J. Agr. Sci. Tech. (2022) Vol. 24(5): 1187-1204

Structural stability analysis of naturally ventilated polyhouses under different conditions

L. Singh[1*], A. Kaushal[1], J. Singh[2], and R. Sharda[1]

ABSTRACT

This research work on structural stability analysis of naturally ventilated polyhouses was carried out at the Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana. There were 12 treatments which were combination of four different sizes of polyhouses i.e. 560 (T1-T3); 1,008 (T4-T6); 2,080 (T7-T9); 4,000 m^2 (T10-T12), with three design wind speeds of 100, 150, and 200 km h^{-1}, respectively. Stability analysis of truss members, columns, and foundation was carried out by considering dead loads, live loads and wind loads. Support reactions were computed on truss and column joints. Member forces were computed by using force method. For every 17 set of truss members, four members [two in compression (small arc) and two in tension (truss bracings)] failed in treatments with 150 and 200 km h^{-1} wind speed, while in treatments with 100 km h^{-1} wind speed, two members [in compression, (small arc)] failed. Minimum structural GI pipe material requirement for structurally stable polyhouses was under treatment T1 (2,407 kg) and the maximum was under treatment T12 (19,550 kg).

Keywords: Factor of safety, Force method, Protected cultivation technology, Wind speed.

INTRODUCTION

In protected cultivation technology, the environment surrounding the plants is controlled to some extent or completely as per the need of the crop during growth period. During protected cultivation climatic conditions like temperature, solar radiation, wind, humidity and air compositions (adequate concentration of carbon dioxide) are controlled. Adoption of these technology changes the cycles of traditional cropping, lengthen time of harvesting, improves quality and yield of crop and gives offseason production, which results in increasing the profitability of the farmers (Wittwer and Castilla 1995). The technology of protective cultivation helps us to obtain high value products (Kyrikou *et al.*, 2011).

A polyhouse is a type of greenhouse that 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 (Nayak *et al.*, 2018). Rainfall and heavy wind storms are the major causes that damage the structure and film of polyhouse; therefore, all components have to be designed properly with a suitable factor of safety. For a satisfactory level of protection and to avoid huge damage, the design parameters must be based on relative standards, which provide guidelines for evaluating different design loads (Elsner *et al.*, 2000). The structural design of greenhouse must be able to carry combination of all types of loads (Nayak *et*

[1] Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, Punjab, India 141004.
[2] Department of Civil Engineering, Punjab Agricultural University, Ludhiana, Punjab, India 141004.
*Corresponding author; e-mail: singhlovepreet1611@gmail.com

al., 2018). The greenhouse structure should be designed in such a way that it fortifies against destruction due to rain, wind and extremities of temperature (Jensen and Malter, 1994). 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 1,396.25 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.

Indian standard for layout, design and construction of greenhouse structures (IS: 14462-1997) does not offer a procedure for the structurally stable design of greenhouses. As the wind speed varies from place to place, so does the wind load acting on the structure, resulting in geographically different designs. There is a need to lay more stress on structural design as the properly designed poly houses are always safe and cheaper. If a polyhouse is under designed, it will collapse like it is happening in many states of India including Punjab, and when the polyhouse is over designed, its cost increases many-folds. Hence, the present study was planned with the objective to carry out structural analysis of naturally ventilated polyhouse under different conditions.

MATERIALS AND METHODS

Methodology

Treatment Details

There were 12 treatments taken for the research study and were combination of four different sizes of polyhouses i.e. 560 m^2, 1,008 m^2, 2,080 m^2 and 4,000 m^2 with three design wind speeds of 100, 150, and 200 km h^{-1} as shown in Table 1. Their detail drawings were drawn and their dimensions and materials were studied in details with their technical specifications. Figure 1 shows the photograph of different views of 560 m^2 sizes of naturally ventilated polyhouse located in Punjab Agricultural University, Ludhiana Punjab.

The procedure for structural stability analysis consists of checking the stability of trusses including its each member, main and side columns and foundations for each of the twelve treatments (T1–T12) as shown in Table 2. The truss member includes main column, bottom chord, big arc, small arc, and truss bracings as shown in Figure 2. The specification of structural components of different sizes of polyhouse and truss members are shown in Tables 2 and 3, respectively, which were taken from Indian Standard (IS:14462 1997) and technical recommendations (Anonymous, 2019).

The lower portion of polyhouse structure consist of five major components (Figure 3) i.e. main column, side column, horizontal bracing, hockey, curtain runner and side column to column inclined bracing and initial dimensions of these components are shown in Table 3.

Table 1. Treatment details.

Treatments	Treatment details
T1, T2 and T3	Polyhouse size 560 m^2 with wind speed 100, 150 and 200 km h^{-1} respectively
T4, T5 and T6	Polyhouse size 1008 m^2 with wind speed 100, 150 and 200 km h^{-1} respectively
T7, T8 and T9	Polyhouse size 2080 m^2 with wind speed 100, 150 and 200 km h^{-1} respectively
T10, T11 and T12	Polyhouse size 4000 m^2 with wind speed 100, 150 and 200 km h^{-1} respectively

Figure 1. Front view of 560 m^2 polyhouse at PAU, Ludhiana.

Table 2. Initial specifications taken for stability analysis of different truss members for different treatments (T1–T12)

S no	Truss members	Sub-truss members	Length (m)	Diameter (mm)	Thickness (mm)
1	Main column	1	1.60	76	2
		2	0.30	76	2
		3	0.60	76	2
2	Bottom chord	4	2.10	60	2
		5	1.90	60	2
		6	1.90	60	2
		7	2.10	60	2
3	Big arc	8	2.29	48	2
		9	2.48	48	2
		10	0.72	48	2
4	Small arc	11	2.25	48	2
		12	2.25	48	2
5	Truss bracings	13	1.54	32	2
		14	2.48	32	2
		15	2.48	32	2
		16	1.33	32	2
		17	1.03	32	2
6	Purlins	18	4.0	48	2

