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Estimation of wind load on a greenhouse and evaluation of its structural stability

AJIT K. NAYAK AND K.V. RAMANA RAO

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See end of the Paper for authors' affiliation

Correspondence to :

AJIT K. NAAK
Irrigation and Drainage Engineering Division, Central Institute of Agricultural Engineering, BHOPAL (M.P.) INDIA
Email : anayak62@gmail.com

■ **ABSTRACT :** Among all the loads that act on the greenhouse, wind load is the major one. In India, the basic wind speed varies from 33 to 55 m/s. Along with wind speed, wind load also depend on the geometry, height to width ratio, effective frontal area etc. So greenhouse design should be customized as per the localized wind load. 'One size fits all approach' in greenhouse design may leads to failure of the structure or being expensive. Unfortunately the standard for greenhouse design is lagging far behind in India. In this experiment, wind load for the double arch type naturally ventilated greenhouse was estimated as per IS code 875 (part 3) and IS 14462: 1997. The design wind pressure estimated to be 772 N/m^2 and wind load on the roof of the greenhouse is 222 kN (Suction) and 185 kN (Pressure). A model of the greenhouse is developed by means simulation with Finite Element Method using ANSYS 15.0 to test its stability at the calculated wind load. The truss and columns are studied with deflections and failure zones diagrams and possible failures were found out to redesign the elements.

■ **KEY WORDS :** Wind load, Structural stability, FEM, Pressure co-efficient, Truss

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Greenhouses are frames of inflated structure covered with a transparent material in which crops are grown under controlled environment conditions. Greenhouse cultivation as well as other modes of controlled environment cultivation have been evolved to create favorable micro-climates, which favours the crop production could be possible all through the year or part of the year as required. Greenhouses and other technologies for controlled environment plant production are associated with the off-season production of ornamentals and foods of high value in cold climate areas where outdoor production is not possible. The primary environmental parameter traditionally controlled is temperature, usually providing heat to overcome extreme cold conditions. However, environmental control can also include cooling to mitigate excessive temperatures, light control either shading or adding supplemental light, carbon dioxide levels, relative humidity, water, plant nutrients and pest control.

In developed countries, greenhouses are used for commercial production of crops and vegetables under adverse condition. In Japan, 84% of area under greenhouse is utilized for vegetable cultivation and in China, the area under protected cultivation is more than 2.5 m ha and 90 per cent area is under vegetables (Singh and Sirohi, 2008). In India, it is used for floriculture and horticultural crops like cabbage, cauliflower, rose, knol khol, tomato, spinach etc. for year round production. But the spatial distribution of greenhouse is quite skewed and most of them are located in and around cities like Bangalore, Pune, Delhi, Hyderabad etc. In India, almost 5000 ha of area are under greenhouse and 0.23% of total area under horticultural cultivation is under protected cultivation. The major reason for lack of its penetration to the resource poor farmers is its high cost as the cost of a Medium range greenhouse with pad and fan system (without automation) varies from Rs.800 to Rs.1100 per sq. meter (Tiwari, 2010). Structural components of greenhouse amounts to 70% of the cost of production of vegetables.

In France, there are altogether different standards for different kinds of green house such as glass, Multiplan, tunnel etc. (CEN 1995, CEN 2001 and CEN 2003). Similarly, in Germany, depending on the geometric shape of the building, appropriate aerodynamic coefficients is standardised for surface of every sector of the structure. Moreover, in Greece, financing of greenhouses is subjected to approval of the structural design as per greenhouse specification with clear cut mention in the concentrated vertical load at various nodes, crop loads for various crops etc. In Italy, the building rules are adjusted for greenhouse despite the fact that building characteristics and uses are quite different from those of greenhouse. In Netherlands, since storms are frequent causes of damage so a testing authority was set up to verify design calculation and to test specific construction details experimentally. Overall greenhouse design is strongly influenced by the climate. Moreover, various load requirements depend on climatic conditions. This is reflected in European National standard which is missing in Indian context. Much research has not been done so far in the way of analysing the various types of load and its distribution in the greenhouse. Existing Indian standards (IS 14462:1997- Recommendation for layout, design and construction of green house) unlike Eurocodes do not provide a methodology for the design of greenhouses. Therefore, the design is more or less empirical. The key design parameter in this type of structure is the stress and deformation anlysis. Hence, an understanding of characteristic structural behaviour of greenhouse component subjected to various types of load is desirable. Classical methods such as mechanics of material methods and theory of elasticity are difficult to apply in the case of greenhouse, which is subjected to varying loads. So numerical techniques such as finite element method can be used for simplifying the analysis.

