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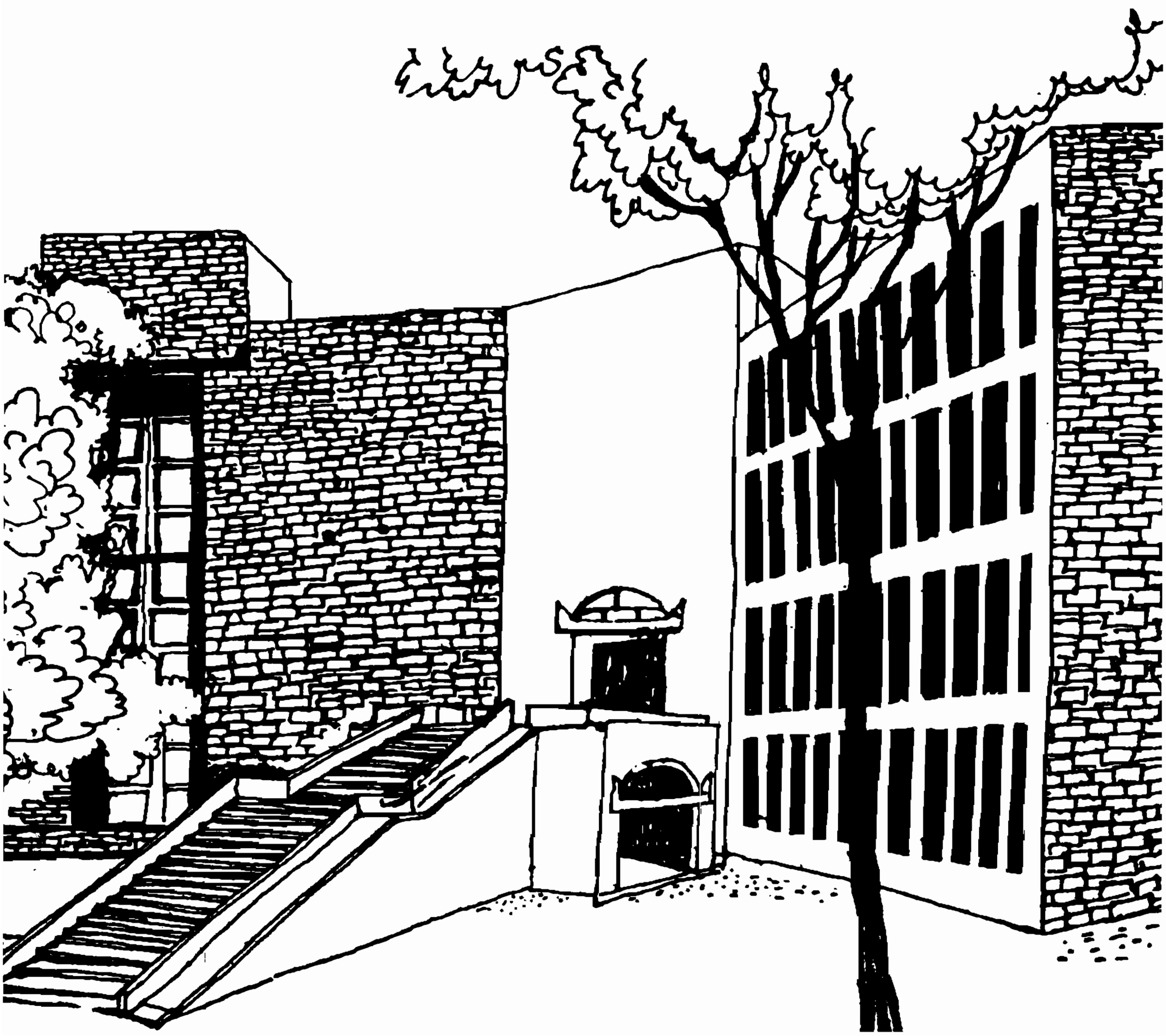

STRUCTURAL DESIGN FOR GREENHOUSE AT BHUJODI

By

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Abstract

This write up contains design computations for selection of structural members for a greenhouse to be installed at Bhujodi. Straight wall gable roof form was selected. Wind load estimates made for wind angle 0° and 90° on air tight structure. Analysis was also carried out for left wall open. Effect of wind on the structure will be more serve when it is blowing at 0°. If the greenhouse happens to be open during high wind, the possibility of damage is increased. The steel requirement of structure in the present analysis is too high (28 kg/m^2).Conventionally it should not exceed 10kg/m^2. Therefore we will be reworking the structural design to reduce steel requirement. We will present it in next paper.