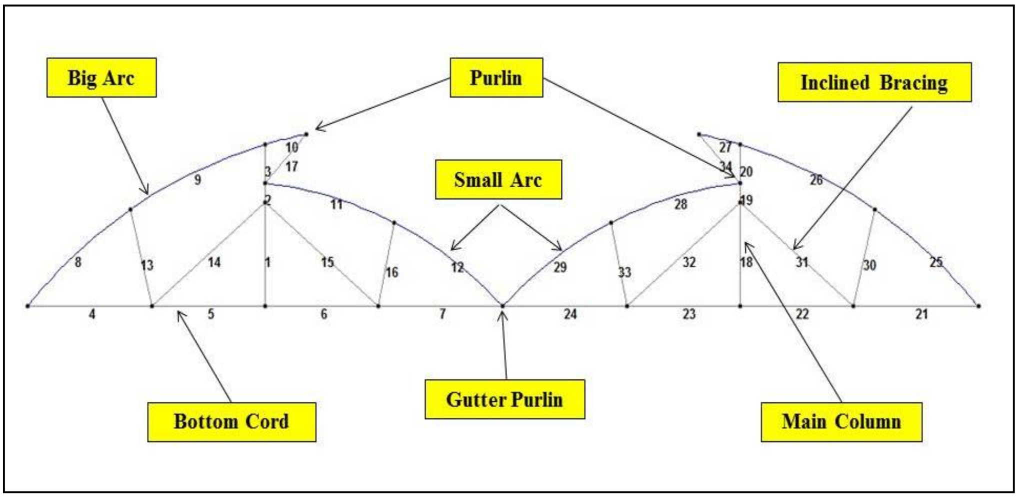

Figure 2. Details of truss members of polyhouse structure.

Table 3. Initial specifications taken for stability analysis of lower portion members for different treatments (T1–T12).

S no	Items	Diameter (mm)	Thickness (mm)
1	Main column	76	2
2	Side column	76	2
3	Horizontal bracings	42	2
4	Hockey	60	3
5	Curtain runner	33	2
6	C/C inclined bracing	42	2

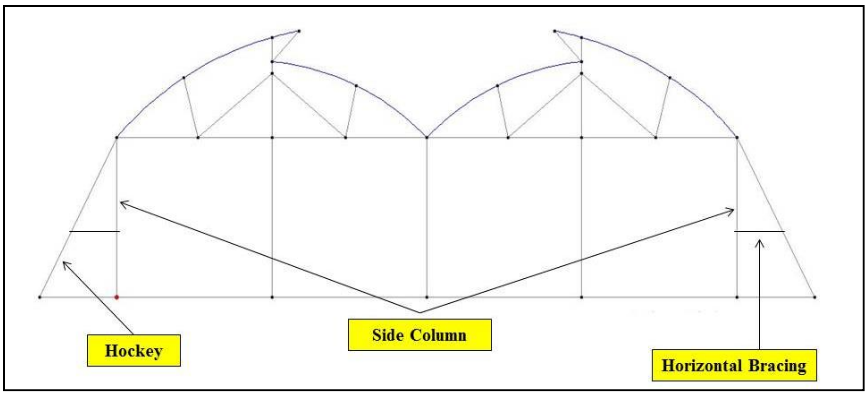

Figure 3. Lower portion members of polyhouse structure.

Methodology of Structural Stability Analysis

Dead Load, Live Load and Wind load were computed as per code recommendations. Load combinations were considered as per codal recommendations. Design load was computed as per guidelines of IS 875 (Part 5): 1987.

Computation of Support Reactions and Member Forces

The support reactions shown in Figure 4 were determined for all the treatments. Figure 4 shows the support reactions on 560 m^2 polyhouse. Computation of member forces was carried out using force method. Positive sign of member force due to loads indicates that the force acts towards the structural element where as a negative force indicates that the force is acting away from the structural element.

Design Strength of Truss Members

Depending upon the magnitude and sign of the design force, the member was designed as a Tension or a Compression member. Design strength of Tension and Compression members was checked by following the procedure given in IS 800:2007

Stability Analysis of Column Members and Foundation

Critical loads were determined and compared with design force calculated as per

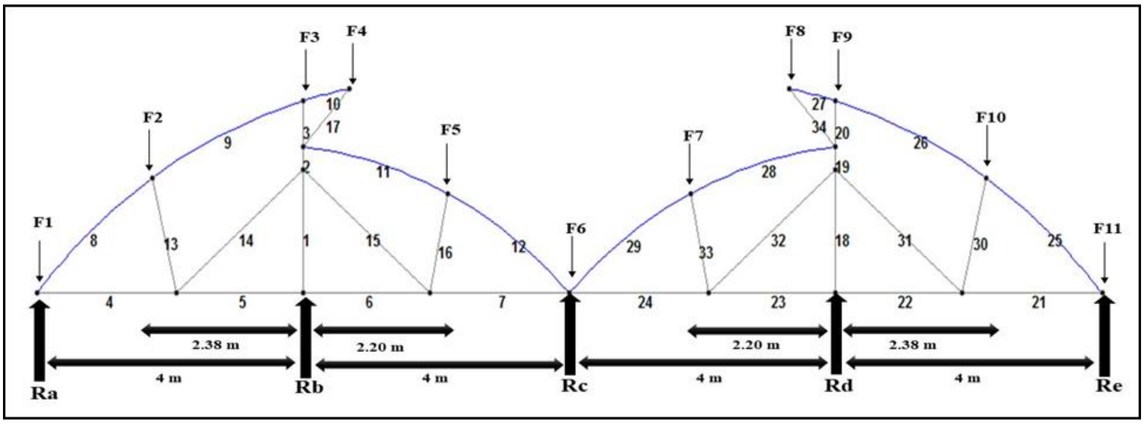

Figure 4. Support reactions on trusses.

the procedure given in IS 800:2007. Stability analysis of foundation footings was done by computing bearing strength of concrete and comparing it with bearing pressure of concrete.

RESULTS

Truss Stability Analysis

The truss member forces were calculated by the following force method. Treatment T1/T2/T3 contains 34 truss members (Figure 5), out of which 17 member forces are shown in Tables 4-6 with their stable diameters and their designed force value that are more than the maximum force value, a condition for their structural stability, while the rest of 17 members forces repeat themselves. Treatment T4/T5/T6 contains 68 truss members (Figure 6), out of which 17 member forces are shown in Tables 7–9 with their stable diameters and their designed force value that are more than the maximum force value, a condition for their structural stability, while the rest of 51 members forces repeat themselves after every 17 members. Treatment T7/T8/T9 contains 102 truss members (Figure 7), out of which 17 member forces are shown in Tables 10–12 with their stable diameters and their designed force value that are more than the maximum force value, a condition for their structural stability, while the rest of 85 members forces repeat themselves after every 17 members. Treatment T10/T11/T12 contains 204 truss members (Figure 8), out of which 17 member forces are shown in Tables 13–15 with their stable diameters and their designed force value that are more than the maximum force value, a condition for their structural stability, while the rest of 187 members forces repeat themselves after every 17 members. Initial specifications (diameter) for different truss members, as recommended by Indian standards, were reduced in size for each truss member and complete structural analysis was carried out.