The design load of a greenhouse includes the dead load, live load, wind load, snow load etc. Similarly it is also subjected to wind load, snow load, seismic load etc. The calculation of wind load is based on unit weight of the structural components and the covering materials. In some cases fixed equipments such as heating, lighting, irrigation systems, shading and thermal screens are also included in the dead load. Crop load is included under dead loads which are suspended through vertical strings. If crops are suspended on separate horizontal wires, the horizontal tensile force transmitted to the gables has to be taken into account. The calculation of snow load is based on measurement of snow fall on the ground given by snowfall mapgiven by special metrological map. The exposed area is calculated by taking the horizontal projection of the roof. Several coefficients need to be multiplied on account of shape of roof as per the IS code.

Wind load depends on the basic wind speed, pressure coefficients and the shape of the greenhouse (Von Elsner *et al.*, 2000). Wind load appears as pressure and suction forces on the surface of the greenhouse. The dynamic wind pressure depends on the effective height of the green house which is defined as the distance between ground level and the average height between gutter or eaves and the highest point of the roof. Local pressure coefficients are higher in gable corners, the sidewalls roof side. So the total load of greenhouse depends on climatic parameters of the locality. Typical wind speeds can be taken from wind map prepared by Survey of India N. However, local wind speed depends strongly on terrain and can vary significantly from values given in wind map. Hence the wind load should be estimated precisely before designing the greenhouse. In India, most of the design is more or less empirical and as a result many structures fail miserably as it happened recently in Madhya Pradesh. Under designed structures fails due to excessive loads whereas overdesigned structures are expensive. So an optimal design is the one which is designed as per the wind load of that particular locality and also considering the other loads with proper factor of safety. The estimation of wind load is essential for its safe and economic design. Minimum design load as prescribed IS 14462: 1997 is shown in Table A (NCPAH, 2011). However, the wind load need to be estimated before the design and installation of greenhouse as in a country like India, there is a huge spatial variation of basic wind speed through the width and breadth of the country. So, a single value of wind load may not hold well throughout the country.

The key design parameter in this type of structure is the analysis of the load-carrying mechanism of in terms of strength and displacements. The aim is to optimize the design of the structure through the reliable determination of the governing wind loads and any other actions, and by exploiting the design strength and by minimizing the structural components. The steel structural design and the foundations design then may follow the conventional design approaches as dictated by the corresponding IS codes.

There are basically two types of green house naturally ventilated and greenhouse with fan and pad cooling system. Naturally ventilated greenhouses are best suited for temperature range of 15 to 30^0 C. The structure must have sufficient number opening for ventilation else the the temperature will rise extremely in midsummer. The percentage of ventilation will be upto 60% of the floor area depending on the climatic conditions. Roof vent is very common than side wall vent ventilation. The ventilations are kept airtight in winter and open in summer. Greenhouse with fan and pad cooling system is best suited for hot dry conditions of the northern plain where temperature goes beyond 30°C. The underlying principle is evaporation causes cooling. Cool air is allowed to flow through cool pad is replaced by co axial fans and hot air is replaced by co-axial fans mounted on the opposite end of the wall. The ideal temperature for greenhouse range from 20°C to 28° C for better growth of crops. Fan and pad is controlled by thermostat. Wet pad is faced towards wind and fan on leeward side. In the tropics, the sides of greenhouse structures are often left open for natural ventilation. Tropical greenhouse is primarily a rain shelter, a cover of polyethylene over the crop to prevent rainfall from entering the growing area. This mitigates the problem of foliage diseases. Ventilators were located on both roof slopes adjacent to the ridge and also on both side walls of the greenhouse.