Local Climatic Features

Kutch region is hot, arid and windy. Zabeltitz [1], Chandra [2], Jensen and Malter [3] have indicated some general considerations for structures in such areas. Structure should be stable and strong enough to withstand loads from wind, self weight, rains and others that arise from particular use. Structure should also conform to local building codes. Structure should offer minimum impediment to penetration of light. It should permit installation of cooling, chemigation and other necessary systems. Some examples of free standing structures often used for greenhouses are quonset, straight wall arch roof, straight wall gable roof, straight wall single or double slope roof, gothic arch and saw tooth (**figure 1**).

Design Procedure

Design will be done in four steps.

1. Selection of form
2. Estimation of loads

3. Structural analysis of plane frame with rigid joints
4. Selection of member size

1. Selection of Form

Analysis of solar altitude angle over Bhujodi indicated that sun will be virtually overhead at noon in summer. Since ambient temperatures are generally high in the region, it is desirable that roof be pitched so as to reflect away a part of the light. The forms such as the quonset will present a near perpendicular surface to incident rays and thus will not be desirable in this region. Accordingly, we select straight wall pitched roof (gable) form.

2. Estimation of Loads

(a) Wind

Consider a straight wall gable roof structure (**figure 2**), made of galvanised steel.

Let

s	span (m)
l	length (m)
h	height of side wall (m)
WL	wind load acting on a member (kg)
C_p	external pressure coefficient (dimensionless) from catalogue
P_d	wind pressure intensity (N/m^2)
A	surface area of structural element (m^2)
V_z	design wind speed (m/s)
V_b	basic wind speed (m/s), listed in IS wind code for various locations in the country
K_1	risk coefficient (dimensionless), from catalogue
K_2	terrain, height and size factor (dimensionless), from catalogue
K_3	topography factor (dimensionless), from catalogue

LL live load

DL dead load

CL loading due to cladding weight

SL load due to self weight and systems as overhead sprinklers, etc.

$$V_z = V_b \,.\, K_1 \,.\, K_2 \,.\, K_3 \quad \ldots\ldots\ldots\ldots \quad (1)$$

$$P_d = 0.6\ V_z^2 \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$WL = P_d \,.\, C_p \,.\, A \quad \ldots\ldots\ldots\ldots \quad (3)$$

IS Wind Code (1987)**[4]** gives the basic wind speed for Bhuj (15 km from Bhujodi) as 50 m/s. Keeping in mind the cyclonic winds which occur there, we shall take a higher basic speed, 55 m/s (200 km/hr). Thus,

$$V_b = 55 \text{ m/sec}$$

IS - 875 Part 3 (1987) gives the external pressure coefficient (C_p) for structures of various forms, size and two angles of attack (0° and 90°). **[4]**

On a priori considerations, we have decided to build a greenhouse of 100 m^2 floor area with span, length and wall height as below.

$$s = 5 \text{ m}$$

$$l = 20 \text{ m}$$

$$h = 2.5 \text{ m}$$

$$\frac{h}{s} = 0.5 \qquad \frac{l}{s} = 4$$

Accordingly, 'C_p' values for 'rectangular clad structure with pitched roof' (*tables 4 and 5* of the code) are given in **table 1.**

Table 1 External Pressure Coefficient (for rectangular clad pitched roof structure)						
Wind Angle (degree)	C_p (Walls)				C_p (Roofs)	
	Left Wall AA' EE'	Front Face ABEF	Rear Face A'B'E'F'	Right Wall BB'FF'	EE'GG'	FF'GG'
0	+0.7	-0.6	-0.6	-0.25	0	-0.4

Examination of the values indicates that the left wall, the one on which wind is incident, will have a C_p of 0.7. As against this, the opposite wall (leeward side) will have negative pressure with C_p of (-)0.25. Sloping roof on the windward side will have no wind pressure. The one on leeward side will have negative pressure (C_p = -0.4) Both the front and rear walls will have negative pressure.

Now,

K_1 = 0.89 for 55 m/sec and life 25 years (from *table 1* of IS Code Catalogue)

K_2 = 0.98 for category 2 (open terrain with well scattered obstruction having height 1.5 to 10 m) and structure category class B

K_3 = 1.36 (maximum value)

Substituting these, in (3),

$$V_z = 55 \times 0.89 \times 0.98 \times 1.36$$

$$= 65.24 \text{ m/sec}$$

Substituting it, in (2),

$$P_d = 0.6\,(65.24)^2$$

$$= 260.32 \text{ kg/m}^2$$

Bay Size

Bay size refers to spacing between two frames. Closer this spacing, greater the hindrance tc light penetration. Cost may also increase particularly due to extra foundation, civil work, etc. needed, because of greater number of members. Large and smaller sections may also affect costs. Positive aspect of closer spacing is that it may reduce flutter in the cladding or the need for cross members for cladding support. Many of the illustrations given by Zabeltitz have 2 to 5 m bay; IARI Quonset usually have 1 m; commercially available such as Jain Greenhouses 3-4 m; and G.A.U., Navsari Project 2 m bay. We will keep the bay size as 2 m. Now, consider one frame (**figure 3**) of the structure. This frame will be required to resist wind load from 2 m long strip of the cladding.

