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Structural analysis of common existing greenhouses designs in different agro climatic zones of India

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ABSTRACT : Greenhouse is popular throughout the country for growing high value crops, which is available in different designs suiting different agro climatic conditions but single design of greenhouse cannot be adopted throughout the country.The wind is the major force responsible for failure of the structure, therefore popular greenhouse designs Quonset, walk in tunnel, gothic and double arc single span and multi-span were selected for the study. In India, the basic wind speed varies from 33 to 55 m/s. The pressure co-efficients due to local wind load were determined as per IS : 14462: 1997 for the designs. Selected designs were analyzed for dead load, live load, snow load, wind load and load combination as per Loads were calculated as per BIS standards. Standards IS: 875 (1987) (Part I – Dead Load, Part II-Live Load, Part III-Wind Load and Part IV-Snow Load) and NGMA.All the forces acts on the structures due to individual and combination of loading were determined and behaviour of structural member analyzed and studied using ANSYS 15.0 (finite element model).Two wind angle of attack 0° and 90° were used in dynamic loading of the structures. Wind load was found in the range of 772. 42 to 1396.25 N/mm^2. It has been found that some of the specification of the structures need to be revised as some members of the structure fail under combination of loadings. Major changes in specification of structural members (G.I. pipe) of truss, purlins and column of selected greenhouse were determined and standardized to suit local wind loading conditions for greater stability. Results were also validated in field for one of the selected design by installing its improved structure andit was found that total stress value reduced by 35- 46 per cent and deformation by 8-10 per cent. It means sufficient strength was added to the structure without dismantling and any additional cost.

KEY WORDS : Agro climatic zones, Greenhouse, Crops, Climatic

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Day by day agricultural land is reducing to meet out the demands of increasing population in developing countries like India. There is dire need to produce more from unit area which is only possible by intervention of modern growing techniques of protected cultivation such as greenhouse cultivation. Greenhouses are made of frame structure of G.I or M.S pipe which is covered with a transparent material in which crops are grown under controlled environment conditions. Greenhouse are very popular in India and available in different design and types. This specific variation are made to suit local conditions of different agro climatic zones. Greenhouse design is single most important factor which decides its performance to maintain desired microclimate inside the structure. Microclimate consists of; light, gas concentration, temperature and RH etc. Single greenhouse design could not be adopted through the country due to variability in climate, location and topography etc. In India, almost 5000 ha of area is under greenhouse cultivation which is lower as compare to the other developed nations. The major reason for lack of its penetration is the cost associated with it which ranges from Rs. 500 to 4000 per m^2. Structural components of greenhouse amounts to 70% of the cost of production of vegetables. Hence economical design is required which depends on various factors such as local weather conditions and specific purpose or use. These greenhouse structures are supplied by different manufacturers in the country. It has been observed that different manufacturers provide different greenhouse designs, materials, their specifications, shape etc. differs supplier wise. There is lack of specific design for a particular region. It is observed that some of the structures get damaged whereas some of them seem overdesigned. Though number of structures is increasing day by day, location specific standard designs are yet to be available in India. Some design may be successful in particular region but it may fail in others.The structural design of a greenhouse must provide protection againstdamage caused by wind, rain, heat and cold (Jensen and Malter, 1994).

Research on analyses of various types of load and its distribution on the greenhouse is less and not done as per Indian conditions. Dead and dynami cloads are significantly affected by structural materials of the greenhouses (Emekli *et al.*, 2010). Wind load is important in context of Polyhouse and act as pressure and suction forces on the surface of the greenhouse. The dynamic wind pressure depends on the effective height of the green house. Greenhouse structures should be designed toresist a wind speed of 130 km/hr. The actual load depends on wind angle, greenhouse shape and size, and the presence or absence of openings and wind breaks (Jensen and Malter, 1994). Wind load should be estimated precisely before designing the greenhouse. The estimation of wind load is essential for its safe and economic design. However, the wind load needs to be estimated before the design and installation of greenhouse. 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 may not hold well through out the country.

■ METHODOLOGY

Selected regions of study:

Cold and temperate region: J & K (Srinagar), Plains, semi-arid and sub humid: Punjab (Ludhiana)Junagadh (Gujarat), Udaipur (Rajasthan), Semi-arid: Raichur (Karnataka), Hilly: Gangtok (Sikkim), Almora (Uttrakhand) and Barapani (Meghalaya). The selected site situated in different agro climatic zones of India. As per the Indian standard code design (IS 875: 2003) India is divided into different wind zones. Hence all the supporting standards and values of parameters for topography, local environment conditions and selected structures were used for this selected region on the basis of this code *i.e.* as per IS code 875 (part 3) and IS 14462: 1997. Information on structural characteristics were collected after survey and visits to selected sites which is given in detail in Table A and estimated wind zone properties location wise estimated and listed in Table B On-farm survey conducted during the study revealed that Indian farmers prefer naturally ventilated small size (ranging from 200 m^2 to 4000 m^2) saw tooth shape greenhouse structures.