In India, Naturally ventilated greenhouse varies from 100 m^2 to 1500 m^2 with ridge height varies from 3.5 to 4.5 m. Ridge vents are kept 80-90 cm and side vent depending upon the requirement and openingis fixed with 4o mesh UV stabilized screen. Gutter slope is kept 2%. Gutter material 20 gauge or 1 mm thick GI sheet with perimeter of 500 mm or more preferably of single length without joint. There is aprovision for opening one portion at either side for entry of small tractor or power tiller for intercultural practices. Complete structure is made up of 2 mm wall thickness and structural members are bolted. Columns are 48/42 mm with 2 mm thick cover. Bottom and top cord are of 42 mm with 2 mm thickness. Trusses and purlins are having 33 mm outer diameter with 2 mm thickness. Telescopic foundation is common with 42 mm outer diameter and foundation depth of 48 cm. foundation is grouted with cement concrete mixture of 1:2:4 using telescopic insertion. Entrance room are of size 3mx3mx3m covered with 200 micron UV stabilized transparent plastic film. Two hinge doors are mounted of 2 m width and 2.5 m height. Cladding materials are UV stabilized 200 micron transparent confirming IS standards (IS 15827: 2009). The following materials are required for a greenhouse having 4mx20 m floor area: GI pipe class A (25 mm diameter, 85 cm long, 30 m total length), GI pipe class B (15 mm diameter, 6.0 m long, 21 No.s), GI sheet (20 gauge, size 90x24 cm, 4 sheets), MS flat (25, 3 mm size, 4 m length), Lateral support to end frames (10 mm diameter rod, 10 m length),Cement concrete (1: 3: 6 mix, 1.0 m^3), UV- stabilized LDPE film (single layer 800 gauge, 5.4 m^2/kg,), Polygrip (channel 2000 3.5-4 cm, 2 No.s; Angle 2000 -2 cm, 2 Nos; both made from the procured 20 gauge GI sheet, key 6 mm diameter, 56 mm length), Wooden end frames (5 cm wood, 0.15 m^3), Nuts and bolts 96 mm diameter, 35 mm long, 70 sets), Miscellaneous items like nails, hinges and latches as per requirement

In the present study it was aimed to estimate the wind load acting on the greenhouse and evaluate its stability under all the loads combined together.

Table A : Minimum design loads for greenhouse main frame

Load description	Minimum value (N/m^2)
Dead	
Pipe frame polythene cover	100
Truss frame	250
Supported crops	200
Live	
Worker repair material	250
Wind load	500

METHODOLOGY

The Study was conducted in the Precision Farming Development Centre field, Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh. The greenhouse under study is a double arch, naturally ventilated greenhouse with 560 m^2 floor area (Fig. A).

Fig. A : Double arch, naturally ventilated greenhouse

First of all, wind load acts in the glazing. The glazing transfers the load to the primary members through glazing connectors and secondary members such as purlin members. The primary members (columns and trusses) transfer the load to the foundation then to the earth. Telescopic foundations were used in the greenhouse which is bolted to the main column (Hoxey *et al.*, 1984). The width and the length are 14m and 40 m, respectively. The main columns are of outer diameter of 75mm with thickness of 4mm. Total height of the structure is 6.5 m and the height of gutter is 4.5 m. All the dimensions are measured and the structure was modeled in ANSYS 15.0 using file-input as well as user interface facility. The experiment of simulation was carried on the structure and wind load was applied.

In order to preserve the integrity of coverings and installations, the main parameter involved in the design is the control of displacements, defined as the change in the position of a point, and deflections defined as the deformation perpendicular to the surface on which the action acts. In this paper, the results of the test, deformations and stresses and possible failure of the structure are visualized.

In a structural simulation, Finite element method (FEM) helps in producing stiffness and strength visualizations. It also helps to minimize material weight and its cost of the structures. FEM allows for detailed visualization and indicates the distribution of stresses and strains inside the body of a structure. Many of FE software packages are available to analyze the load distribution in the structure. Several modern FEM packages include specific components such as fluid, thermal, electromagnetic and structural working environments. FEM allows entire designs to be constructed, refined and optimized before the design is manufactured. This powerful design tool has significantly improved both the standard of engineering designs and the methodology of the design process in many industrial applications. The use of FEM has significantly decreased the time to take products from concept to the production line. Hence, in this study the method will be exploited to take the advantage of the advent of faster generation of personal computers for the analysis and design of low cost yet structurally safe green house with material replacement and material substitution with precision level of accuracy.

