extensive construction purposes.

Bamboo as a building material is used for the construction of scaffolding, bridges and structures, houses. Due to a distinctive rhizome-dependent system, bamboos are one of the fastest-growing plants in the world and their growth is three times faster than most other species of plants. They are a renewable and extremely versatile resource with multi-purpose usage. Among many uses of bamboo, housing is one of the major areas of applications especially in the wake of residential shortages around the globe. The utilization of the bamboo for the construction is achieved by a structural frame technique that is related to the same approach applied in the usual timber frame design and construction. Das and Sarkar (2018) [4] studied the importance of bamboo in building construction. Bamboo is a very versatile material because of its high strength-to-width ratio, easy workability, and ease of availability. As the material is light in weight, it is beneficial for earthquake-prone areas as its chances of falling are very less due to its flexibility. Hence, they concluded that due to better wear and tear resistance resilience properties, bamboo serves as a better building material. Bamboo has played a vital role in the growth of enterprises and rural transformation. In India, the regions where bamboos are

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found in abundance there it continues to be used in traditional and rural areas as a cost-effective housing material.

Bamboo based houses are essentially framed systems with many elements being joined together to act in unison upon the application of loads, especially lateral loads. Bamboo has a high compressive strength than wood, brick, and concrete and exhibits a tensile strength that rivals steel. However, bamboo has over 1200 different species worldwide which makes it a common and easily accessible material. One such bamboo-based house which is generally observed in the flood plains of Assam (North-East India) are the stilted house. Stilted houses are built primarily as a protection against flooding, and they also keep out vermin. The shady space under the house can be used for work or storage if the water is not present there. Isfa Sastrawati (2009) [5] has studied the characteristics of the self-supported stilted houses in terms of structural aspects. Some findings of this research, are described as: The shape of the stilted house gives a shacking impact on the structure when there is an earthquake. The stilted houses are very adaptable to the climatic conditions. The basic floor plan of the stilt house which is a symmetric rectangular makes the structure more stable. The use of a gable roof like which has resistance towards the blowing of wind enables run-off for the rain on the slope side. The stilted house is commonly made of concrete, concrete and timber, and traditionally by bamboo. There are numerous advantages of the stilted house some of which are: first, it provides flood protection. This is not only applicable to the coastal people but also riverine people, people like to live near rivers and streams (especially in lowland rainforest). Second, more airflow in hot climates. Both increased airflow from underneath the freeboards, and increased wind from the slight elevation. Third, the stilted house can be built on hilly/non-flat terrain.

The objective of the present study is to account for the seismic vulnerability of the traditional stilted house in the flood plains of Assam, India. The present study consists of modeling of bamboo stilted houses in SAP 2000®. The model has the most accurate representation of the structure including spring elements to account for soil-structure interaction. Spring elements are used in SAP 2000® to represent soil. The stiffness of the soil is used as an input in SAP 2000® in the form of spring elements for establishing soil-structure interaction. Kuladeepu et al. (2015) [6] studied the dynamic behavior of building frames under seismic forces including soil-structure interaction effect. This analysis was carried out using FEM software SAP 2000®. For the soil-structure interaction analysis of building frames, foundation and soil are considered as parts of a single compatible unit, and the soil is idealized using the soil models for analysis. Soil is considered as a homogeneous, isotropic, and elastic of half-space for the elastic continuum model, for which dynamic shear modulus and Poisson's ratio are the inputs. The result parameters such as seismic base shear, lateral displacement, storey drift, and lateral natural period were evaluated. The stiffness of the soil is calculated as per the formulations given by Raheem et al (2015) [7]. The seismic performance of the finalized model is evaluated by response spectrum analysis as per IS 1893 (Part 1): 2016. The results obtained from response spectrum analysis are checked against IS 15912: 2012 for its credibility.

## 2. Field Study

### *2.1 Site Investigation*

The site selected is one of the worst-affected flood plain areas of Jorhat, Assam, known as Nimati near the bank of the Brahmaputra river. Visits are made to different locations and several stilted houses are studied. The joinery details of the bamboo stilted houses are studied carefully. Fig2 illustrates the stilts and the joints with the superstructure. The stilts are about 1.5m-2m high. Some more information can be extracted from Fig 1 i.e. the base of the stilted house is over the number of bamboos supports. Fig 2 shows the joints between posts and horizontal bamboo members present at the base of the stilted house. The uppermost part of the bamboo stilts, where the joints are found, is cut in a semi-circular groove shape to place bamboo members horizontally which is then tied with rope or GI wire.