Structural analysis methodology and steps:

Finite element method:

It is most common method of analysis under dynamic loading conditions. Finite element method

Table A : Structural characteristics of selected most common designs of selected location

Design of polyhouse	Span type	Span (m)	Size (m^2)	L,(m)	GH (m)	RH/CH,(m)	W, (m)	V.A (%)	S.P (m)	S.T (m)
Quonset/walk-in tunnel	Single	-	50-150	10-15	-	2- 3	2-5	3-5	0.5-1.5	-
Arc type	Single/ Multi	8-10	250-4000	25- 60	4.5- 5.5	3- 3.5	8- 66	20	2 - 3	2-2.5
Gable frame	Single	4-5	50-100	10- 20	2.5- 3	3.5- 4.5	4-5	10-15	2 - 3	1.5-2.5
Gothic	Single	-	80- 200	15- 20	-	3- 3.5	5- 9	3-5	0.5- 1.5	-
Double Arc/ saw tooth	Single/Multi	4- 8	560-4000	28-60	4-4.5	6.5- 7	20-76	20	2.65	4

GH: Gutter height, RH: Ridge height, CH: Central height, W: Width, L: Length, V.A: Ventilation area, S.P: Spacing purlins, S.T: Spacing truss

Fig. A and B : Walk-in tunnel/Quonset and Gothic type polyhouses in J & K, Uttarkhand and Himachal

Fig. C and D : Double and Multi-span saw tooth polyhouses of Punjab, Gujarat, Raichur and Rajasthan

(FEM) helps in observing stiffness and strength visualizations. It also helps to minimize material weight and cost of the structures. FEM allows detailed visualization and indicates the distribution of stresses and strains inside the body of a structure. Many of FEM software packages are available to analyse the load distribution in the structure. FEM allows entire designs to be constructed, refined and optimized before the design is manufactured. It is a common practice used to approximate solutions of differential equations as the basis for structural analysis. Greenhouse is designed by considering the prevailing loading conditions on the structures. Main loads on the greenhouse which have to be taken into account during design of greenhouse are dead load, imposed loads, installations, wind load, snow and seismic load. The design loads as described below were determined as per the IS 875-1 (1987), IS 875-2 (1987) and IS 875-3 (1987). Dead load, live loads and snow load determined as per the standards. As wind load is the major force responsible for the performance of the selected structures at sites. Hence, detailed procedure of wind load and stress due to combined loading is explained as follows.

Wind load:

The wind load of the greenhouse structures shall be estimated as prescribed in IS: 875 (Part 3).

Dead load and live load:

In present study, dead load was taken as 0.35 kN/m^2 [IS: 875- Part 1 (1987)]. Live load on the structure including crop load was assumed as 0.45 kN/m^2 [IS: 14462 (1997)].

Wind load calculation:

Wind load on a greenhouse structure is determined as per following steps (IS: 875 (Part 3) – 1987).

– Basic wind speed, V_b (m/s) for a particular site is obtained

– Design wind speed,

$$V_z = k_1 k_2 k_3 V_b$$

where; k_1 is a probability factor or risk coefficient obtained from Table 1 of IS: 875 (part 3) – 1987. k_2 is terrain, height and structure size factor which is obtained from Table 2 of IS: 875 (part 3) – 1987. k_3 is a topography factor obtained from IS: 875 (part 3) – 1987

– Design wind pressure,

$$P_z = 0.6 \times V_z^2$$

P_z = Design wind pressure in N/m^2 at height z, and V_z - design wind velocity in m/s at height Z.

Calculated and presented in Table 3.

– Wind Load on Individual Members

When calculating the wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, F, acting in a direction normal to the individual structural element or cladding unit is given as,

$$F = (Cpe - Cpi) \times A \times P_z$$

C_{pe} = external pressure co-efficient IS: 875 (part 3) – 1987

C_{pi} = internal pressure co-efficient

Important Step : selection of pressure coefficients (Cpe and Cpi):

Internal pressure co-efficient (Cpi) are decided on the basis of percentage opening areas as per the designed codes and estimatedfor selected designs

Design	Opening area	Cpi
Arc/ qounset	< 5 %	+2/-2
Gothic Polyhouse		
Gable type freestanding	5 – 20 %	+5/-5
Double Arc Polyhouse	5 – 20 %	+5/-5
Multi span saw tooth	>20%	+7/-7

Load combination:

As per IS: 875 (part 5) following load combinations are used during study.