For treatment T1, Table 4 indicates that the structure was found to be stable when diameter of members 1, 2, and 3 was reduced from 76 to 60 mm, members 4,5,6, and 7 were reduced from 60 to 42 mm, members 8,9, and 10 were reduced from 48 to 32 mm, and members 11 and 12 were reduced from 48 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as * in Table 4).

Table 4. Truss member forces under different combinations of loads for stable structure in treatment T1.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	60	0.44	3.08	16.14	24.87	74.67
2	60	0.44	3.08	16.14	24.87	82.68
3	60	0.17	1.07	5.67	8.75	82.32
4	42	-0.14	-0.86	-4.48	-6.93	-27.39
5	42	0.05	0.73	1.55	2.79	39.19
6	42	0.05	0.73	1.55	2.40	39.19
7	42	-0.13	-0.82	-4.33	-6.69	-27.39
8	32	0.18	1.13	5.94	9.18	14.66
9	32	0.12	0.76	3.76	5.82	12.81
10	32	0.06	0.53	2.67	4.10	39.38
11	42	0.28	3.96	14.76	22.80	34.16
12	42	0.25	1.79	9.41	14.49	34.16
13	32*	0.13	1.13	4.32	6.69	26.38
14	32*	-0.20	-1.71	-6.51	-10.10	-15.04
15	32*	-0.20	-1.71	-6.51	-10.10	-15.04
16	32*	0.13	1.12	4.28	6.64	31.27
17	32*	0.07	0.54	1.26	2.25	35.98

For treatment T2, Table 5 indicates that the structure was found to be stable when diameter of member 4, 5, 6, and 7 was reduced from 60 to 48 mm, diameter of members 8, 9, and 10 were reduced from 48 to 42 mm, diameter of members 11 and 12 increased from 48 to 60 mm, diameter of members 14 and 15 increased from 32 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 5).

For treatment T3, Table 6 indicates that the structure was found to stable when diameter of members 11 and 12 increased to 76 mm and diameter of members 14 and 15 increased to 60 mm , keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 6).

Table 5. Truss member forces under different combinations of loads for stable structure in treatment T2.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.44	3.08	34.08	51.77	99.45
2	76*	0.44	3.08	34.08	51.77	105.49
3	76*	0.17	1.07	11.60	17.65	105.26
4	48	-0.14	-0.86	-9.47	-14.41	-34.81
5	48	0.05	0.73	3.28	4.99	50.27
6	48	0.05	0.73	3.28	4.99	50.27
7	48	-0.13	-0.82	-9.14	-13.91	-34.81
8	42	0.18	1.13	12.54	19.09	31.15
9	42	0.12	0.76	7.98	12.14	27.88
10	42	0.06	0.53	4.18	6.37	54.76
11	60	0.28	3.96	31.01	46.93	66.29
12	60	0.25	1.79	19.79	30.06	66.29
13	32*	0.13	1.13	9.11	13.87	26.38
14	42	-0.20	-1.71	-13.76	-20.93	-27.39
15	42	-0.20	-1.71	-13.76	-20.93	-27.39
16	32*	0.13	1.12	9.04	13.76	31.27
17	32*	0.07	0.54	4.82	7.34	35.98

Table 6. Truss member forces under different combinations of loads for stable structure in treatment T3.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.44	3.08	57.94	87.57	99.45
2	76*	0.44	3.08	57.94	87.57	105.49
3	76*	0.17	1.07	13.70	20.80	105.26
4	60*	-0.14	-0.86	-16.07	-24.31	-49.64
5	60*	0.05	0.73	5.60	8.48	71.03
6	60*	0.05	0.73	5.60	8.48	71.03
7	60*	-0.13	-0.82	-15.52	-23.48	-49.64
8	48*	0.18	1.13	21.29	32.21	43.62
9	48*	0.12	0.76	13.50	20.42	52.00
10	48*	0.06	0.53	7.54	11.40	52.50
11	76	0.28	3.96	48.21	72.74	92.94
12	76	0.25	1.79	31.63	47.81	92.94
13	32*	0.13	1.13	15.50	23.45	26.38
14	60	-0.20	-1.71	-23.40	-35.39	-49.64
15	60	-0.20	-1.71	-23.40	-35.39	-49.64
16	32*	0.13	1.12	15.38	23.26	31.27
17	32*	0.07	0.54	7.49	11.34	35.98

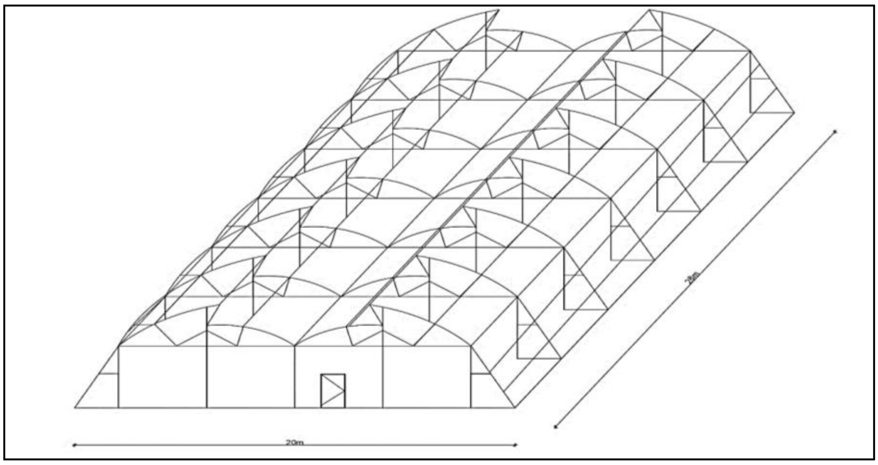

Figure 5. Isometric view of 560 m^2 polyhouse structure (T1/T2/T3).

For treatment T4, Table 7 indicates that the structure was found to be stable when diameter of members 1, 2, and 3 were reduced from 76 to 60 mm, for members 4, 5, 6, and 7were reduced from 60 to 42 mm, for members 8, 9, and 10 were reduced from 48 mm to 32 mm, and for members 11 and 12 were reduced from 48 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 7).