(a) Wind Load on Frame

Load on segment AE = 0.7 x 5 x 260.32

= 911.12 kg ≈ 915 kg

OR $\frac{915}{2.5} = 366\ kg/m$

This will act in (+) X direction or towards the frame

Load on segment BF = -0.25 x 5 x 260.32

= -325.4 kg

OR = -132 kg/m

This will also act in (+) X direction, in this case away from frame.

Load on segment EG = 0

Load on segment GF = -0.4 x 5.8 x 260.32

= -603.94 ≈ 605 kg

Acts in the direction of outward normal to frame.

(b) Live Load (LL)

Conventionally live load intensity from crops is taken as 50 kg/m^2 of floor area. Load will be carried by members EH and HF. This member will act as trellis support. Thus, total live load will be,

LL = 50 x 10 = 500 kg or 100 kg/m

This is acting in (-)Y direction or downwards.

(c) Dead Load (DL)

For calculating self weight of frame, we assume 90 mm steel tube (medium class) weighing 9.72 kg/m will be used. We will later modify this, should the member dimensions turn out to be significantly different after structural analysis.

Ground supports weight of member AE and BF. Weight of member EG and GF will be carried by themselves with weight of member GH (we are ignoring point load due to member GH). Likewise member EH and HF will carry their load independently.

Load on segment EGF = 9.72 x 7.32 = 71.15 ≈ 75 kg or 12.88 kg/m ≈ 13 kg/m

Load on segment EHF = 9.72 x 5 = 48.6 ≈ 50 kg or 10 kg/m

(d) Weight of Cladding (CL)

Double polyethylene weighs 0.4 kg/m^2 of area.

Total weight of cladding = 0.4 x 21.64 = 8.65 kg

We will ignore it, as it is negligible comparing to others.

(e) Water-lines System Load (SL)

Load intensity of overhead water-lines supported from frame is assumed as 5 kg/m^2 of floor area. This load will be carried by member EHF.

SL = 5 x 10 = 50 kg **or** 10 kg/m

All dead loads will act in (-)Y, direction.

Resume of Load Estimates

Combined loading is given in **figure 4**. Segment AE (m1) has only wind load of 915 kg or 366 kg/m. Load is acting perpendicular to member coinciding with (+) X direction, towards the frame. Segment EG (m2) has Load due to it's self weight equal to 38 kg or 13 kg/m. Load is acting in (-) Y direction. Segment GF (m3) has wind load (208 kg/m) and dead load due to self weight(13 kg/m). Vector sum works out to 570 kg or 196 kg/m. This load acts outward from frame and behave as lift force. Segment EH (m4) has live load (100 kg/m), system load(10 kg/m) and dead load due to self weight (10 kg/m). Total load on member is 300 kg or 120 kg/m. Load is acting in (-) Y direction. Segment HF (m5) has live load (100 kg/m), system load(10 kg/m) and dead load due to self weight (10 kg/m). Total load on member is 300 kg or 120 kg/m. Load is acting in (-) Y direction. Segment FB (m6) has only wind load of magnitude 330 kg(132 kg/m). Load is acting perpendicular to member and coincides with (+) X direction, outward from the frame. Segment GH (m7) has no load (It's own weight being neglected).

Analysis: Force Response

Force response was obtained using STASS package. Programme uses stiffness matrix method for structural analysis. Results are given in **Table 2 (a) and (b)**.

Let,

Lx(i)	Applied load in ‘X’ direction on ‘i’th member
Ly(i)	Applied load in ‘Y’ direction on ‘i’th member
Sxx(i,j)	Axial force in ‘i’th member at ‘j’th end
Sxy(i,j)	Shear force in ‘i’th member at ‘j’th end
Mxy(i,j)	Bending moment in ‘i’th member at ‘j’th end
Rx(i,j)	Fixed end reaction in ‘i’th member at ‘j’th end in ‘X’ direction
Ry(i,j)	Fixed end reaction in ‘i’th member at ‘j’th end in ‘Y’ direction
Rm(i,j)	Fixed end reaction moment in ‘i’th member at ‘j’th end
i	Member number (1,2,....,7)
j	Member end (1 and 2)

Sign convention

Clockwise moments (+)

Anticlockwise moments (-)

Table 2(a) Force Response of Plane Frame with Rigid Joints (Wind at 0^{o} and two fixed supports)						
Member	Axial Force (kg), Sxx		Shear Force(kg),Sxy		B.M.(kg.m), Mxy	
	J_{end}	K_{end}	J_{end}	K_{end}	J_{end}	K_{end}
1	21.43 (C)	-21.43 (C)	**950.4**	-35.04	**906.1**	325
2	-28.27 (T)	47.67 (T)	-86.70	119.08	-234.7	-65.42
3	26.97 (C)	-36.42 (C)	-288.48	-281.96	-51.4	46.3
4	-55.4 (T)	55.40 (T)	110.33	189.6	-90.4	-8.7
5	90.25 (C)	-90.25 (C)	-55	355	-92.8	-419.6
6	**131.96 (C)**	**-131.96 (C)**	266.55	-596.56	373.2	705.6
7	**-134.6 (T)**	**134.6 (T)**	145.6	-145.6	116.8	101.6
C = Compressive		T = Tensile force				

Table 2(b) Fixed End Reactions			
Joint No.	Horizontal Reaction(Rx),kg	Vertical Reaction (Ry), kg	Resisting Moment(Rm) kg-m
1	-950.04	21.43	906.18
6	-596.55	131.96	705.61

Force response is diagramatically shown in **figure 5**.