– Dead load+ Live load

– Dead load+ Wind load

– Dead load+ Live load+ Wind load

Permissible stresses increased by 33 per cent when wind load was considered. According to IS: 875, out of live load and snow load only one should be considered at a time.Selected design of polyhouse h/w ratio lies between 0.5- 1.5 hence wind pressure co-efficients were selected accordingly and wind load was estimated for gable type polyhouse. The structure is then analyzed for total stress, starin and deformation for estimated load combinatio of Dead load, live load and wind load for Sikkim and meghalaya region.Similary Cpe was estimated for walkin tunnel and gothic for srinagar and multispan doublc arc for Punjab, rajasthan and Raichur regions.

All load values calculted and presented in (Table B, C, D, E and F).

ANSYS modelling and analysis procedure:

Members of Polyhouse were designed in solid works software as per the collected specification. Then all CAD drawings were converted into IGES platform *i.e.* accessible to import files in ANSYS. ANSYS workbench module was used in this study for simulation and modelling. The following general procedure was adopted for all the selected designs.

It consist three major steps;

Pre-process:

Selection of structural model is the first step. Next step is assigning engineering properties to the model. Most of the structural members are made of G.I. pipes, foundation concreted and cladding most common LDPE polythene. Hence material selected and accordingly properties were assigned in the model for steel, plastic and concrete.Next important step next to it is meshing, there are three type of mesh fine, medium and course. Number of elements and number of nodes are dependent of type of meshing and methods of meshing. It represents the number of differential equation for particular conditions and boundary conditions are executed to complete given task. As column pipes of all the structures were fixed in foundation. The fixed support is assigned to the bottom of the structure restricting its movement in all axis. It can be done by auto or default mode. Assigning force or estimated load value uniformly over the members at two wind angles 0^0 and 90^0.

Solution/ process:

Solution is the term given to the actual simultaneous equation solving of the mathematical model. The structure is analyzed for the desired output which is given in this step *i.e.* total equivalent von miss stress and deformation.

Post process:

The General Postprocessor is used to look at the results over the whole model at one point in time. This is the final step in determination of the stresses and deformation under load. The results are generated. The blue and red color indicates the value of stress or deformation depending upon the intensity of the colour. Dark red represents member under max value of stress or deformation but in case of blue colour it has minimum value (Fig. E-N).

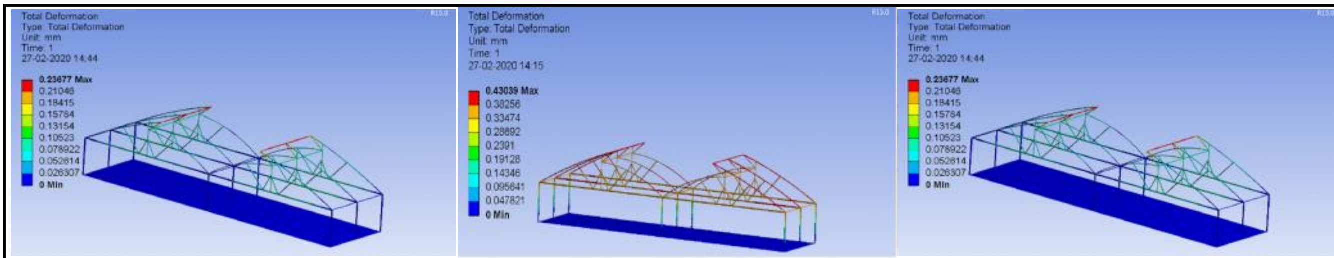

Fig. E : **Total deformation and stress value for double arc multi-span (column: 76 mm OD, truss 60 and 42mm) at 90° and 0° (Ver.)**

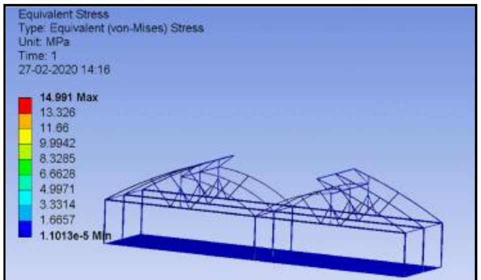

Fig. F : **Total Stress double arc multi-span (column: 76 mm OD, truss 60 and 42mm) at 0° (Hor.) for arid and semi-arid region**