Bamboo joints can be tied together using any of the traditional lashing knots, such as the square lashing, round lashing, diagonal lashing, shear lashing, tripod lashing, floor lashing, or ladder lashing. For modeling these details in SAP 2000® the concept of constraint is used. The horizontal bamboo members supported by the grooves of the stilts can have translation about its length and the member can also rotate about the grooves. To represent this in SAP 2000® translational and rotational degrees of freedom are released. The types of bamboo which are generally used to construct the stilted houses are voluka (bambusa balcooa) or mukal.

### *2.2 Subsoil Investigation*

Standard Penetration Test is conducted as per IS 2131: 1981. The observed N-values are corrected for both the overburden and dilatancy and shown in Table 2. As the maximum number of the corrected N-values is less than 10, the soil is classified as soft soil, as per Table 2 of IS 1893 (Part-1): 2016. The stiffness of the soil is calculated based on the values of Table 1.

Fig 1: Stilts of the superstructure

Fig 2: Joinery details

Table1: Stiffness parameters for different soils [After Raheem et al (2015)]

| Soil condition | Poisson's ratio ($\vartheta$) | Modulus of elasticity $E$(t/m$^2$) | $K_x$ (t/m$^2$/m) | $K_y$ (t/m$^2$/m) | $K_z$ (t/m$^2$/m) |
|---|---|---|---|---|---|
| Stiff soil | 0.33 | 23480 | 1127.21 | 1127.21 | 1417.29 |
| Medium soil | 0.33 | 12240 | 563.6 | 563.6 | 708.64 |
| Soft soil | 0.33 | 6120 | 281.8 | 281.8 | 354.32 |

Table 2: Tabulation of N-values.

| Depth(m) | N-Value (Observed) | N-Value (Corrected) |
|---|---|---|
| 1 | 1 | 2 |
| 2 | 6 | 9 |
| 3 | 4 | 6 |
| 4 | 5 | 7 |
| 5 | 10 | 12 |
| 6 | 20 | 19 |
| 7 | 20 | 19 |
| 8 | 20 | 18 |
| 9 | 8 | 9 |
| 10 | 12 | 12 |
| 11 | 12 | 12 |
| 12 | 12 | 11 |
| 13 | 12 | 11 |
| 14 | 12 | 11 |
| 15 | 12 | 10 |
| 16 | 12 | 10 |
| 17 | 10 | 8 |
| 18 | 10 | 8 |
| 19 | 10 | 8 |
| 20 | 10 | 8 |
| 21 | 8 | 6 |
| 22 | 8 | 6 |
| 23 | 8 | 6 |
| 24 | 8 | 6 |
| 25 | 8 | 6 |

The calculation for Soil Spring Stiffness has been done as per the formulation of Raheem et al (2015)as shown in Equation (1-4)

$$K_z = \frac{Gl}{1-\vartheta}\left[0.73 + 1.54\left(\frac{B}{L}\right)^{0.75}\right] \quad (1)$$

$$K_y = \frac{Gl}{2-\vartheta}\left[2 + 2.5\left(\frac{B}{L}\right)^{0.85}\right] \quad (2)$$

$$K_x = K_y - \frac{0.2}{0.75-\vartheta}GL\left(1-\frac{B}{L}\right) \quad (3)$$

$$G = \frac{E}{2(1+\vartheta)} \quad (4)$$

Where G is the shear modulus of soil, E is the modulus of elasticity of soil; $\vartheta$ is the Poisson's ratio of soil. L and B are the length and width of the foundation, $K_z$ = Stiffness of soil along with an axial load, $K_x = K_y$ = Stiffness of soil along a lateral direction at the bottom of a column respectively. [Considering $\frac{B}{L}$ , where B = width, L= length of raft foundation, and D = Diameter, (which is the diameter of bamboo) used for the column in the Stilted house]. Since no such research was available for the foundation purpose of bamboo, therefore the width and the length of the raft foundation [1] is taken as the diameter of the bamboo which is used for modeling of the structure. Therefore $\frac{B}{L} = 1$.