Checks

(a) Equilibrium of whole frame

$\Sigma Fx = Lx(1) + Lx(3) + Lx(6) + Rx(1,1) + Rx(6,2)$

$= 915 + 302.64 + 330 - 950.40 - 596.55 \approx 0$

$\Sigma Fy = Ly(2) + Ly(3) + Ly(4) + Ly(5) + Ry(1,1) + R(6,2)$

$= -37.83 + 524.18 - 37.83 - 300 - 300 + 21.43 + 131.96 \approx 0$

$\Sigma M = Mxy(1,1) + Mxy(6,2) - Rm(1,1) - Rm(6,2)$

$= 906.18 + 705.60 - 906.18 - 705.6 \approx 0$

Small and obvious rounding-of errors were present.

(b) Equilibrium of Member

Figure 6 is free-body diagram of member 1.

$\Sigma F(1) = Lx(1) + Sxy(1,1) + Sxy(1,2)$

$= 915 + 950\ 40 - 35.04 \approx 0$

(c) Joint Equilibrium

Free body diagram of Joint 2 is given in **figure 7.**

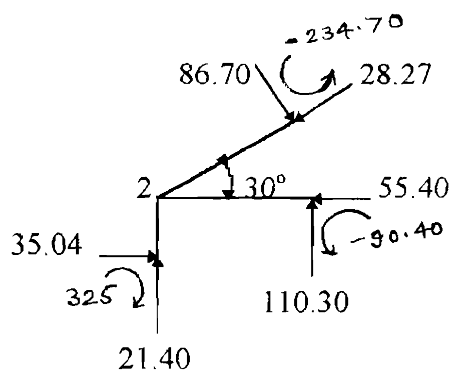


Figure 7: Free Body Diagram of Joint 2

$\Sigma Fx(2) = -28.27 \cos 30 + 86.70 \sin 30 - 55.40 + 35.04 \approx 0$

$\Sigma Fy(2) = -28.27 \sin 30 - 86.70 \cos 30 + 110.30 - 21.43 \approx 0.$

$\Sigma M(2) = 325 - 234.70 - 90.40 \approx 0$

Similarly checks were also carried out for all member and joints and found that these are in equilibrium condition.

Resume of Force Response

When the wind is blowing at 0° to the structure, maximum bending moment (906 kg-m) occurs at 'J'end of member1. Maximum shear force occurs also at 'J'$_{end}$ of member1 (950 kg). Maximum axial force (tension) occurs in member 7 (135 kg). Maximum axial force (compression) occurs in member 6 (132 kg).

Selection of member size

Let,

Fv	allowable maximum shear stress (kg/m^2)
Ft	allowable axial stress in tension (kg/m^2)
Fc	allowable axial stress in compression (kg/m^2)
Fb	allowable bending stress in tension and compression(kg/m^2)
σ_{st}	yield stress of steel (kg/m^2)
I	moment of inertia (m^4)
y	maximum distance from neutral axis (m)
R	radius of curvature of bending (m)
E	modulus of elasticity (kg/m^2)
Z	section modulus i/y (kg/m^2)
L	height of member (cm)
K	radius of gyration (m)
S	slenderness ratio, L / K
D	nominal size of section (cm)
A	cross-sectional area (cm^2)
T	wall thickness (mm)
Pc	load bearing capacity of section in compression (kg)
f_v	computed shear stress (kg/cm^2)

f_t computed axial stress in tension (kg/cm^2)

f_c computed axial stress in compression (kg/cm^2)

f_b computed bending stress (kg/cm^2)

Mechanical properties of closed structurals

Many firms are manufacturing closed structure also. One such is Tata Iron and Steel Company. Their product catalogue **[5]** gives the following properties for steel tube Yst 240 grade.