Table 7. Truss member forces under different combinations of loads for stable structure in treatment T4.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	60	0.56	3.08	16.14	25.05	74.67
2	60	0.56	3.08	16.14	25.05	82.68
3	60	0.15	0.73	3.81	5.94	82.32
4	42	-0.18	-0.86	-4.48	-6.99	-27.39
5	42	0.06	0.14	1.55	2.42	39.19
6	42	0.06	0.14	1.55	2.42	39.19
7	42	-0.17	-0.80	-4.33	-6.74	-27.39
8	32	0.23	1.13	5.94	9.26	14.66
9	32	0.15	0.72	3.77	5.87	12.81
10	32	0.08	0.40	2.11	3.28	39.38
11	42	0.36	2.30	14.68	22.56	34.16
12	42	0.31	1.79	9.38	14.54	34.16
13	32*	0.17	0.82	4.32	6.73	26.38
14	32*	-0.25	-1.04	-6.52	-10.15	-15.04
15	32*	-0.25	-1.04	-6.52	-10.15	-15.04
16	32*	0.17	0.69	4.28	6.67	31.27
17	32*	0.08	0.40	2.09	3.26	35.98

For treatment T5, Table 8 indicates that the structure was found to be stable when diameter of members 4, 5, 6, and 7 diameter were reduced from 60 to 48 mm, members 8,9 and 10 were reduced from 48 to 42 mm, members 11 and 12 increased from 48 mm to 60 mm, and members 14 and 15 increased from 32 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 8).

Table 8. Truss member forces under different combinations of loads for stable structure in treatment T5.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.56	3.08	34.08	51.95	99.45
2	76*	0.56	3.08	34.08	51.95	105.49
3	76*	0.15	0.73	8.05	12.29	105.26
4	48	-0.18	-0.86	-9.47	-14.46	-34.81
5	48	0.06	0.14	3.28	5.00	50.27
6	48	0.06	0.14	3.28	5.00	50.27
7	48	-0.17	-0.80	-9.14	-13.96	-34.81
8	42	0.23	1.13	12.54	19.16	31.15
9	42	0.15	0.72	7.96	12.15	27.88
10	42	0.08	0.40	4.45	6.79	54.76
11	60	0.36	2.30	31.01	47.05	66.29
12	60	0.31	1.79	19.79	30.16	66.29
13	32*	0.17	0.82	9.11	13.92	26.38
14	42	-0.25	-1.04	-13.76	-21.01	-27.39
15	42	-0.25	-1.04	-13.76	-21.01	-27.39
16	32*	0.17	0.69	9.04	13.81	31.27
17	32*	0.08	0.40	4.41	6.74	35.98

For treatment T6, Table 9 indicates that the structure was found to be stable when diameter of members 11 and 12 increased from 48 to 76 mm and for member 14 and 15 increased from 32 to 60 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 9).

Table 9. Truss member forces under different combinations of loads for stable structure in treatment T6.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.56	3.08	57.92	87.72	99.45
2	76*	0.56	3.08	57.92	87.72	105.49
3	76*	0.15	0.73	13.68	20.74	105.26
4	60*	-0.18	-0.86	-16.09	-24.40	-49.64
5	60*	0.06	0.14	5.57	8.44	71.03
6	60*	0.06	0.14	5.57	8.44	71.03
7	60*	-0.17	-0.80	-15.54	-23.56	-49.64
8	48*	0.23	1.13	21.32	32.33	43.62
9	48*	0.15	0.72	13.52	20.50	52.00
10	48*	0.08	0.40	7.56	11.46	52.50
11	76	0.36	2.30	52.73	79.64	92.94
12	76	0.31	1.79	33.63	50.92	92.94
13	32*	0.17	0.82	15.49	23.49	26.38
14	60	-0.25	-1.04	-23.38	-35.45	-49.64
15	60	-0.25	-1.04	-23.38	-35.45	-49.64
16	32*	0.17	0.69	15.37	23.30	31.27
17	32*	0.08	0.40	7.50	11.37	35.98

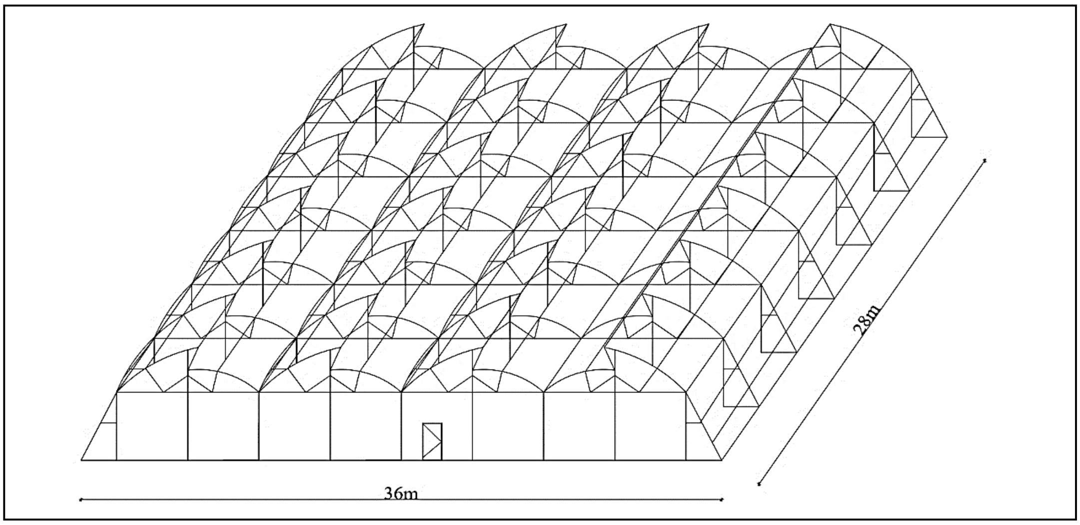

Figure 6. Isometric view of 1008 m^2 polyhouse structure (T4/T5/T6).

For treatment T7, Table 10 indicates that the structure was found to be stable when diameter of members 1, 2, and 3 were reduced from 76 to 60 mm, for members 4, 5, 6, and 7 were reduced from 60 to 42 mm, for members 8,9, and 10 were reduced from 48 mm to 32 mm, and for members 11 and 12 were reduced from 48 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 10).