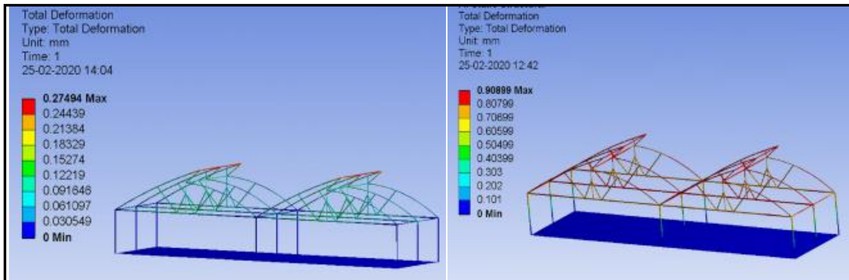

Fig. G : **Total deformation double arc multi-span (column: 60 mm OD, truss 48 mm) at 90° (Ver.) and 0° (Hor.)**

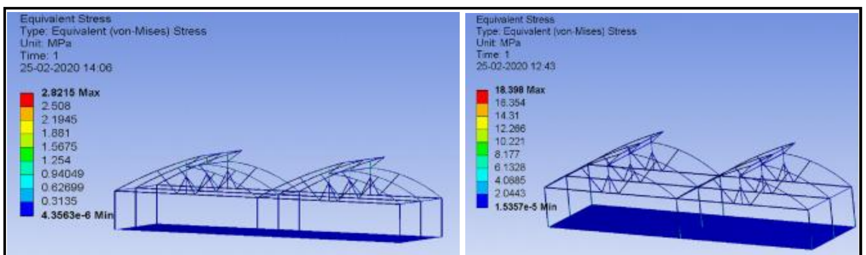

Fig. H : **Total Stress double arc multi-span (column: 60 mm OD, truss 48mm) at 90° (Ver.) and 0° (Hor.)**

