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A Review

A review on stability of polyhouse structures

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Abstract : Naturally ventilated polyhouse is popular all over the world for growing high value cropssuch as capsicum, tomato, lettuce, herbs etc. and these polyhouses are available in different designs as per different climatic conditions. Structure failure is the major problem faced by farmers throughout the world. The several studies carried out throughout the world shows that the single design of polyhouse cannot be adopted throughout the country due to different agro-climatic conditions.As per differentstudies, polyhousestability designs are analyzed for dead load, live load, snow load, wind load and load combination and Loads were calculated by adoptingdifferent National Standards. Moreover, Truss members, columns and foundation stability analysis is carried out by considering dead loads, live loads and wind loads in most of the studies. Support reactions arealso calculated on truss joints and column joints. The optimum design of any polyhouse generally depends on its structural design, specific mechanical and physical properties of the individual structural components *i.e.*, foundation, hoops, lateral support, polygrip, assembly and end frame. From all the studies it is reported that in most parts of the world, wind is the major force responsible for the failure of any polyhouse structure.

Key Words : Polyhouse, Stability, Structure, Truss, Wind load

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Introduction

India is a nation where almost all kinds of field crops, horticulture crops, vegetable, pulses, ornamental crops are grown depending upon different climatic conditions and resources available (Ghani *et al.,* 2019). If climate conditions are controlled, some of the crops can be grown throughout the year and production of such crops may be increased. For favorable climate control conditions farmers should take on protected cultivation (Gopi *et al.,* 2019). The main aim of protected cultivation is to get high value products *i.e.*, vegetables, fruits, flowers, ornamentals and seedlings. There are multiple types of protected cultivation techniques which includes mulching, direct covers, wind breaks, low tunnelsor high tunnels greenhouses (Petchsuk *et al.,*2019).Protected cultivation technology is a technology where environment surrounding the plants is controlled to some extent or completely as per the need of the crop during growth period. In protected cultivation climatic conditions like temperature, solar radiation, wind, humidity and air compositions are controlled in very good manner. Adopting these technologies, changes the cycles of traditional cropping, lengthen the time of harvesting, improves the quality of crops, increases the yield of crop and gives opportunity to grow off seasonal crops which

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results in increasing the profitability of the farmers (Wittwer and Castilla 1995; Kyrikou *et al.,* 2011). A polyhouse is a type of greenhouse which is covered with flexible transparent plastic films permitting entry of natural light. In India, the most common greenhouse structures are naturally ventilated polyhouses, basically steel tube structures enclosed by insect proof screen on the sides and UV stabilized polythene sheet on top (Hong *et al.,* 2017; Nayak *et al.,* 2018). Rainfall and heavy wind storms are the major sources which can damage the structure and film of polyhouses; therefore, all components have to be designed properly under the loads for their safety.The design parameters must be based on relative standards, which provide guidelines for evaluating different design loads for satisfactory level of protection as well as to avoid huge damage. (Elsner *et al.,* 2000; Castellano, 2007). Design loads of polyhouse includes mainly crop load, dead load, wind load and live load throughout the world. It is very important for any structural design of polyhousethat it must be able to carry combination of all types of loads (Nayak *et al.,* 2018). In addition, the structure of polyhouse should be designed and constructed in such a way that it fortifies against destruction due to heavy rain, high wind speed and extreme temperature (Jensen and Malter, 1994; Saltuk, 2019).

As per present Indian standard *i.e.*, IS:14462 1997 for construction, plan and design of polyhouse does not offer a procedure for the structurally stable design. But, farmers, businessmen and scientists from all over the world are restructuring the greenhouse designs from last fifty years.It is found that a less care is given to the structural strength of the polyhouse in order to provide a cheap polyhouse to the farmers. As the loads acting on polyhouses are varying location to location, hence the structural design and stability is geographically different. In this paper several studies related to structural stability of polyhouses throughout the word by different researchers have been reviewed and discussed under following sub-heads.

Structural analysis and design of polyhouse:

Kendirli (2006) conducted a study on structural analysis of greenhouses in Turkey. A research was done to find the functional and structural characteristics of greenhouses. The information about the kinds of greenhouse, properties of material, location and arrangement of structures in the research region was collected by questionnaire, after that all structures in enterprises were separated in groups on the basis of cladding material, capacity of material to resist a load and direction of structure settlement. All four kinds of structures with appropriate economical cross-section, chosen one from each group and loads were calculated. The two methods such as force method and moment distribution method were used to study the loads acting on each beam of structure. Finally, the achieved results were compared statistically to judge the best method for analysis of structure.