Calculating the soft soil spring stiffness and shear modulus is given below:

Soft Soil:

$$G = \frac{E}{2(1+\vartheta)} = \frac{6120}{2(1+.33)} = 2300.75\ t/m^2 = 23007.5\ kN/m^2 \quad (5)$$

Where, G = Shear Modulus

E = Modulus of Elasticity of Soil = 6120 t/m$^2$

$\vartheta = 0.33$ Poisson's ratio

Now,

Equating the value of Shear Modulus G, modulus of elasticity of soil E, Poisson's ratio of soil $\vartheta$, L and B is the length and width of the foundation in the equation, we get

$$K_z = \frac{GL}{1-\vartheta}[.73+1.53(\frac{B}{L})^{.75}] = \frac{23007.5\times0.1}{1-0.33}[.73 + 1.53 \times 1^{.75}] = 7760.7\ kN/m^2/m \quad (6)$$

Again, equating the value of Shear Modulus G, modulus of elasticity of soil E, Poisson's ratio of soil $\vartheta$, L and B is the length and width of the foundation, we get

$$K_y = \frac{GL}{2-\vartheta}[2+2.5(\frac{B}{L})^{.85}] = \frac{23007.5\times0.1}{2-0.33}[2 + 2.5 \times 1^{.85}] = 6199.6\ kN/m^2/m \quad (7)$$

Subtracting, the value $\{\frac{0.2}{.75-\vartheta}GL\ (1-\frac{B}{L})\}$, we get

$$K_x = K_y - \frac{0.2}{.75-\vartheta}GL\ (1-\frac{B}{L}) = 6199.6 - 0 = 6199.6\ kN/m^2/m \quad (8)$$

These stiffness values are incorporated in the model in SAP 2000®using the spring element in the structures. Here,$K_z$ = Stiffness of soil along with an axial load, $K_x = K_y$ = Stiffness of soil along a lateral direction at the bottom of a column respectively.

### 3. Modeling of the Structure

The modeling of the existing bamboo stilted house is done in SAP 2000®. The concept of constraints is used for modeling various joints in the bamboo stilted house. For modeling of the existing structure in SAP 2000® the bamboo members in the base of the stilted house are considered to be parallel to the Y-axis as shown in Fig 6. Different joints are assigned different constraints based upon the grooves in the bamboo members and also based upon whether the bamboo members pass through a joint. The extreme bamboo members present at the periphery of the base of the stilted house parallel along the X-axis passes through the bamboo stilts and the bamboo members along the extreme periphery along Y-axis rests upon the connection. The nodes marked yellow Fig 7 have degrees of freedom released in translation along the X-axis and rotation about the X-axis. The nodes marked yellow in Fig 8 have degrees of freedom released in translation along the Y-axis and rotation about the Y-axis. The constraints incorporated in these nodes are based upon the orientation of the grooves at each node. The rotational degrees of freedom in the truss joints are released about X, Y, Z-axis. To see the effect of soil flexibility, the model is first made with bases as fixed and then bases with springs to account for soil flexibility. As per the field data, the length and breadth of the models are 5m and 5m respectively. The floor level is 2m above the ground level. The floor height is 3 m, and 1m is the rise of the truss (as shown in Fig 3 and Fig 4). The outer diameter of the bamboo is 100mm and its thickness is taken as 10mm. As per the bamboo type that is bambusa balcooa the modulus of elasticity of the bamboo is taken as $1.62\text{x}10^6\text{kN}/m^2$ and unit weight as 7.68 $\text{KN}/\text{m}^3$ (As per IS: 15912:2012) for this approach of modeling. Some properties of bambusa balcooa like shrinkage, tensile strength and shear strength along the grain have not been found in the literatures and also in IS 15912:2012 , however these properties are not utilised in this work.