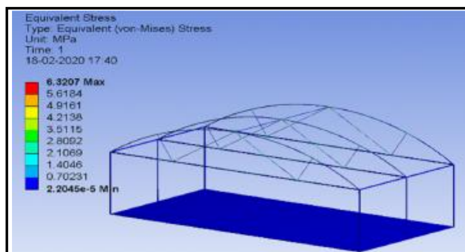

Fig. I : **Total Stress Quonset at 90° (Ver.)**

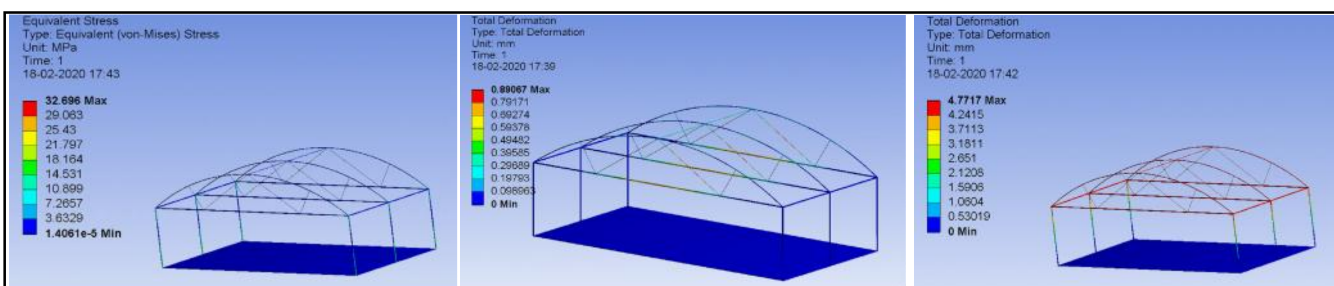

Fig. J : **Total Stress and deformation of Quonset at 0° (Hor.)and 90° (Ver.)**

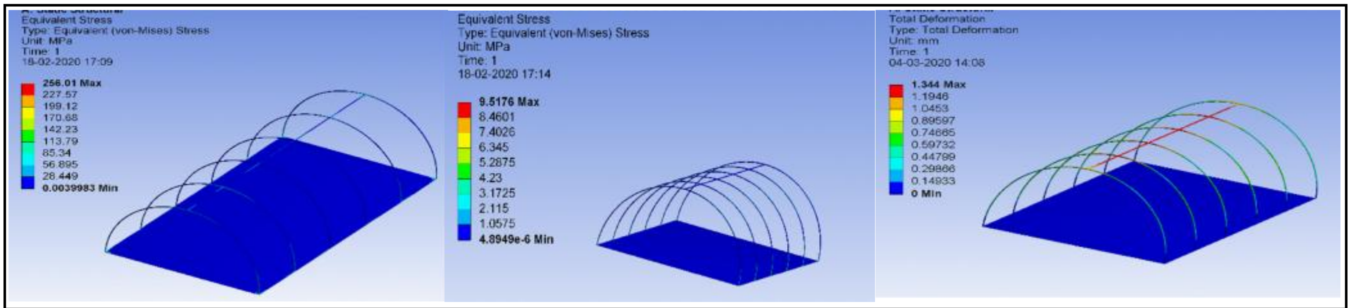

Fig. K : Total Stress and deformation of Quonset at 0° (Hor.)and 90° (Ver.)

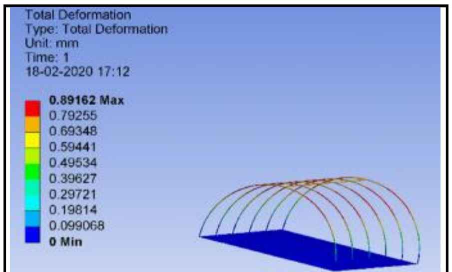

Fig. L : Total deformation Walk-in type/ Arc (40 mm OD at 0° (Hor.)

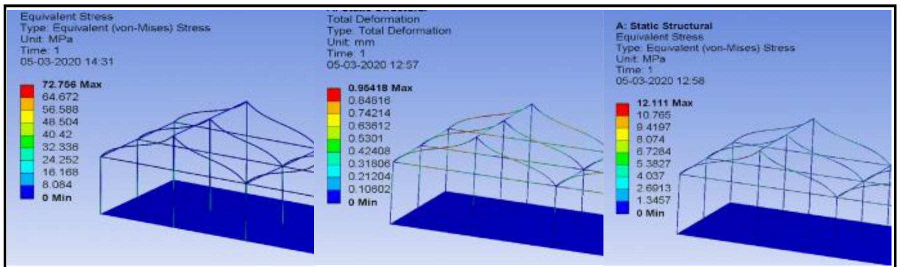

Fig. M : Total stress and deformation for gothic structures at 0° and 90°

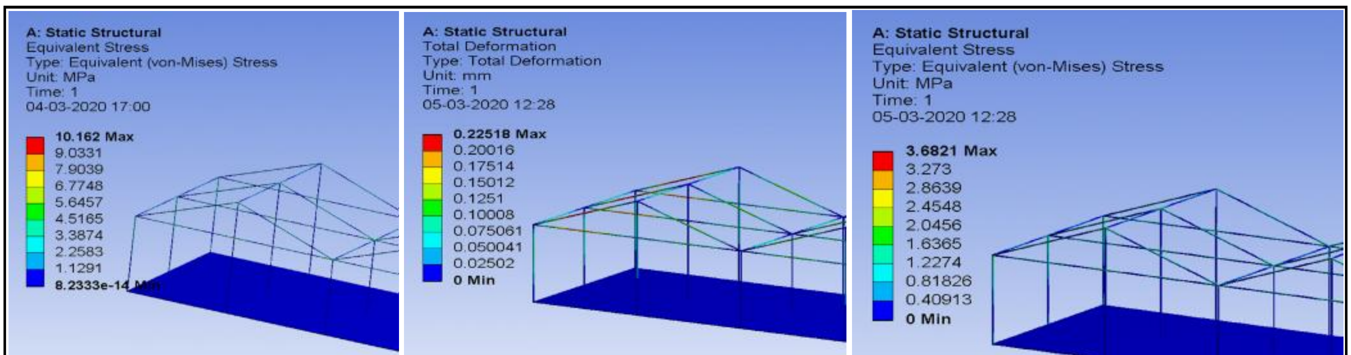

Fig. N : Total stress and deformation at 0° and 90° for even span structures

Table B : Wind zone properties of selected sites

Region	Site	Climatic Zone	Basic wind speed Vb (m/s)	Designed wind speed (Vz) (m/s)	Designed wind pressure (Pd), N/m^2	Design of polyhouse
Jammu & Kashmir	Srinagar		39	35.88	772.42	– Quonset/walk-in tunnel
Uttarkhand	Almora	Mountainous	47	43.44	1121.81	– Gothic
Sikkim	Gangtok		47	57.52	1985.69	– Gable frame (Even Span)
Meghalaya	Barapani	Humid subtropical	50	61.2	2247.26	
Punjab	Ludhiana		47	42.30	1073.57	– Double Arc/Saw tooth
Rajasthan	Udaipur	Arid and	47	43.56	1138.95	(Single/Multi span)
Gujarat	Junagadh	Semi-arid	50	45	1215.00	– Arc/semi arc type
Karnataka	Raichur		39	35.88	772.42	
Jharkhand	Ranchi	Humid subtropical	39	36.96	819.46	