Ubolsook and Thepa (2011) conducted a study on structural analysis of bamboo trusses structure in greenhouse. The purpose of this study was to analyze the cross-section and shape of single span greenhouse in Thailand. The structure was designed as it opened at the top for air circulation and some geometric features for the reduction of deflection. For the truss shape and design problem analysis, the self-weight, cross-section and displacement of bamboo structure were computed. Different truss profiles *i.e*. pratt, double howe, W shape, modified Fan, modified Queen, Fan, M shape and double W were designed and axial forces were calculated in each truss shape members by checking their displacements under dead loads, live loads, and wind loads.All the displacement results showed the minimum displacement in Modified Fan truss shape and minimum weight in Double Howe truss shape.

Dova *et al.,* (2012) conducted a study on differences in required structural efficiency of standard commercial steel greenhouses among European Union Countries. The study associated with structural analysis of a steel Venlo type multi span greenhouse, originally designed and dimensioned in Italy. Firstly, the parts of structure such as primary internal bearing steel frame, sides, gable ends were shaped as multi-bay single-story frames, original designed braces were also included and the whole load of structure was acted at tip of exterior column with equal horizontal seismic forces for both primary directions as per Hellenic code. The results of the non-linear study indicated that column and vertical members of trellis girder were heavily overstressed. Due to this reason structure had to redesign, without disturbing its geometric parameters, using broader cross-section and best bracing system. The final design gives all design requirements without any harm to functions and global performance of structure.

Choi *et al.* (2014) conducted a study on analysis of the characteristics of greenhouses in Korea. The study was conducted to form structural safety guidelines and standardization for greenhouse structure design on reclaimed land with the help of local farmers. The results showed that, the structure was divided into single and multi-span structures and most were arch or single to double W types. The 50-59 cm deep pipe and concrete foundations were used for single-span and multi-span greenhouse structures, respectively. Near about 95.3% greenhouses used plastic film as cladding material rather than glass covering.

For arid and hot areas agricultural greenhouses, the challenges of design were studied by Ghani *et al.* (2019). It was reported that depending on ambient conditions and type of crop grown in greenhouse, the best design of greenhouse must provide control of elements of micro-climate *i.e.,* temperature, carbon dioxide concentration, relative humidity and light.

Saltuk (2019) conducted a study on structural analysis of steel constructed greenhouses.The results revealed that greenhouse constructed without any static and strengthcalculations take more materials and had less safety. In this research structural design was done over one-span glass covered gable-roofed greenhouse. SAP 2000 programme had been used for structural design. Before the analysis mechanical properties of material and loads were calculated theoretically using TS 498 and TS EN 13031-1 Turkish standards. The results showed that with an optimized area of 720 m^2, the greenhouse saves 2.736 kg of building material. An average of 11.8% of the building materials can be saved in onedeclare area. Considering the same load conditions; the use of SAP2000 analysis reduces the cost, and there is no change in strength.

Indore *et al.* (2020) conducted a study on structural analysis of common existing greenhouses designs in different agro climatic zones of India. Prevalent design of greenhouse like gothic type, quonset, double arc single span, multi-span and walk in tunnel were selected for the study. Wind load was found in the range of 772. 42 to 1396.25 N/mm^2. The results indicated that some of the specification of the structures need to be revised as some members of the structure fail under combination of loadings.

Different loads in polyhouse structure:

Loads interaction study for steel greenhouse design structure was done by Castellano (2007). For the steel greenhouse the design methodology was developed which correlated main design parameters, whose fabrication demand by high level of standardization, like depth of gutter and spacing between frames, with the actions on the structure. In this research the interaction domains allowed a clear and direct interpretation of structural behaviour to design load combinations. The study focusses on both parameters such as accomplishment of structure standard requirement and safety levels corresponding to design load combinations.

Emekli *et al.* (2010) conducted a study on structural analysis and functional characteristics of greenhouses in the Mediterranean region of Turkey. In this study five kind of most economic cross-sections of greenhouse structure were selected and loads subjected to members of structure were calculated. The stretch ratio, due to loads on beams of each structure was analyzed by SAP 2000 programme. As per the data collected, it was seen that the selected five type structures could not bear the dead and/or dynamic loads safely. It was found that covering material had great influence on dead loads rather than dynamic loads at 5 % probability level. Both dynamic and dead loads were greatly affected by the structural material.

Analysis of load on greenhouse foundation was studied by Yun *et al.* (2014). The snow and wind load from upper structure were transferred to foundation of greenhouse to get optimum and economical design of greenhouse. The analysis showed that upper structure takes18.2 to121.5 kg/m^2 wind load and snow load of 3.1 to 104.6 kg/m^2. Axial direction maximum load on greenhouse foundation was found to be 437 kg due to facility and crop loads, while the maximum pulls out foundation load was 1557 kg due to wind load. The maximum compressive foundation load found to be 6094 kg due to snow load.