Fv = 108 MPa (1100 kg/cm^2)

Ft = 144 MPa (1467 kg/cm^2)

Fb = 158 MPa (1610 kg/cm^2)

σ_{st} = 240 MPa (2445 Kg/cm^2)

Catalogue also contains allowable axial stresses in compression for various combination of Slenderness Ratio and grade of steel

The flextural formula **[6]** ,

$$\frac{M_{xy}}{I} = \frac{F_b}{Y} = \frac{E}{R} \qquad \text{..........(4)}$$

$$M_{xy} = \frac{I \times F_b}{Y} \qquad \text{...........(5)}$$

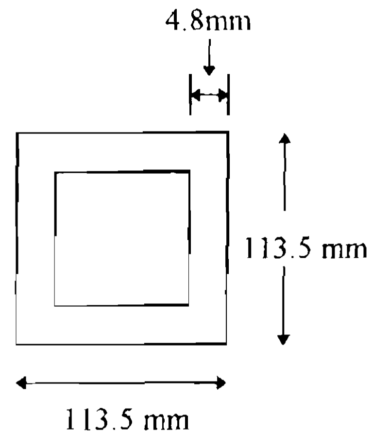
Maximum bending moment occurs at 'J'end of first member

$M_{xy(1,1)}$ = 906.18

Fb = 1610 kg/m^2

From **Eq.5**,

Z = (90600 / 1610) = 56.27 cm^3



Available commercial section nearest to the required Z is

D 113.5 X 113.5 mm,

A 20.25 cm^2,

T 4.8mm,

Z 69.30 cm^3,

K 4.40 cm.

The shear, tensile and compressive stresses induced in selected section are given below .

Shear stress (f_v)

$$f_v = 1.591 \ x \ \frac{S_{xy(1,1)}}{A} \qquad \ldots\ldots \ldots. (6)$$

As seen earlier, $S_{xy(1,1)}$ = 950.40 kg

f_v = 1.591 x (950.40 / 20.25) = 74.67 kg/cm^2 (say, 75 kg/cm^2)

Tensile stress (f_t)

$$f_t = \frac{S_{xx(7)}}{A} \qquad \ldots\ldots\ldots\ldots\ldots (7)$$

$S_{xx(7)}$ = 134.6 kg.

f_t = 134.60 / 20.25

= 6.64 kg/cm^2 (say, 7 kg/cm^2)

Bending Stress (fb)

Maximum bending moment i.e Mxy (1,1) = 906 kg-m.

Section modulus of selected section Z = 69.30 cm^3

Using Eq.5,

$$fb = 90600 / 69.30 \ kg/cm^2$$
$$\approx 1307 \ kg/cm^2$$

Axial Compression

$$S = \frac{L}{K} \quad \ldots\ldots\ldots\ldots(8)$$

$$= \frac{250}{4.40}$$
$$= 56.81$$

Allowable stress in compression (F_c) for above slenderness ratio and selected grade of steel (Y_{st} 240) is 119 MP_a (1212 kg/cm^2).

$$Pc = Fc \times A \quad \ldots\ldots\ldots\ldots(9)$$
$$= 1212 \times 20.25$$
$$= 24543 \ kg$$

Stress	Induced	Allowable
Shear stress	75 kg/cm^2	1100 kg/cm^2
Tensile stress	7 kg/cm^2	1467 kg/cm^2
Bending stress	1307 kg/cm^2	1610 kg/cm^2
Axial compression force	132 kg	24543 kg

AISC specification also suggests that member should be safe against combined effect of bending, tension and compression. Following criteria is stipulated [7].

1. Slenderness Ratio (L / K) be less than 200
2. ($f_t / 0.6\sigma_{st}$ or fa / Ft) + (f_b / Fb) $\leq$ 1.0 for tension induced by bending
3. (f_c / Fc) + (f_b / Fb) $\leq$ 1.0 for compression induced by bending

In the present case,

f_t = 6.64 kg/cm^2

$Ft = 1467\ kg/cm^2$

$f_c = 6.5\ kg/cm^2$

$Fc = 1212\ kg/cm^2$

$f_b = 1307\ kg/cm^2$

$Fb = 1610\ kg/cm^2$

$$L / K = 250 / 4.40$$
$$= 56\ 81$$

$$(fa / 0.6Fy) + (fb / Fb) = (6.6 / 1467) + (1307 / 1610)$$
$$= 0.815$$

$$(fa / Fa) + (fb / Fb) = (6.5 / 1212) + (1307 / 1610)$$
$$= 0.815$$

Thus the selected section is safe against combined effect as well.

Effect of Wind at 90°

Wind at 90° to the structure will act perpendicular to the front wall (**figure 8**). External wind pressure coefficients are shown in **table 3**.

Table 3

External Pressure Coefficients

Wind Angle (degree)	C_D (Walls)				C_D (Roofs)	
	Left Wall AA' EE'	Front Face ABEF	Rear Face A'B'E'F'	Right Wall BB'FF'	EE'GG'	FF'GG'
90	-0.5	+0.7	-0.1	-0.5	-0.7 (P_1) - 0.6 (P_3)	-0.7 (P_2) - 0.6 (P_4)

Coefficient reflect the fact that as wind blows along the longitudinal axis of the structure, it will exerts positive pressure on the front face on which it is directly incident. Rear face and both the side wall will have negative pressure. Roof surface will also have suction effect. Loading diagram is shown in **figure 9.**

Here segment AE(m1) has wind load of 265 kg/m acting in (-) X direction outward from frame. Segment EG(m2) and GF(m3), each is having wind load of 365 kg/m acting in direction of outward normal to the member. Segment FB (m6) also carries wind load of same intensity as on segment AE (265 kg/m), but now it acts in (+) X direction. All the loads except wind load will remain same as estimated in previous section.