Table C : Calculated loads on quonset and gothic polyhouse

Region	Type of load	Load (KN)			
		Arc (10m x 5m x 2.15m)		Gothic (20m x 9m x 3.5m)	
J & K	Dead Load	0.08		0.19	
Uttarakhand	Live Load			0.49	
	Snow Load			0.41	
	Wind Load				
	Wind speed (m/s)	θ=0°	θ=90°	θ=0°	θ=90°
	35	0.65	0.67	0.29	4.20
	40	0.85	1.25	0.66	0.94
	45	1.07	1.59	1.17	1.68
	50	1.32	1.96	1.60	2.29

Table D : Calculated wind load for gable type single span bamboo polyhouse

Region	Vb (m/s)	Vz (m/s)	Pz(N/m^2)	θ=0°		θ=90°					
				Pr. Coeff.				Total wind load, kN			
				Windward	Leeward	Windward	Leeward	θ=0°		θ=90°	
				Cpe-Cpi		Cpe-Cpi					
Sikkim	47	45.34	1233.73	-0.7	-1	-1.3	-0.3	-0.86	-1.23	-1.60	-0.37
Meghalaya	50	48.24	1396.26	-0.7	-1	-1.3	-0.3	-0.98	-1.40	-1.82	-0.42

Table E : Total calculated wind load on multi-span type polyhouse

Wind speed (m/s)	First span (kN/m^2)		First intermediate span (kN/m^2)		Other intermediate span (kN/m^2)		End span (kN/m^2)	
	a	b	c	d	m	n	x	z
33	0.72	-0.78	-0.78	-0.61	-0.61	-0.72	-0.72	-0.55
39	0.96	-1.04	-1.04	-0.82	-0.82	-0.96	-0.96	-0.74
44	1.20	-1.29	-1.29	-1.02	-1.02	-1.20	-1.20	-0.92
47	1.34	-1.44	-1.44	-1.13	-1.13	-1.34	-1.34	-1.03
50	1.52	-1.63	-1.63	-1.28	-1.28	-1.52	-1.52	-1.17

-ve: represents negative pressure

Table F : Estimated load semi arc tooth polyhouse

Site	Basic wind speed (m/s)	Wall wind load (kN/m^2)	Roof wind load (kN/m^2)	DL+LL (kN/m^2)	Total load (kN/m^2)
Karnataka and Jharkhand	39	1.04	-1.06	0.8	1.86
Punjab and Rajasthan	47	1.44	-1.47	0.8	2.27
Gujarat	50	1.63	-1.67	0.8	2.47

RESULTS AND DISCUSSION

All the structures were analyzed as per the estimated load for respective wind zone. The design wind load on the roof was determined as resultant effect of internal air pressure and external air pressure.It was found that in most of the design only two type of truss were used one is king post and w type truss. In theoretical calculation by method of joint and section, it was found that in case of arc type structure the tensile forces in rafters are maximum just above the ground level, as the height of structure increases these gets reduces. In case of purlins the tensile forces reduces as height of the structure increases. The top purlins carry maximum compressive forces *i.e.* the ridgeline, as compared to bottom purlins.Maximum stresses occurs at the eaves *i.e.* the junction between the columns, rafters and purlins. Ratio of Length-width: 80: 20 or 75:25 then Side Height should be in the range of 3-5m and central height is 3-9m. Gothic shape type design was found to be best in heavy snow load conditions. In semi-arid regions, it is recommended that side vent of 1m without shade net provides favorable microclimate inside polyhouse structure. The change of the ratio h/s from 0.3 to 0.6 caused an increase in the maximum stresses of 60- 66%

Table 1 : Revised specification of exiting design of Arc shape greenhouse structure