Bronkhorst *et al.* (2017) conducted a study on wind loads for stability design of large multi-span duo-pitch greenhouses. A wind tunnel study was conducted to determine the overall horizontal wind load on multi-span duo-pitch greenhouses structure. The results showed the stability design of inflexible cladding structure by using Class A in EN 13031-1 with roof pitch angles of 23 to 24° and ridge heights of 7.5 to 8 m. For the determination of overall horizontal wind pressure both static force and fluctuating pressure measurements were performed. The horizontal wind load was calculated with the help of mean pressure co-efficients which were obtained from fluctuating pressure and showed good agreement with static force measurements. Non-conservative outcomes were provided by EN 13031-1 for overall horizontal wind force on examined duo-pitch greenhouse which was having greater than thirty spans. While, code EN 1991-1- 4 was conservative witha greater number of spans.

Hong *et al.* (2017) conducted a study on structural safety of single-span greenhouses under wind load of costal reclaimed lands using SAP 2000. The purpose of this research was to check the structural safety of peach type and even-span type greenhouse structures under the wind characteristics of coastal reclaimed lands. From the wind tunnel study, the wind pressure co-efficients measured for both structures which were acting on the walls and roofs of greenhouses and it was observed that measured co-efficients were two times greater than those suggested by the existing design guidelines. The design analysis done by existing guidelines might lead to structural failure under coastal wind conditions. Peach type greenhouse constructed in a reclaimed land could be damaged by approximately 48 % of the design wind speed and needed improvement of structural designs. This study suggested that increasing the space of rafters with thicker pipes for peach type greenhouse enhances economic feasibility under strong wind conditions.

Hur and Kwon (2017) conducted a study on fatigue analysis of greenhouse structure under wind load and self-weight. The strength of structure was analyzed by applying wind load using wind load pressure co-efficients as per design code. The studyconcluded that the fatigue stress model was normalized by square of wind speed, fatigue stress estimatedwas corrected to static stress due to self-weight, and the square of wind speed was used as the dynamic load.

Nayak *et al* (2018) conducted a study on estimation of various loads of a naturally ventilated saw tooth type greenhouse. It was reported that the wind load was the main load out of various loads that acts on the structure of greenhouse. The value of wind load was found to be 772 N/m^2. Indian standard code IS 875 part-3 with IS 14462: 1997 were used to estimate the wind load. The crop load, frame load, truss load and live load found to be 200,100, 250, 250 N/m^2, respectively.

Kang *et al.* (2019) conducted a study on failure conditions for standalone coldframe greenhouse under snow loads. This study determined the structural failures and examined the reasons through scaled-down experiments and nonlinear structural analysis. The 2D scaled-down model of greenhouse structure was prepared as per similarity law. Results of the experiment were compared with nonlinear structural analysis of linear elastic–plastic models. The relative displacement error of 6.10% was observed between experimental values and finite analysis value at fixed boundary condition for both ends under uniform snow loads. The results showed that failure of structure with hinge boundary conditions occurred in all cases for the supports at both ends under uniform and non-uniform snow loads. The huge deformation behavior of the structure was observed with a hinge-to-hinge boundary condition and non-uniform snow loads where the horizontal displacement was similar to vertical displacement.

Wind effects and ventilation aspect of polyhouse structure:

Papadakis *et al.* (1996) conducted a study on measurements and analysis of air exchange rates in a naturally ventilated greenhouse with continuous roof and side opening. In this study two types of pressure differences were considered *i.e.*, static as well as turbulent. The research showed that air exchange rate depends strongly on velocity of wind as well as opening area of total ventilation, while its dependency on direction of wind was not significant. Study indicated that if wind speed is more than 1.8 m/s, the effect of thermal buoyancy could be ignored. Efficiency achieved by roof and side ventilation was more as compared to side ventilation. The model that considers thermal buoyancy and wind effect gives the better result for computed ventilation flux.

Mistriotis *et al.* (1997) conducted a study on ventilation analysis of greenhouse at low and zero wind speed with help of computational fluid dynamics (CFD). Initially the validity of this method was judged by comparing the numerical outcomes with experimental data taken from tertiary sources.The predicted numerical values of ventilation efficiency of greenhouse were achieved for different ventilator configurations. These computer simulations were based on actual representation of boundary values and heat sources associated with problem. The involvement of ventilators to exchange the inside air of greenhouse was studied. The significant of side wall ventilators for thermal air exchange was confirmed. For the development of well improved ventilated designs, the CFD was most appropriate tool.