Force response is given in **Table 4(a) and (b).**

Table 4(a)
Force Response of Plane Frame with Rigid Joints
(Wind at 90°)

Member	Reactions					
	Axial Force (Kg)		Shear Force (Kg)		Bending Moment (Kg-m)	
	J_{end}	K_{end}	J_{end}	K_{end}	J_{end}	K_{end}
1	**-583.39(T)**	**583.39(T)**	-447.88	-214.62	**-411.67**	120.10
2	-347.59	349.33	**-590.89**	-438.43	-250.62	31.19
3	-349.34	347.59	-440.36	-588.95	-31.19	250.61
4	-220.58	220.58	102.12	197.88	130.52	-250.21
5	-220.58	220.58	197.88	102.12	250.21	-130.52
6	**-583.39(T)**	**583.39(T)**	-214.62	-447.88	-120.10	**411.67**
7	-395.75	395.75	0.00	0.00	0.00	0.00

T = Tensile force

Table 4(b) Fixed End Reactions

Joint No	Horizontal Reaction (Rx), kg	Vertical Reaction (Ry), kg	Resisting Moment (Rm) kg-m
1	447.88	-583 38	-411.67
6	-447.88	-583.38	411.67

Equilibrium Checks

(a) Equilibrium of whole frame

$\Sigma Fx = Lx(1) + Lx(2) + Lx(3) + Lx(6) + Rx(1,1) + Rx(6,2)$

$= -662.5 - 531.07 + 531.07 + 662.50 + 447.88 - 447.88 \approx 0$

$\Sigma Fy = Ly(2) + Ly(3) + Ly(4) + Ly(5) + Ry(1,1) + R(6,2)$

$= 919.56 - 37.83 + 919.56 - 37.83 - 300 - 300 - 583.88 - 583.88 \approx 0$

$\Sigma M = Mxy(1,1) + Mxy(6,2) - Rm(1,1) - Rm(6,2)$

$= -411.67 + 411.67 + 411.67 - 411.67 \approx 0$

Some obvious rounding of errors were present.

(b) Equilibrium of member

Figure 10 is free body diagram of member 1.

$\Sigma F(1) = Lx(1) + Sxy(1,1) + Sxy(1,2)$

$= 662.5 - 447.88 - 214.62 \approx 0$

(c) Joint Equilibrium

Free body diagram of Joint 2 is given **figure 11.**

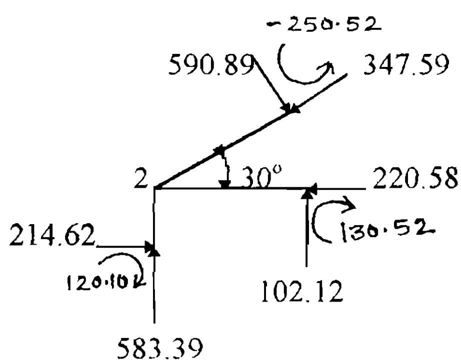


Figure 11: Free Body Diagram for Joint 2

$\Sigma Fx(2) = -347.59 \cos 30 + 590.89 \sin 30 - 220.58 + 214.62 \approx 0$

$\Sigma Fy(2) = -347.59 \sin 30 - 590.89 \cos 30 + 102.12 - 583.39 \approx 0.$

$\Sigma M(2) = 120.10 + 130.52 - 250.52 \approx 0$

Similarly checks were also carried out for all member and joints. Note also that now there is symmetry in forces induced. This is due to the fact that wind and other loads are also symmetrical about the longitudinal axis.

Magnitude and location of maximum induced forces are shown in **table 5**. Note that all induced forces are symmetrical.

Table 5

Maximum Induced Forces

End Forces	Wind Attack	
	0°	90°
Maximum bending Moment (Mxy)	906.18 kg-m, Mxy(1,1)	411.67 kg-m, Mxy(1,1)
Maximum shear force (Sxy)	906.10 kg, Sxy(1,1)	590.89 kg, Sxy(2,1)
Maximum Axial force in Tension (Sxx)	134.60 kg, Sxx (7)	583.39 kg, Sxx(1)
Maximum axial force in Compression (Sxx)	131.96 kg, Sxx (6)	----

All the values are of lower magnitude than earlier. Hence, no revision of size of member is needed.