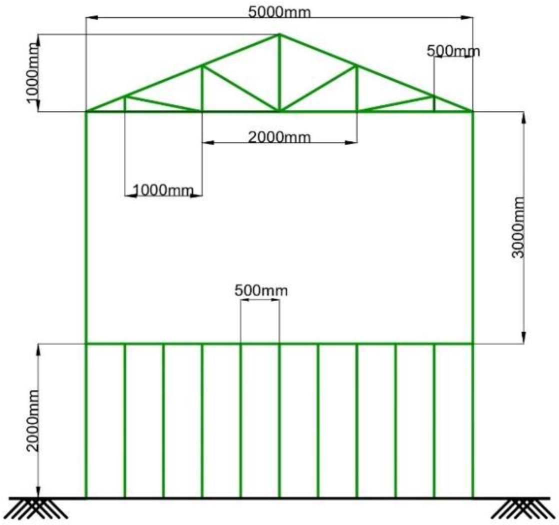


Fig 3: Line diagram of the existing stilted house

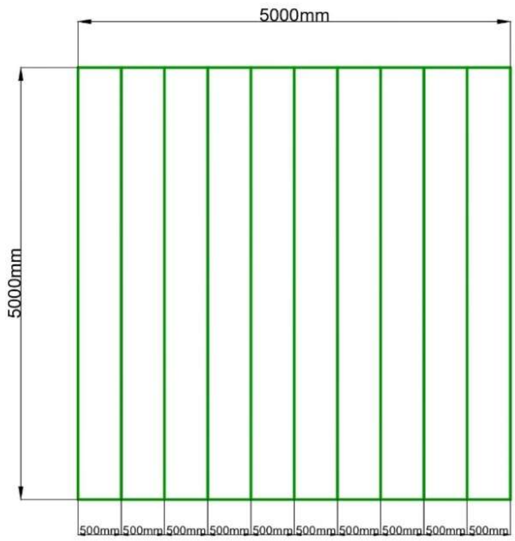


Fig 4: Line diagram of the top view of the base of the existing stilted house

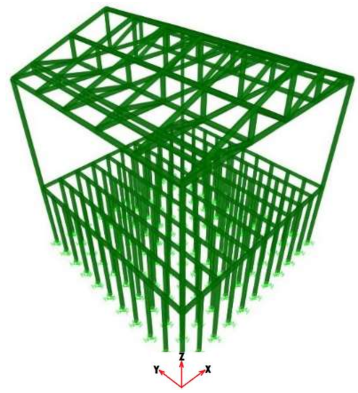

Fig 5: 3D view of Bamboo frames with intermediate stilted house with bamboo members at its base parallel along Y-axis (with respect to the universal coordinate system of SAP 2000®

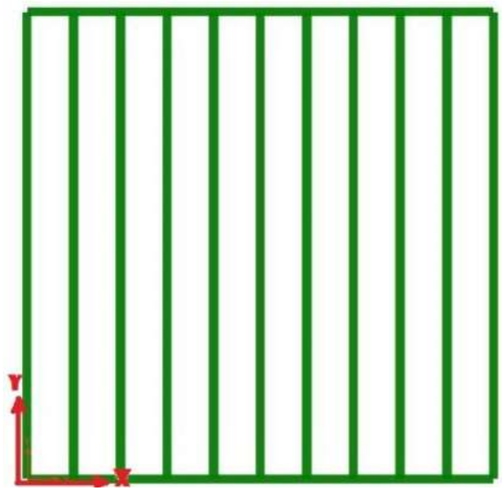


Fig 6: Floor plan of the stilted house where the bamboo members are parallel to the Y-axis of the universal coordinate system of SAP 2000®

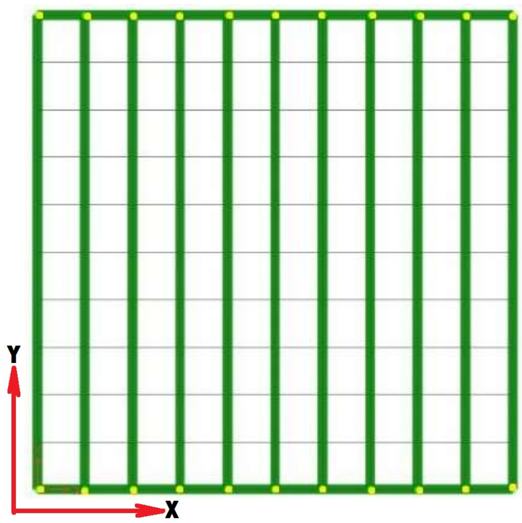


Fig 7: Release of constraint in the floor level of the stilted house in translation along X-axis and rotation about X-axis (with respect to the universal coordinate system of SAP 2000®)