There are two major approaches to the analysis: Analytical and Numerical. Analytical approach which leads to closed-form solutions is effective in case of simple geometry, boundary conditions, loadings and material properties. However, in reality, such simple cases may not arise. As a result, various numerical methods are evolved for solving such problems which are complex in nature. For numerical approach, the solutions will be approximate when any of these relations are only approximately satisfied. The numerical method depends heavily on the processing power of computers and is more applicable to structures of arbitrary size and complexity like greenhouse. It is common practice to use approximate solutions of differential equations as the basis for structural analysis.

Though there are many numerical methods, the few that are commonly used to solve solid and fluid mechanics problem are finite difference method (FDM), finite element method (FEM), finite volume method, Boundary element method. There is a fundamental difference between the FDM and FEM. In FDM, there are an array of grid points called nodes and is a point wise approximation whereas in case of FEM, there are array of small interconnecting sub regions and is a piece wise approximation. The advantage of using FEA for the simulation and structural analysis of greenhouse, FEA can take any geometry such as double arch or gothic type under any type of loading conditions. However, the fact that cannot be overruled that there is always a slight discrepancy between prediction and experimental measurements which can be minimised by proper meshing and proper interpretation of the model.

The following steps are performed for finite element analysis of the loads in the existing structure. One, Disretisation of the continuum: The continuum is divided into a number of elements by imaginary lines or surfaces. The interconnected elements may have different sizes and shapes. Two, Identification of variables: The elements are assumed to be connected at their intersecting points referred to as nodal points. At each node, unknown displacements are to be prescribed. Three, Choice of approximating functions: Displacement function is the starting point of the mathematical analysis. This represents the variation of the displacement within the element. The displacement function may be approximated in the form a linear function or a higher order function. A convenient way to express it is by polynomial expressions. The shape or geometry of the element may also be approximated. Four, Formation of the element stiffness matrix: After continuum is discretised with desired element shapes, the individual element stiffness matrix is formulated. Basically it is a minimization procedure whatever may be the approach adopted. For certain elements, the form involves a great deal of sophistication. The geometry of the element is defined in reference to the global frame. Coordinate transformation must be done for elements where it is necessary. Five, Formation of overall stiffness matrix: After the element stiffness matrices in global coordinates are formed, they are assembled to form the overall stiffness matrix. The assembly is done through the nodes which are common to adjacent elements. The overall stiffness matrix is symmetric and banded. Six, Formation of the element loading matrix: The loading forms an essential parameter in any structural engineering problem. The loading inside an element is transferred at the nodal points and consistent element matrix is formed. Seven, Formation of the overall loading matrix: Like the overall stiffness matrix, the element loading matrices are assembled to form the overall loading matrix. This matrix has one column per loading case and it is either a column vector or a rectangular matrix depending on the number of loading cases. Eight, Incorporation of boundary conditions: The boundary restraint conditions are to be imposed in the stiffness matrix. There are various techniques available to satisfy the boundary conditions. One is the size of the stiffness matrix may be reduced or condensed in its final form. To ease computer programming aspect and to elegantly incorporate the boundary conditions, the size of overall matrix is kept the same. Nine, Solution of simultaneous equations: The unknown nodal displacements are calculated by the multiplication of force vector with the inverse of stiffness matrix. Ten, Calculation of stresses or stress-resultants: Nodal displacements are utilized for the calculation of stresses or stress-resultants. This may be done for all elements of the continuum or it may be limited to some predetermined elements. Results may also be obtained by graphical means. It may desirable to plot the contours of the deformed shape of the continuum.

Therefore, the study focus on distribution of load on existing naturally ventilated double arch type green house with varying load condition and creating a model subjected to the loads to visualize the stress distribution. This analysis will help immensely for reducing the cost by material substitution as well as material replacement.