Table 10. Truss member forces under different combinations of loads for stable structure in treatment T7.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	60	0.67	3.08	15.72	24.59	74.67
2	60	0.67	3.08	15.72	24.59	82.68
3	60	0.08	0.73	3.71	5.68	82.32
4	42	-0.22	-0.86	-4.37	-6.88	-27.39
5	42	0.06	0.14	1.51	2.36	39.19
6	42	0.06	0.14	1.51	2.36	39.19
7	42	-0.21	-0.80	-4.22	-6.64	-27.39
8	32	0.29	1.13	5.79	9.11	14.66
9	32	0.19	0.72	3.67	5.78	12.81
10	32	0.08	0.40	2.05	3.20	39.38
11	42	0.42	2.30	14.31	22.09	34.16
12	42	0.38	1.79	9.13	14.26	34.16
13	32*	0.20	0.82	4.20	6.61	26.38
14	32*	-0.30	-1.04	-6.34	-9.97	-15.04
15	32*	-0.30	-1.04	-6.34	-9.97	-15.04
16	32*	0.20	0.69	4.17	6.55	31.27
17	32*	0.14	0.40	2.03	3.26	35.98

For treatment T8, Table 11 indicates that the structure was found to be stable when diameter of members 4,5,6, and 7 were reduced from 60 to 48 mm, for members 8,9, and 10 were reduced from 48 to 42 mm, for members 11 and 12 were increased from 48 mm to 60 mm, and for members 14 and 15 were increased from 32 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 11).

Table 11. Truss member forces under different combinations of loads for stable structure in treatment T8.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.67	3.08	33.19	50.79	99.45
2	76*	0.67	3.08	33.19	50.79	105.49
3	76*	0.08	0.73	7.84	11.87	105.26
4	48	-0.22	-0.86	-9.22	-14.16	-34.81
5	48	0.06	0.14	3.19	4.88	50.27
6	48	0.06	0.14	3.19	4.88	50.27
7	48	-0.21	-0.80	-8.90	-13.67	-34.81
8	42	0.29	1.13	12.22	18.76	31.15
9	42	0.19	0.72	7.75	11.90	27.88
10	42	0.08	0.40	4.33	6.62	54.76
11	60	0.42	2.30	30.21	45.95	66.29
12	60	0.38	1.79	19.27	29.48	66.29
13	32*	0.20	0.82	8.88	13.61	26.38
14	42	-0.30	-1.04	-13.40	-20.55	-27.39
15	42	-0.30	-1.04	-13.40	-20.55	-27.39
16	32*	0.20	0.69	8.80	13.50	31.27
17	32*	0.14	0.40	4.30	6.653	35.98

For treatment T9, Table 12 indicates that the structure was found to be stable when diameter of members 11 and 12 increased from 48 to 76 mm and for members 14 and 15 were increased from 32 to 60 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 12).

Table 12. Truss member forces under different combinations of loads for stable structure in treatment T9.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	0.67	3.08	56.42	85.64	99.45
2	76*	0.67	3.08	56.42	85.64	105.49
3	76*	0.08	0.73	13.32	20.10	105.26
4	60*	-0.22	-0.86	-15.68	-23.84	-49.64
5	60*	0.06	0.14	5.42	8.23	71.03
6	60*	0.06	0.14	5.42	8.23	71.03
7	60*	-0.21	-0.80	-15.14	-23.02	-49.64
8	48*	0.29	1.13	20.77	31.59	43.62
9	48*	0.19	0.72	13.17	20.04	52.00
10	48*	0.08	0.40	7.36	11.17	52.50
11	76	0.42	2.30	51.35	77.66	92.94
12	76	0.38	1.79	32.77	49.72	92.94
13	32*	0.20	0.82	15.09	22.93	26.38
14	60	-0.30	-1.04	-22.78	-34.62	-49.64
15	60	-0.30	-1.04	-22.78	-34.62	-49.64
16	32*	0.20	0.69	14.97	22.75	31.27
17	32*	0.14	0.40	7.31	11.17	35.98

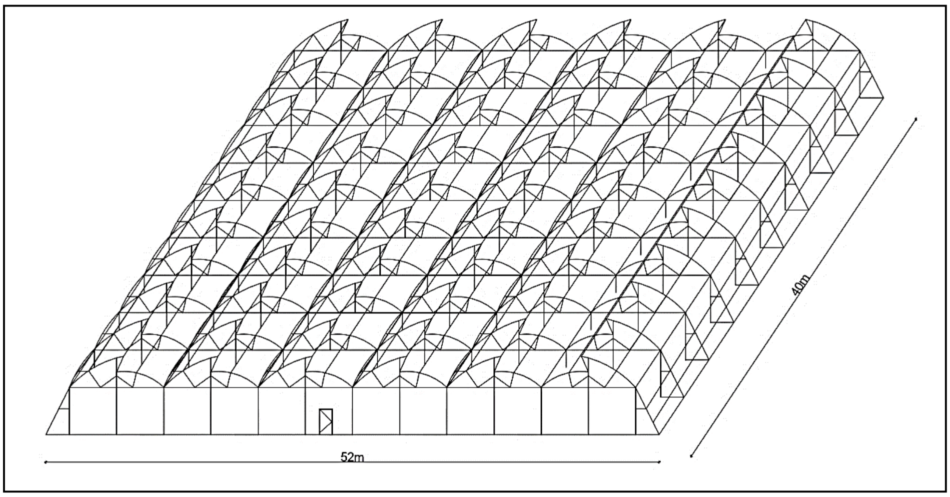

Figure 7. Isometric view of 2080 m^2 polyhouse structure (T7/T8/T9).

For treatment T10, Table 13 indicates that the structure was found to be stable when diameter of members 1, 2, and 3 was reduced from 76 to 60 mm, for members 4,5, 6, and 7 was reduced from 60 to 42 mm, for members 8,9, and 10 was reduced from 48 to 32 mm, and for members 11 and 12 was reduced from 48 to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 13).