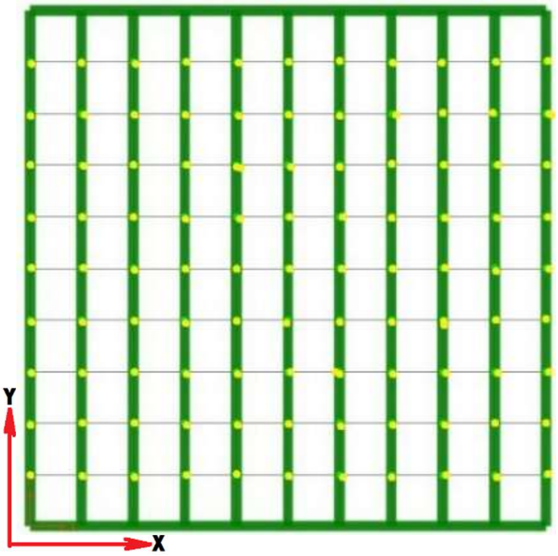


Fig 8: Release of constraint in the floor level of the stilted house in translation and rotation along and about Y-axis (with respect to the universal coordinate system of SAP 2000®)

Table 3: Modal analysis result

| Mode Shapes | Frequency (Hz) (Restrained Base) | Frequency (Hz) (Base with Spring Elements) |
|---|---|---|
| 1 | 0.75 | 0.73 |
| 2 | 0.80 | 0.76 |
| 3 | 4.83 | 2.05 |

## 4. Seismic Response

*4.1 Response spectrum Analysis of Existing Structure*

The modal frequencies of the modeled structure after modal analysis are tabulated in Table 3.

Response spectrum analysis of the model (spring elements at the footing level which represents soil-structure interaction) is done in SAP 2000®. From the analysis results, the maximum joint displacement comes out to be 6.4m (at the topmost panel point of the roof truss). This value of the joint displacement is not acceptable from the serviceability viewpoint.

*4.2 Structural Modification*

It has been seen in 4.1 that the existing bamboo stilted house is vulnerable to seismic damage. To make it earthquake resistant the cross bracings are incorporated in the modeled structure in both the faces along the XZ plane and YZ plane (with respect to the universal coordinate system of SAP 2000®) respectively. The structurally modified structure is shown in Fig 10.

*4.3 Load Calculations for the finalized model*

Length of the roof truss = 5m
Rise of truss = 1m
Height of truss above G.L = 5m

a) Angle of roof truss:

$\tan(\alpha) = \frac{1}{2.5}$

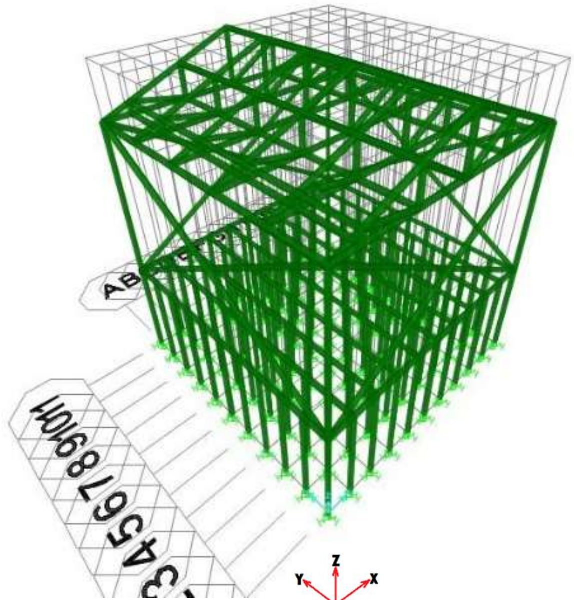


Fig 9: 3Dview of the finalized model with all the modifications

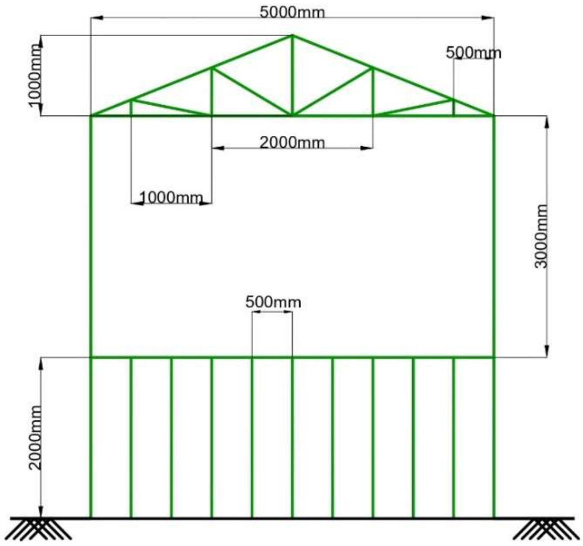


Fig 10: Line diagram of the improvised model

Therefore, $\alpha = 21.80^{\circ}$ (9)