Left Wall of Greenhouse Open (Wind angle 0^o)

So far we have analysed the effect of wind on air tight greenhouse. However, there are many chances for greenhouse to remain open during normal and accidental events. One such is possibility of open left side (one long wall). In this section, we will examine the effect of wind at 0^o to such open structure.

External and internal pressure coefficients created because of wind flowing at 0^o when left wall (AA'EE') is open are presented in **table 6**.

Table 6

Pressure Coefficients

External Pressure Coefficient						Internal Pressure Coefficient (on all sides and under roof)
Cp (walls)				Cp (roof)		
Left wall AA'EE'	Front face ABEF	Rear face A'B'E'F'	Right wall BB'FF'	EE'GG'	FF'GG'	
--	-0.7	-0.7	-0.5	-0.3	-0.4	0.8

Loading diagram is shown in **figure 12**

Here all-wind load acts in outward direction from structure. Wind load is acting as lift on the roof of greenhouse. All other loads remains same as discussed in previous sections.

Force response is given in **table 7(a) & (b)**.

Table 7(a) Force Response of Plane Frame with Rigid Joints (Wind angle 0° and left wall open)						
Member	Axial Force (kg), Sxx		Shear Force(kg),Sxy		B.M.(kg.m), Mxy	
1	**-1177.34**	1177.336	339.24	-339.24	290.471	557.629
2	-513.017	677.141	-973.98	-646.373	-492.527	27.5
3	-657.31	478.763	-835.802	-935.247	-86.797	245.466
4	-400.44	400.44	-78.21	378.21	-65.103	-505.422
5	-319.985	319.985	206.174	93.826	444.036	-303.601
6	-954.463	954.463	-249.34	**-1443.16**	58.134	**1434.14**
7	-584.385	584.385	80.456	-80.456	59.297	61.387

Table 7(b) Fixed End Reactions			
Joint No.	Horizontal Reaction(Rx),kg	Vertical Reaction (Ry), kg	Resisting Moment(Rm) kg-m
1	-339.24	-1177.33	290.47
6	-1443.16	-954.46	1434.14

Equilibrium Check for Whole Frame

ΣFx = Lx (2) + Lx (3) + Lx (6) + Rx (1,1) + Rx (6,2)

= -976.72 + 1065.36 + 1692.50 - 339.24 - 1443.16 $\approx$ 0

ΣFy = Ly (2) + Ly (3) + Ly (4) + Ry (5) + Ry (1,1) + Ry (6,2)

= 1344.34 + 1466.34 - 300 - 300 - 1177.33 - 954.46 $\approx$ 0

ΣM = Mxy (1,1) + Mxy (6,2) - Rm (1,1) - Rm (6,2)

= 290.47 + 1434.14 - 290.47 - 1434 14 $\approx$ 0

Some obvious rounding of errors are present

Selection of Member Size

Maximum bending moment occurs at 'k' end of 6th member i.e. Mxy (6,2) = 1435 kg-m.

Using Eq.5,

$$Z = \frac{143500}{1610} = 89.13$$

Available cross section close to this requirement is

D	132 x 132 mm
A	23.83 cm^2
t	4.80 mm
Z	96.12 cm^3
K	5.16 cm

Shear stress, tensile stress induced in the selected section are given below.

Shear Stress (fv)

Maximum shear force i.e. Sxy (6,2) = 1445 kg

Using Eq.6,

fv = 96.59 kg/cm^2 say, 97 kg/cm^2

Tensile Stress (ft)

Maximum tensile force i.e. Sxx (1,1) = 1178 kg

Using Eq.7,

ft = 49.40 kg/cm^2 say, 50 kg/cm^2

Bending Stress (fb)

Maximum bending moment i.e Mxy (6,2) = 1435 kg-m.

Section modulus of selected section Z = 96.12 cm^3

Using Eq.5,

fb = 1492.92 kg/cm^2

$\approx$ 1493 kg/cm^2

Axial Compression

From Eq.8, $S = \frac{250}{5.16}$

$= 48.44$

Allowable stresses in compression for above slenderness ratio is 128 MP (1304 kg/cm^2)

i.e. $F_c = 1304$ kg/cm^2

Using Eq.9,

$P_c = 1304 \times 23.83$

$= 31081$ kg

Stresses	Induced	Allowable
Shear stress	97 kg/cm^2	1100 kg/cm^2
Tensile stress	50 kg/cm^2	1467 kg/cm^2
Bending stress	1493 kg/cm^2	1610 kg/cm^2
Compressive force	-	31081 kg

Checks for AISC Conditions

1. L/K = 48.44
2. (fa / 0.6Fy) + (fb / Fb) = 0.96
3. No induced compressive force

Thus all the AISC conditions are satisfied and section is safe against combined effect.