Naturally ventilated top screen greenhouse was studied by Nielsen (2002). It was reported that during hot summers, it is very difficult to reduce the air temperature in the plant zone. The vents are entirely open and air temperature is very high. The exchange of air in the plant zone is extremely less. In the greenhouses which are having roof vents only and no vents on the sides, it is a visible problem. The air goes out through the roof vents without having any influence on air in the plant zone. It was suggested that by placing one-meter-high screen on top of greenhouse parallel to ridge, enhancement in the air exchange in the plant zone takes place (upto 50%). There was decrease of 2.1ºC temperature by placing this screen.

Robertson *et al.* (2002) conducted a study on wind pressures on permeable and impermeable clad structures. In this study design parameters were taken from EU codes and wind load parameters were taken from code ENV 1991- 2-4: 1995. A deficiency in wind loading was that of pressure co-efficient data for permeable covering structure. For designing, pressure data were obtained from large-scale tests conducted in the Jules Verne climatic wind tunnel at CSTB, Nantes, in 1999. This study consisted of experiments conducted on an arch structure and on a flat-roof structure, which was covered with impermeable plastic film insect net (33%) open area and shade net (39%) open area. The pressure co-efficient data obtained with each covering were compared for both structures.

Hwang and Lee (2014) conducted a study on wind pressure coefficient determination for greenhouses built on a reclaimed land using CFD technique. The study showed that wind load has significant aspect in the structure design. The study also considered the related factors such as wind load and wind pressure co-efficient. The fruitful feature of CFD technique was computing the qualitative and quantitative detailed information in less time and cost which was beneficial for the study of wind pressure co-efficient of greenhouse structure in reclaimed land. ESDU programme was used for design of vertical wind profiles to consider the characteristics of reclaimed land and the designed wind profile was applied to the CFD simulation and wind tunnel test as a boundary condition. For the accuracy validation confirmation of CFD model, the wind pressure coefficients of 1-2 W arch type structure were measured in the wind tunnel test. The results of wind tunnel measurement were agreed with designed wind profile by ESDU with 2.7% error differences. The IOA value was evaluated as 0.753 which imply that CFD simulation was reliably designed.

Kim *et al.* (2014) estimated wind pressure coefficients on even-span greenhouse built in reclaimed land. The wind pressure co-efficient and local wind pressure co-efficient on even-span greenhouse was measured using wind tunnel test. ESDU had been adopted to realize wind characteristics *i.e.*, wind and turbulence profiles. In tunnel test, when wind direction was zero degree, it was observed that KBC 2009 standard underestimated scale of wind pressure co-efficients at roof area of greenhouse whereas NEN-EN 2002 standard underestimated at every surface of greenhouse, while in case ofninety-degree wind direction, both standards did not meet the characteristics of wind pressure distribution.

Kwon *et al.* (2016) evaluated wind pressure co-efficients of single-span greenhouses built on reclaimed coastal land using a large-sized wind tunnel. The greenhouse structures were considered as light weight structures that exposed to heavy wind speed. To evaluate the structural safety of greenhouses according to the wind characteristics for coastal reclaimed lands, the wind environments of these regions were simulated in a large-scale Eiffel type wind tunnel. The code ESDU (Engineering Sciences Data Unit, E01008) was used under wind and turbulence intensity profiles for calculation of variations in the windward terrain roughness. The wind pressure co-efficients for Even-span, Three-quarter, Peach and Mono-span greenhouse structures were measured in the wind tunnel according to wind direction, roof slope and the radius of curvature of the roof.

Ryu *et al.* (2019) conducted a study on damage index estimation by analysis of meteorological disasters on film plastic greenhouses. Effect of typhoons, heavy snow, strong wind, and heavy rain on plastic film greenhouse were analyzed. The total damaged area was 20279 hm^2 and damage rates of typhoons, heavy snow, strong wind, and heavy rain were 46.4%, 47.4%, 2.5%, and 3.8%, respectively. The damage index data and the cumulative damage areas were divided using the Jenks' natural breaks method. The study also showed that average index was 0.66 and indices were high in metropolitan cities.

Conclusion:

Cultivation of value crops under protected cultivation is followed all over the world and it is a fast-growing sector of agriculture. However, designs and structures of polyhouses are influence by local climatic conditions. It is true that there are several types of covering materials are available in the market which can fit in the local conditions. The radiation transmittance, insulating performance and ventilation system of a polyhouse are very important factors. It is concluded that climate is one of the major factors which can influence both functional and structural characteristics of polyhouses. In addition, different load combinations are depending upon the type and design of structure. Design of a polyhouse is a multi-parameter optimization problem and safety rules related to structural failures are difficult to explain. After reviewing different studies, it is good to say that there are some specific methods which can help to design a polyhouse for different wind load conditions. Improvements are still going on and continuous efforts are made to create solutions from both experience and scientific researches.

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