b) Length of Principal Rafter

$$x = \sqrt{1 + 2.5 \times 2.5} = 2.693\text{m} \quad (10)$$

c) Half Plan Area:

$$y = \frac{5}{2} \times 1 = 2.5\ \text{m}^2 \quad (11)$$

d) Half Slope Area:

$$z = 2.693 \times 1 = 2.693\text{m}^2 \quad (12)$$

Therefore, the weight of the roofing material is $= 7.68 \times 2.693 \times 5 = 103.4$ kn $\left[\text{Where, } 7.68\ {}^{kn}/_{m^3} \text{ is the unit weight of bamboo}\right]$

Also, the weight of purlins $= 7.68 \times 2.5 \times 5 = 96$ kN

Also, self-weight of the roof truss= $10 \times \left(\frac{5}{3} + 5\right) \times 2.5 = 166.67$ N $= 0.17$ kN

Therefore, total load $= 103.4 + 96 + 0.17 = 199.57$ kN

On one side of the roof truss, there are three full panel points.

Therefore, the dead load on each full panel point $= \frac{199.57}{3} = 65.52$ kN

Also, the dead load on each end panel point $= \frac{65.52}{2} = 33.26$ kN

Calculation of the live load of roof truss [As per IS 875:1987 (Part-2)]:

Live load on purlin= $0.75\ {}^{kn}/_{m^2}$ [As per IS 875(part 2) − 1987, Table − 2]

As per $\alpha = 21.80^{\circ}$, Live load on purlin= $0.75 - (21.80^{\circ} - 10^{\circ}) \times 0.02 = 0.514\ {}^{kN}/_{m^2} > 0.40\ {}^{kN}/_{m^2}$ ……………. Hence ok.

Live load on roof truss= $\frac{2}{3} \times 0.514 = 0.343\ {}^{kN}/_{m^2}$

Total live load $= 0.343 \times 2.5 = 0.858$ kN

Live load on Full panel points on one side of the truss= $\frac{0.858}{3} = 0.286$ kN

Live load on Full panel points on one side of the truss= $\frac{0.286}{2} = 0.143$ kN

Also, as per Table 1 of IS 875:1987 (Part-2), a concentrated load of 1.4 kN is applied at each joint present in the base of the stilted house.

*4.4 Response Spectrum Analysis of The Finalized Model*

The mass source is ascertained in which the multiplying factor for the dead load is 1 and for the live load is 0.25. The response spectrum function is as per IS 1893 (Part-1): 2016, for Zone V (for the place Jorhat, Assam, India), Soil type-III(as the soil is soft as per test), Importance Factor 1, Response Reduction Factor =5 (Assuming ductile joint, as it is made with GI wire) and Zone Factor =0.36.

The load combinations as per Cl 6.3.2.2 of IS 1893 (Part-1):2016 are used for the analysis purpose. These are listed below:

1.2 [DL + IL ± (ELx ± 0.3Ely)] and
1.2 [DL + IL ± (ELy ± 0.3ELx)];
1.5 [DL ± (ELx ± 0.3ELy)] and
1.5 [DL ± (ELy ± 0.3ELx)];
0.9DL ± 1.5(ELx ± 0.3ELy) and
0.9DL ± 1.5(ELy ± 0.3ELx).
1.5(DL+IL)

## 5. Results and Discussion

*5.1 Modal Analysis*

The modal analysis results of the finalized model after incorporation with cross bracings are shown in Table 4.

Table 4: Modal frequencies and nature of mode shapes

| Mode shapes | Nature of mode shapes | Frequency (Hz) |
|---|---|---|
| 1 | Translation (along X-axis) | 1.29 |
| 2 | Translation (along Y-axis) | 2.33 |
| 3 | Torsion (about Z-axis) | 10.17 |

*5.2 Response Spectrum Analysis*

From the response spectrum analysis, the maximum displacement of the finalized model (at the highest panel point in the roof truss of the finalized model) is 0.7m which is acceptable and is very less as compared to the maximum joint displacement of the existing structure which is 6.4m.

a. Check for maximum bending stress

Moments present in all the elements are found out. The highest moment is 0.95kN-m observed in bamboo stilt (at the starting point of the stilt i.e. the connection of the stilt with floor level).