Table 13. Truss member forces under different combinations of loads for stable structure in treatment T10.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	60	1.02	3.08	17.52	27.81	74.67
2	60	1.02	3.08	17.52	27.81	82.68
3	60	0.27	0.73	4.14	6.62	82.32
4	42	-0.32	-0.86	-4.87	-7.78	-27.39
5	42	0.11	0.14	4.22	6.49	39.19
6	42	0.11	0.14	4.22	6.49	39.19
7	42	-0.31	-0.80	-4.22	-6.79	-27.39
8	32	0.42	1.13	6.45	10.31	14.66
9	32	0.27	0.72	4.09	6.53	12.81
10	32	0.15	0.40	2.28	3.65	39.38
11	42	0.66	2.30	15.94	24.90	34.16
12	42	0.58	1.79	10.18	16.13	34.16
13	32*	0.31	0.82	4.68	7.49	26.38
14	32*	-0.47	-1.04	-7.07	-11.30	-15.04
15	32*	-0.47	-1.04	-7.07	-11.30	-15.04
16	32*	0.31	0.69	4.65	7.43	31.27
17	32*	0.15	0.40	2.27	3.62	35.98

For treatment T11, Table 14 indicates that the structure was found to be stable when diameter of members 4, 5, 6, and 7 were reduced from 60 mm to 48 mm, for members 8, 9, and 10 were reduced from 48 mm to 42 mm, for members 11 and 12 diameters should be increased from 48 mm to 60 mm, and for members 14 and 15 it should increase from 32 mm to 42 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 14).

Table 14. Truss member forces under different combinations of loads for stable structure in treatment T11.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	76*	1.02	3.08	37.01	57.05	99.45
2	76*	1.02	3.08	37.01	57.05	105.49
3	76*	0.27	0.73	8.74	13.52	105.26
4	48	-0.32	-0.86	-10.28	-15.90	-34.81
5	48	0.11	0.14	3.56	5.50	50.27
6	48	0.11	0.14	3.56	5.50	50.27
7	48	-0.31	-0.80	-9.93	-15.36	-34.81
8	42	0.42	1.13	13.62	21.07	31.15
9	42	0.27	0.72	8.64	13.36	27.88
10	42	0.15	0.40	4.83	7.47	54.76
11	60	0.66	2.30	33.67	51.50	66.29
12	60	0.58	1.79	21.49	33.10	66.29
13	32*	0.31	0.82	9.90	15.31	26.38
14	42	-0.47	-1.04	-14.94	-23.11	-27.39
15	42	-0.47	-1.04	-14.94	-23.11	-27.39
16	32*	0.31	0.69	9.82	15.18	31.27
17	32*	0.15	0.40	4.79	7.41	35.98

For treatment T12, Table 15 indicates that the structure was found to be stable when diameter of members 1, 2 and 3 increased to 88 mm, members 11 and 12 increased from 48 to 76 mm, and member 14 and 15 increased from 32 to 60 mm, keeping the diameter of the remaining members the same as given in Table 2 (shown as *in Table 15).

Table 15. Truss member forces under different combinations of loads for stable structure in treatment T12.

Member no	Member diameter (mm)	Member force due to dead load (kN)	Member force due to live load (kN)	Member force due to wind load (kN)	Maximum force (kN)	Design force (kN)
1	88	1.02	3.08	62.93	95.92	116.66
2	88	1.02	3.08	62.93	95.92	122.60
3	88	0.27	0.73	14.72	22.49	122.60
4	60*	-0.32	-0.86	-17.48	-26.70	-49.64
5	60*	0.11	0.14	6.17	9.42	71.03
6	60*	0.11	0.14	6.17	9.42	71.03
7	60*	-0.31	-0.80	-16.88	-25.78	-49.64
8	48*	0.42	1.13	23.16	35.38	43.62
9	48*	0.27	0.72	14.89	22.74	52.00
10	48*	0.15	0.40	8.35	12.75	52.50
11	76	0.66	2.30	57.60	87.38	92.94
12	76	0.58	1.79	36.54	55.67	92.94
13	32*	0.31	0.82	16.91	25.83	26.38
14	60	-0.47	-1.04	-25.53	-38.99	-49.64
15	60	-0.47	-1.04	-25.53	-38.99	-49.64
16	32*	0.31	0.69	16.78	25.62	31.27
17	32*	0.15	0.40	8.22	12.55	35.98

For every 17 set of truss members, 4 members (two in compression (small arc) and two in tension (truss bracings)) failed in in treatments with 150 and 200 km h^{-1} wind speed, while 2 members (in compression, small arc) failed in treatments with 100 km h^{-1} wind speed.

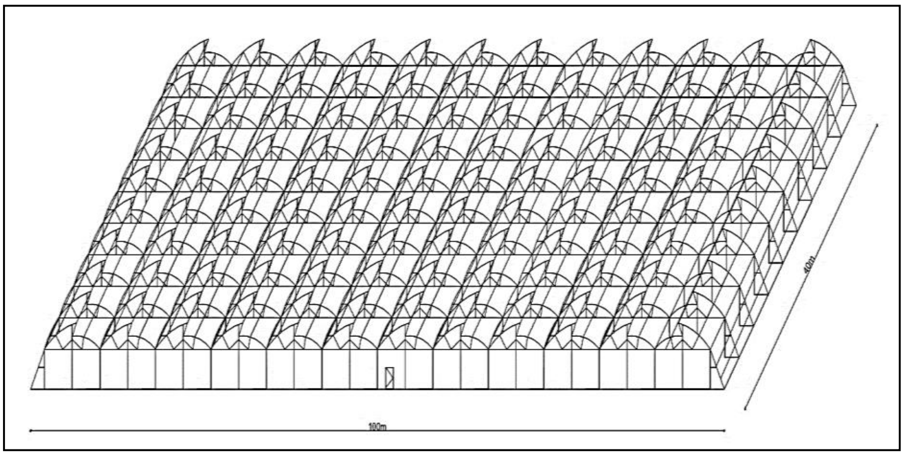

Figure 8. Isometric view of 4000 m^2 polyhouse structure (T10/T11/T12).

Column Stability Analysis

The three diameters (48, 60, and 76 mm) were taken for wind speed 100, 150, and 200 km h^{-1}, respectively, as shown in Table 16. The 48 mm diameter columns remained safe after analysis with 100 km h^{-1} wind speed, whereas 60 and 76 mm were not safe with 150 and 200 km h^{-1}, respectively. In case of failure of column members, the maximum force value is more as compared to design value. Therefore, there was need to change the column member with the next available section by increasing its diameter as per market availability.

Table 16. Column forces under different load combinations (T1–T12).