Min- Max	Purlin		Truss		Column		Foundation	
Vb (m/s)	OD (mm)	t (mm)	OD (mm)	t (mm)	OD (mm)	t (mm)	OD (mm)	t (mm)
33	33.7	2.65	33.7	2.65	60.3	2.9	48.3	2.9
39	33.7	2.65	33.7	2.65	60.3	2.9	48.3	2.9
44	33.7	2.65	33.7	2.65	60.3	3.25	48.3	2.9
47	33.7	3.25	33.7	3.25	60.3	3.25	48.3	2.9
50	33.7	3.25	33.7	3.25	60.3	3.25	48.3	3.25
55	33.7	3.25	42.4	2.65	60.3	3.65	48.3	3.25

Table 2 : Revised specification of exiting design of saw tooth shape greenhouse structure

Min- Max	Purlin		Truss		Column		Foundation	
Vb (m/s)	OD (mm)	t (mm)	OD (mm)	t (mm)	OD (mm)	t (mm)	OD (mm)	t (mm)
33	33.7	2.65	33.7	2.65	60.3	2.9	48.3	2.9
39	33.7	2.65	33.7	2.65	60.3	2.9	48.3	2.9
44	33.7	2.65	33.7	2.65	60.3	2.9	48.3	2.9
47	33.7	3.25	33.7	3.25	60.3	3.25	48.3	2.9
50	33.7	3.25	33.7	3.25	60.3	3.25	48.3	2.9
55	33.7	3,25	42.4	3.25	60.3	3.25	48.3	2.9

Table 3 : Revised specification of exiting design for quonset/walkin shape polyhouse

Wind speed (m/s)	Column	Rafter	Purlin
	ϕ (mm)	ϕ (mm)	ϕ (mm)
35	42.4L	60.3L	21.3L
40	42.4L	60.3L	21.3L
45	42.4L	60.3L	21.3L
50	42.4L	60.3L	21.3L
55	42.4L	60.3H	21.3L

Table 4 : Revised specification of exiting design for gothic shape polyhouse

Gothic shape	Column		Rafter			Purlin	
	Entrance	Rear	Entrance	Middle	Rear	Top (Ridge)	Sides
33	33.7L	2.69H	4.24L	4.24M	3.37 M	2.13 L	4.24L
39	3.37L	3.37L	4.24M	6.03L	4.24L	2.13 L	4.24L
47	3.37L	3.37L	4.24M	6.03 L	4.24 L	2.13 L	4.24L

L&L = Light section, M= Medium section, H= Heavy section

Table 5 : Suggested modification in specification for Double arc type multi span polyhouse

Members Name	Outside Diameter(mm)	Thickness (mm)	Wt. per meter length (kg)
Columns	60	2	3.75
Top Purlins	48	2	2.00
Gutter Purlins	42	2	2.00
Top Arches of the truss	42	2	2.00
Bottom Chord of the truss	60	2	3.00
Internal Bracings of the truss	33	2	1.60
Corridors/Balconies	60	2	3.0
Curtain Runner	42	2	2.00
Flap control pipe	21	2	1
Curtain Shaft	27	2	1.30
Cross Bracing	33	2	1.60