The calculation for finding out the bending stress in the extreme bamboo fibers:

The external diameter of bamboo member (D)= $0.1m$

Wall thickness of bamboo member = 0.01m

Internal diameter of the bamboo member (d) $= 0.1 - 0.01 - 0.01 = 0.08$m

Therefore, the moment of inertia of the cross-section of bamboo member $= \frac{\pi}{64}(D^4 - d^4) = 2.898 \times 10^{-6} m^4$

Highest moment (clockwise/anticlockwise direction) = 0.95kN = 950N

Distance from the centroid of the cross-section to the extreme fiber = 0.05m = 50mm

Therefore, the bending stress $f_y = \frac{M}{I} \times y = (10^{-3} \times (0.95 \times 0.05)) \div 2.898 \times 10^{-6} = 16.3\ {}^{N}/_{mm^2}$

This maximum bending stress comes into action due to the load combination:

1.5 [DL − (ELx + 0.3ELy)].

Therefore, unfactored bending stress $= 16.3 \div 1.5 = 10.86\ {}^{N}/_{mm^2}$

As per IS 15912: 2012, extreme fibre stress for Bambusa balcooa is 16.4 ${}^{N}/_{mm^2}$ which means the calculated bending stress that is 10.86 ${}^{N}/_{mm^2}$ is less than the permissible bending stress. Hence the structure is safe and has a factor of safety of 1.5.

b. Check for maximum axial stress

The value of the highest compressive force is 35.31 kN (at the column of modeled structure).

Now, maximum compressive stress

$$= (35.31 \times 1000) \div \left(\frac{\pi}{4}(100^2 - 80^2)\right) = 12.48\ {}^{N}/_{mm^2}$$

This maximum compressive stress comes into action due to the load combination:

1.5 (DL + IL)

Therefore, unfactored compressive stress $= 12.48 \div 1.5 = 8.32\ {}^{N}/_{mm^2}$.

As per IS 15912: 2012, for Bambusa balcooa the allowable compressive force is 13.3 $N/_{mm^2}$, and the maximum compressive force is $8.32\,N/_{mm^2}$, which is less than the allowable permissible value. Hence the structure is safe and has a factor of safety of 1.5.

The value of the highest tensile force is $6.5\times10^{-3}$ kN (At the principal rafter of the truss)

Now, maximum tensile stress

$$= (6.5\times10^{-3}\times1000) \div \left(\frac{\pi}{4}(100^2-80^2)\right)$$

$$= 2.3\times10^{-3}\,N/_{mm^2}$$

This maximum tensile stress comes into action due to the load combination:

$1.5\,[\mathrm{DL} + (\mathrm{ELx} + 0.3\mathrm{ELy})]$.

Therefore, unfactored tensile stress $= 2.3\times10^{-3} \div 1.5 = 1.53\times10^{-3}\,N/_{mm^2}$.

IS 15912: 2012 does not provide any permissible limits for the tensile stress of bambusa balcooa. Since the tensile stress obtained is very negligible, hence it is taken to be within the permissible limit.

The maximum bending stress and the maximum compressive and tensile stresses in the members of the finalized bamboo structure are within the permissible limit. Hence the structure is safe and has a factor of safety of 1.5.

Combined stresses have not been checked as there are no guidelines in the bamboo IS code.

Table 5: Response Spectrum Analysis results based on SAP 2000®

| Category | Existing Structure | Improvised Structure |
|---|---|---|
| | Values | Values |
| Maximum joint displacement | 6.4m | 0.7m |
| Maximum bending stress | 10.86 N/mm$^2$ | 10.86 N/mm$^2$ |
| Maximum compressive stress | 8.32 N/mm$^2$ | 8.32 N/mm$^2$ |
| Maximum tensile stress | $1.53\times10^{-3}$ N/mm$^2$ | $1.53\times10^{-3}$ N/mm$^2$ |

## 6. Conclusion

An existing bamboo stilted house in flood plains of Assam have been studied for the seismic vulnerability. As the structure is not safe from the seismic point of view, modification of structural configuration is suggested. A structural configuration of the bamboo stilt house is suggested in this work.

The response spectrum analysis of the suggested structure is done in SAP 2000®. From the analysis results, the maximum bending stress and maximum axial stresses for the worst load combination are found to be within the permissible limits. Hence the existing building typology of bamboo stilted house would be modified to satisfy the seismic demand.

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## Disclosures

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