Treatments	Column number	Diameter of column (mm)	Maxi factored load (kN)	Design load (kN)	Stability remarks
T1	1	48	16.338	17.740	Pass
	2	48	16.338	17.740	Pass
	3	48	16.338	17.740	Pass
T2	1	60	33.990	33.870	Fail
	2	60	33.990	33.870	Fail
	3	60	33.990	33.870	Fail
T3	1	76	57.484	61.343	Fail
	2	76	57.484	61.343	Fail
	3	76	57.484	61.343	Fail
T4	1	48	16.625	17.740	Pass
	2	48	16.625	17.740	Pass
	3	48	16.625	17.740	Pass
T5	1	60	34.460	33.870	Fail
	2	60	34.460	33.870	Fail
	3	60	34.460	33.870	Fail
T6	1	76	58.170	61.343	Fail
	2	76	58.170	61.343	Fail
	3	76	58.170	61.343	Fail
T7	1	48	16.323	17.740	Pass
	2	48	16.323	17.740	Pass
	3	48	16.323	17.740	Pass
T8	1	60	33.693	33.870	Fail
	2	60	33.693	33.870	Fail
	3	60	33.693	33.870	Fail
T9	1	76	56.798	61.343	Fail
	2	76	56.798	61.343	Fail
	3	76	56.798	61.343	Fail
T10	1	48	18.473	17.740	Fail
	2	48	18.473	17.740	Fail
	3	48	18.473	17.740	Fail
T11	1	60	37.853	33.870	Fail
	2	60	37.853	33.870	Fail
	3	60	37.853	33.870	Fail
T12	1	76	63.623	61.343	Fail
	2	76	63.623	61.343	Fail
	3	76	63.623	61.343	Fail

In column stability study, sections of failed column were redesigned, as shown in Table 17, which compares the maximum load on column with its design values and shows stability remarks.

Foundation Stability Analysis

The foundation stability analysis was performed for all the treatments as shown in Table 18.

Table 17. Redesigning of column forces under different load combinations.

Treatments	Column number	Column diameter (mm)	Maximum factored load (kN)	Design load (kN)	Remarks
T2	1	76	33.990	61.343	Pass
	2	76	33.990	61.343	Pass
	3	76	33.990	61.343	Pass
T3	1	76	57.484	61.343	Pass
	2	76	57.484	61.343	Pass
	3	76	57.484	61.343	Pass
T5	1	76	34.460	61.343	Pass
	2	76	34.460	61.343	Pass
	3	76	34.460	61.343	Pass
T6	1	76	58.170	61.343	Pass

Table 17 is continued:

Continued Table 17.

Treatments	Column number	Column diameter (mm)	Maximum factored load (kN)	Design load (kN)	Remarks
	2	76	58.170	61.343	Pass
	3	76	58.170	61.343	Pass
T8	1	76	33.693	61.343	Pass
	2	76	33.693	61.343	Pass
	3	76	33.693	61.343	Pass
T9	1	76	56.798	61.343	Pass
	2	76	56.798	61.343	Pass
	3	76	56.798	61.343	Pass
T10	1	60	18.473	33.870	Pass
	2	60	18.473	33.870	Pass
	3	60	18.473	33.870	Pass
T11	1	76	37.853	61.343	Pass
	2	76	37.853	61.343	Pass
	3	76	37.853	61.343	Pass
T12	1	88	63.623	85.332	Pass
	2	88	63.623	85.332	Pass
	3	88	63.623	85.332	Pass

Table 18. Foundation stability analysis (T1–T12).

Treatments	Maximum load on column (kN)	Bearing pressure (N mm^{-2})	Design bearing strength (N mm^{-2})	Remarks
T1	20	0.5	9.0	Pass
T2	40	1.0	9.0	Pass
T3	65	1.63	9.0	Pass
T4	20	0.5	9.0	Pass
T5	40	1.0	9.0	Pass
T6	65	1.625	9.0	Pass
T7	20	0.5	9.0	Pass
T8	40	1.0	9.0	Pass
T9	65	1.625	9.0	Pass
T10	20	0.5	9.0	Pass
T11	40	1.0	9.0	Pass
T12	65	1.625	9.0	Pass

DISCUSSION

The trusses of all structures were found to be indeterminate, therefore, force method was used to compute forces associated with the members. Structural stability analysis of naturally ventilated polyhouse was performed with three design wind speeds viz. 100, 150 and 200 km h^{-1}. wind load is one of the main factor of plastic greenhouse collapse (Jiang *et al*., 2021). it was found that the influence of wind load on the skeleton structure is an important parameter in greenhouse structural design (GB/T-51183, 2016). Twelve treatments were considered in this study. For treatments T1/T4/T7/T10, results indicate that the structure was stable when diameter of members 1, 2, 3 was reduced from 76 mm (Indian standards) to 60 mm, for members 4, 5, 6, 7 was reduced from 60 to 42 mm, for members 8, 9, 10 was reduced from 48 to 32 mm, for members 11, 12 was reduced from 48 to 42 mm, while diameters of members 13, 14, 15, 16 and 17 remained the same (32 mm). For treatments T2/T5/T8/T11, results indicate that the structure was stable when diameter of members 1, 2, 3 remained the same (76 mm), members 4, 5, 6, 7 diameters was reduced from 60 to 48 mm, members 8, 9, 10 was reduced from 48 to 42 mm, members 11, 12 diameters increased from 48 to 60 mm and members 14 and 15 diameters increased from 32 to 42 mm, while diameters of members 13, 16 and 17 remained the same (32 mm). For treatments T3/T6/T9/T12, results indicate that the structure was stable when diameter of members 1, 2, 3 (76 mm), 4, 5, 6, 7 (60 mm), 8, 9, 10 (48 mm) remained the same, and for members 11 and 12, diameters increased from 48 to 76 mm, for members 14 and 15, diameters increased from 32 to 60 mm, while diameters of members 13, 16, and 17 remained the same (32 mm).

In case of column stability analysis, it was found that reduction in column size from 76 mm (Indian standards) to 60 mm provided stable structure for T1, T4, and T7 treatments, while it increased to 88 mm for treatment T12. For every 17 set of truss members, 4 members (two in compression (small arc) and two in tension (truss bracings)) failed in treatments with 150 and 200 km h^{-1} wind speed, while 2 members (in compression, small arc) failed in treatments with 100 km h^{-1} wind speed.