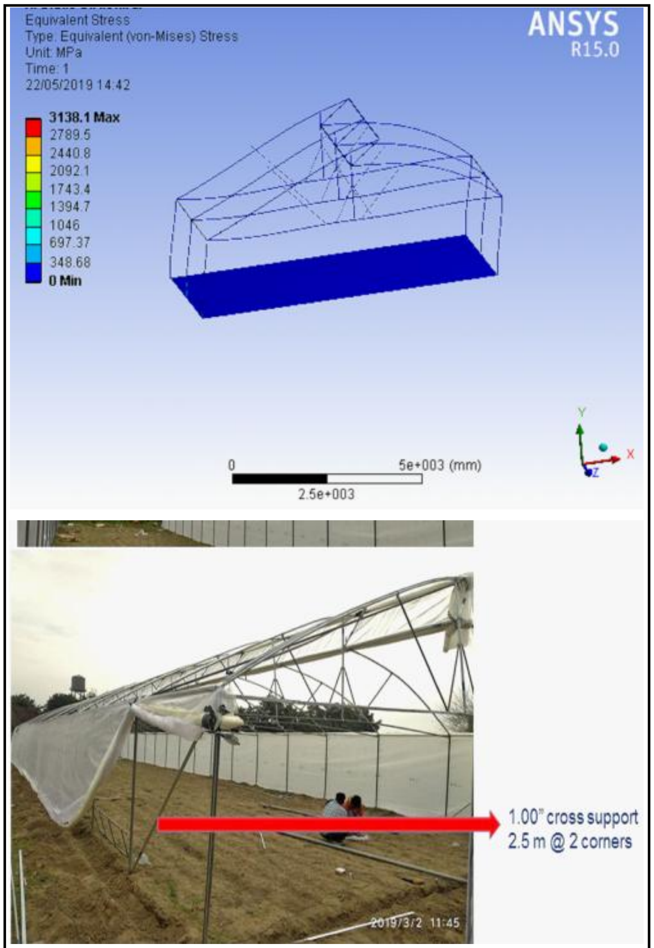

Fig. 1 : Without support

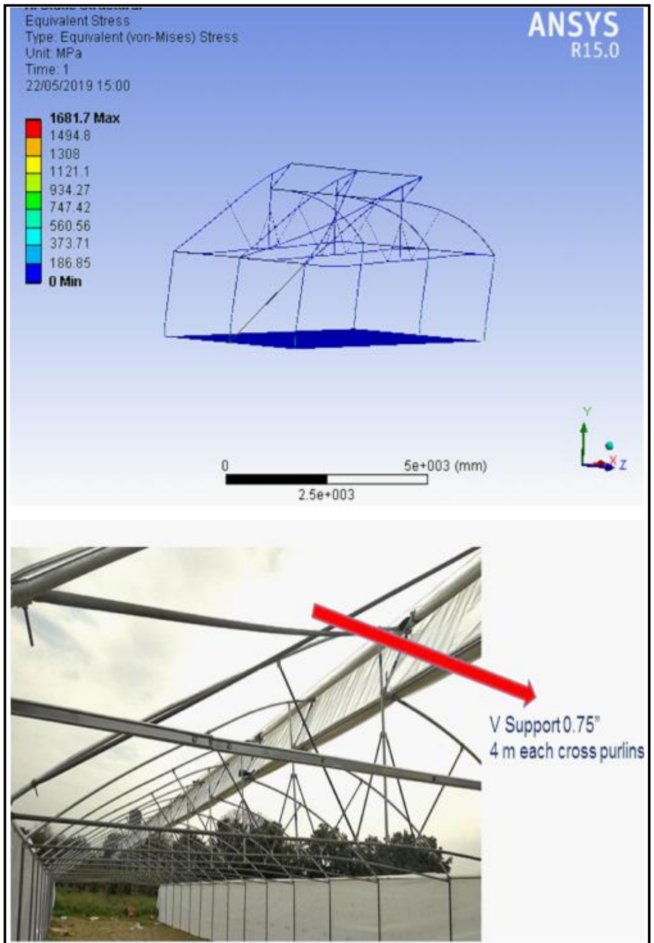

Fig. 2 : Without support

Fig. 3 : New validated design of Polyhouse in the field after analysis

in columns zones and 49- 37% in roof zones. By varying the roof slope from 20 to 26°, with h/s=0.3, it was noted that the maximum stress decreased from13% to 5% and with h/s=0.6, it decreased from 20% to 17%. Both single span and multi-span structures were analyzed for the estimated loads (Table B) at two wind angles of θ =0° and θ =90°. Two different size of the member were used in the study (column 76 mm, 42 mm and another 60mm and 48 mm). The total stress value and deformation in case of multi-span was found to be maximum at wind angle 0° as compare to 90° (Fig. E to Fig. H). As per the simulated data of analysis it is recommended to use 60 mm for column and 48 mm for main purlins, because stress value reduced up to 22% and deformation by 3%.Similarly analysis was done for Quonset type, Arc type, and walk-in tunnel and even span Polyhouse in ANSYS 15.0 (Fig. K- Fig. N). Few simulated models have shown here and then revised specification of the members of the structures are presented in Tables (1-5). Display of extreme red colour required urgent attention, hence member specification was revised in next step of analysis or extra support was added wherever required. The findings of the study revealed that standards needed to be revised to suit agro climatic zone condition. Similar studies reported by (Nayak *et al.*, 2014).

Validation of single span saw tooth design:

One Polyhouse design was modified by giving extra support in purlins of truss and columns without changing major specifications. It has been shown in the (Fig. 2) V support of GI pipe 25.4 mm dia. And cross bar of 38mm dia. at four end corners of structure. The structure was fabricated and installed in the field. Both existing and new designs were analyzed in the ANSYS and it has been found that total stress value was reduced to 46.43% (Fig. 1 and 2). The structure stability was improved which is also verified from after testing its stability in the filed during extreme storm (more than 150 km/h wind speed) of Punjab in 2019.

Future suggestions:

Standards are required also for sheet locking and fixing mechanism, joints between members of the structures for different zones.

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