RESULTS AND DISCUSSION

Till Now India has not published wind load design code for various greenhouses. In this paper, the wind load is calculated based on civil engineering load code of practice of design load for wind load IS-875(part 3)-1987. First of all wind load on the structure was determined and the effect of the wind load on the structure was studied. Since the code is not exclusively for greenhouse design, so necessary assumptions were made regarding pressure coefficients whenever data for double arch type was not available.

Wind data:

Basic wind speed:

Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. Basic wind speeds have been worked out for a 50 year return period and has been already found out by Survey of India. Bhopal comes under Wind zone II with basic speed (V_b) of 39 m/s.

Terrain category:

Selection of terrain categories was made with due regard to the effect of obstructions which constitute the ground surface roughness. Terrain *Category* 2 is open terrain with well scattered obstructions having heights generally between 1.5 to 10 m.

Design factor:

Risk co-efficient factor k_1 = 0.92 (for mean probable life of structure of 25 year)

Terrain and height factor k_2= 1(Class A structure)

Topography factor k_3= 1 (Upwind slope less than 3°)

Permeability of the building: Medium permeability as % open area is roughly 10 %.

Design wind pressure:

Design wind speed= $V_z = V_b x\ k_1 x k_2 x k_3$ = 35.88 m/s

Design wind pressure $P_z = 0.6\ (V_z)^2$ = 772.42 N/m².

Internal Pressure co-efficient:

The pressure coefficients are always given for a particular surface or part of the surface of a building. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient and the design wind pressure at the height of the surface from the ground. As per the code, buildings with medium openings between about 5 to 20 per cent of wall area shall be examined for an internal pressure coefficient of +0.5 from inside and then for a suction of -0.5 from inside, and the analysis which produces greater distress of the members shall be adopted.

$C_{pi} = \pm 0.5$

External pressure coefficient:

From the IS code, external pressure coefficient for double arch type structure is not available. Since it resembles circular section, C_{pe} is interpolated as -0.7 for the full width of the roof over half the length and for remaining portion is 0.5.

Design pressure coefficient for roof:

Positive internal pressure will act towards the roof while negative internal pressure away from it. Hence positive internal pressure will be added to the negative external pressure coefficient and vice versa. The combination will have to be made separately. So the design pressure coefficient of the roof

C_{pnet} for roof= C_{pi}-C_{pf} = -0.7- (0.5) = - 1.2 (Suction)

= 0.5- (-0.5) = 1.0 (Pressure)

Wind load calculation:

Wind load on the roof F = $C_{pnet}\ A_e P_z$

where C_{pnet} = net roof pressure coefficient= C_{pi}-C_{pf} , V_z =

Fig. 1 : Deformed (blue) and unreformed (white) shape of the frame

Fig. 2 : Stress analysis of the frame

Design wind speed, P_z = design wind pressure = 0.6 x V_z^2, A_e = frontal area= 240m^2.

Putting all the values, Design pressure on the roofs is -222.45 kN (Suction) and 185.376 kN(Pressure). So the roof must able to withstand this much wind load in any extreme event.

Structural analysis:

Structural stability of the greenhouse was evaluated by using Finite element analysis through modeling as the 3-D steel frame structure. The rafter was constrained on the ground by using translational and rotational stiffness as real constants of the COMBIN7 element. The calculated wind load is applied to the structure, and possible deformation can be seen (Fig. 1). So the deformed elements of the truss need to be redesigned as per its load bearing capacity. The stress analysis shows clearly it is safe against torsion (Fig. 2). Since the maximum predicted von misses stress is less than the ultimate yield strength, the structure will not break. The critical region was we would expect the beginning of failure is located in the end of the truss.

Conclusion:

Spatially varying basic wind speed, geometry of the structure, its height to width ratio and cladding material are decisive factor in the resistance of the same action of the wind. Proper wind load estimation followed by customized location based design will make the structure safer and cheaper. The findings of the study revealed that IS code 875 part 3 need to revised to suit the greenhouse design. Especially, external pressure coefficient for typical structures like double arch, gothic should be mentioned explicitly in the code for precise estimation of wind load.

Authors' affiliations:

K.V. RAMANA RAO, Irrigation and Drainage Engineering Division, Central Institute of Agricultural Engineering, BHOPAL (M.P.) INDIA

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