CONCLUSIONS

There were 12 treatments taken for the research study. Detailed drawings of naturally ventilated polyhouses were examined along with their technical specifications. Design force values were computed using all the standard codes related to the structural design. Total loads were computed by combining dead load, live loads and wind loads. Support reactions were computed on truss and column joints. Member forces were computed in all the truss members of different treatment by using Force Method. Tension and compression analysis on truss members was carried out to calculate design forces(s) and stability was checked. The approximate cost of polyhouse widely used in our region corresponding to 560, 1,008, 2,080, and 4,000 m^2 is, respectively, Rs 5,93,600, Rs 9,58,995, Rs 18,51,200, and Rs 34,19,998. The cost of Designed Polyhouse corresponding to 560, 1,008, 2,080, and 4,000 m^2 comes out to be Rs 5,87,780, Rs 9,42,480, Rs 17,68,029, and 32,26,156 result in sufficient savings.

It is recommended that the polyhouse construction should be designed by professionals in order that it is safe as well as economical.

ACKNOWLEDGEMENTS

The authors are thankful to Punjab Agricultural University, Ludhiana for their support, facilities and material required for this work.

REFERENCES

1. Anonymous. 2019. *Technical Standards for Naturally Ventilated, Fan and Pad Green House and Shade Net House*. www.nhb.gov.in (accessed 16 April, 2019).
2. Elsner, B. V., Briassoulis, D., Waaijenberg, D., Mistriotis, A., Zabeltitz, C. V., Gratraud, J. and Suay, C. R. 2000. Review of Structural and Functional Characteristics of Greenhouses in European Union Countries. Part I. Design Requirements. *J. Agric. Eng. Res.,* **75:** 1-16.
3. GB/T- 151183. 2016. *Code for Design Load of Horticultural Greenhouse Structures.* China Planning Press, Beijing, China.
4. Indore, N. S., Kale S. J., Akhoon, A. B., Singh, R. K. and Singh, H. 2020. Structural Analysis of Common Existing Greenhouses Designs in Different Agro-Climatic Zones of India. *Int. J. Agric. Engg.,* **13:** 80-89
5. IS:14462. 1997. *Recommendations for Layout, Design and Construction of Greenhouse Structures.* Bureau of Indian standard, New Delhi, PP. 1- 13.
6. IS:800. 2007. *General Construction in Steel Code of Practice.* Bureau of Indian standard, New Delhi, PP. 1 – 150.
7. IS:875. 1987. *Part 1: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures.* Bureau of Indian standard, New Delhi, PP. 1 – 43.
8. IS:875. 1987. *Part 2: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures*. Bureau of Indian standard, New Delhi, PP. 1 – 23.
9. IS:875. 1987. *Part 3: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures*. Bureau of Indian standard, New Delhi, PP. 1-67

10. IS:875. 2015. *Part 3: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures*. Bureau of Indian standard, New Delhi, PP. 1-63
11. IS:875. 1987. *Part 4: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures*. Bureau of Indian standard, New Delhi, PP. 1-11
12. IS:875. 1987. *Part 5: Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures*. Bureau of Indian standard, New Delhi, PP. 1-24
13. Jensen, M. H. and Malter, A. J. 1994. Protected Agriculture a Global Review. Number 253, World Bank Technical Paper, Washington, D.C.
14. Kyrikou, I., Briassoulis, D., Hiskakis, M. and Babou, E. 2011. Analysis of Photo-Chemical Degradation Behavior of Polyethylene Mulching Film with Pro-Oxidants. *Polym. Degrad. Stab.*, **96:** 2237-2252.
15. Nayak, A. K. and Rao, K. R. 2014. Estimation of Wind Load on a Greenhouse and Evaluation of Its Structural Stability. *Int. J. Agric. Eng.*, **7:** 461-66.
16. Nayak, A. K., Rao, K. R., Saxena, C. K. and Kumar, M. 2018. Estimation of Various Loads of a Naturally Ventilated Saw Tooth Type Greenhouse. *Andhra Agric. J.*, **65:** 538-43.
17. Wittwer, S. H. and Castilla, N. 1995. Protected Cultivation of Horticultural Crops Worldwide. *Hort. Tech.*, **5:** 6-23.
18. Jiang, Y., Bai, Y., Wang, C., Wang, Y. and Pang, X. 2021. Dynamic Response Analyses of Plastic Greenhouse Structure Considering Fluctuating Wind Load. *Adv. Civ. Eng.*, Volume 2021, Article ID 8886557, 13 PP.

تجزیه و تحلیل پایداری سازه‌ای گلخانه نایلونی با تهویه طبیعی در شرایط مختلف

ل. سینگ، ا. کایوشال، ج. سینگ، و ر. شاردا

چکیده

این پژوهش روی تجزیه و تحلیل پایداری ساختاری گلخانه‌نایلونی با تهویه طبیعی در گروه مهندسی خاک و آب، دانشگاه کشاورزی پنجاب، در ناحیه لودیانا (Ludhiana) انجام شد. ۱۲ تیماردر پژوهش وجود داشت که ترکیبی از چهار اندازه مختلف گلخانه‌نایلونی یعنی ۵۶۰ متر مربع (T1-T3) بود. ۱۰۰۸ متر مربع (T4-T6)، ۲۰۸۰ متر مربع (T7-T9)، و ۴۰۰۰ متر مربع (T10-T12) بود با سه سرعت باد طراحی شده به ترتیب برابر ۱۰۰، ۱۵۰ و ۲۰۰ کیلومتر در ساعت. تجزیه و تحلیل پایداری اعضای(اجزای) خرپا، ستون ها و فونداسیون با در نظر گرفتن بارهای مرده، بارهای زنده و بارهای باد انجام شد. واکنش های حمایتی بر روی اتصالات خرپا و ستون محاسبه شد. نیروهای اعضا با استفاده از روش نیرو محاسبه شدند. به ازای هر ۱۷ مجموعه از اعضای خرپا، چهار عضو [شامل دو عضو در فشارcompression (قوس کوچک) و دو عضو در کشش و تنش (بندهای خرپایی)] در تیمارهایی با سرعت باد ۱۵۰ و ۲۰۰ کیلومتر در ساعت نا موفق بودند، در حالی که در تیمارهایی با سرعت باد ۱۰۰ کیلومتر در ساعت، دو عضو [در فشار، (قوس کوچک)] نا مناسب بود. حدکمینه نیاز به مواد لوله GI سازه‌ای برای پایداری

سازه‌ای گلخانه‌نایلونی در تیمار T1 (۲۴۰۷ کیلوگرم) و حداکثر آن در تیمار T12 (۱۹۵۵۰ کیلوگرم) بود.