Summary and Conclusions

Design of structural members was carried out for straight wall gable roof form of greenhouse for a wind velocity of 200 km/hr. Various loads(wind, live, dead, cladding and system) were estimated. A structural analysis was carried out using STASS package. Effect of wind at 0° was found to be more serve on the structure than wind at 90°. Size of the members that will constitute the columns is 113.5mm (square cross-section)

If all other members also use this section, the structure will be robust, capable of resisting winds of 200 km/hr. There are some aspects that need consideration. Besides being expensive, such a large amount of steel ($28kg/m^2$) will lead to the problem of heat accumulation. This is also not desirable in Bhujodi, where ambient temperatures are already high. Conventionally steel requirement for greenhouse should not be more than $10kg/m^2$.

Further effect of wind at 0^o on open greenhouse have been examined. Result showed that it is not good to permit high velocity wind inside greenhouse as it increase steel requirement (33 kg/m^2) besides making the structure expensive and disturbs the microclimate.

We will therefore explore the possibilities of reducing the size of members by,

(a) using two different sections--one for vertical columns, other (thinner) for the rest;

(b) providing a central column which will have the effect of reducing the size of member needed.

These will be explored in the subsequent sections.

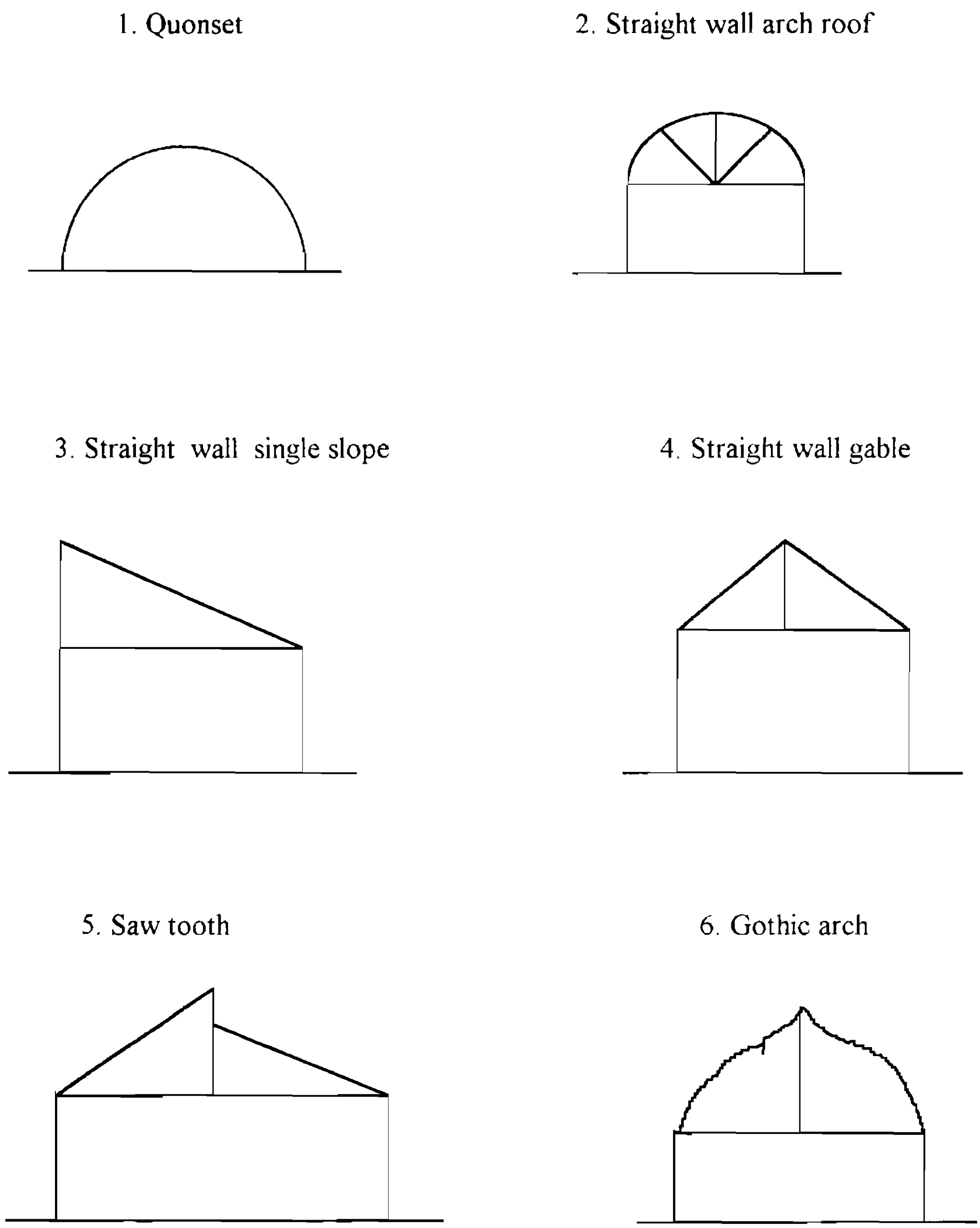


Figure 1: Free Standing Greenhouse - Examples

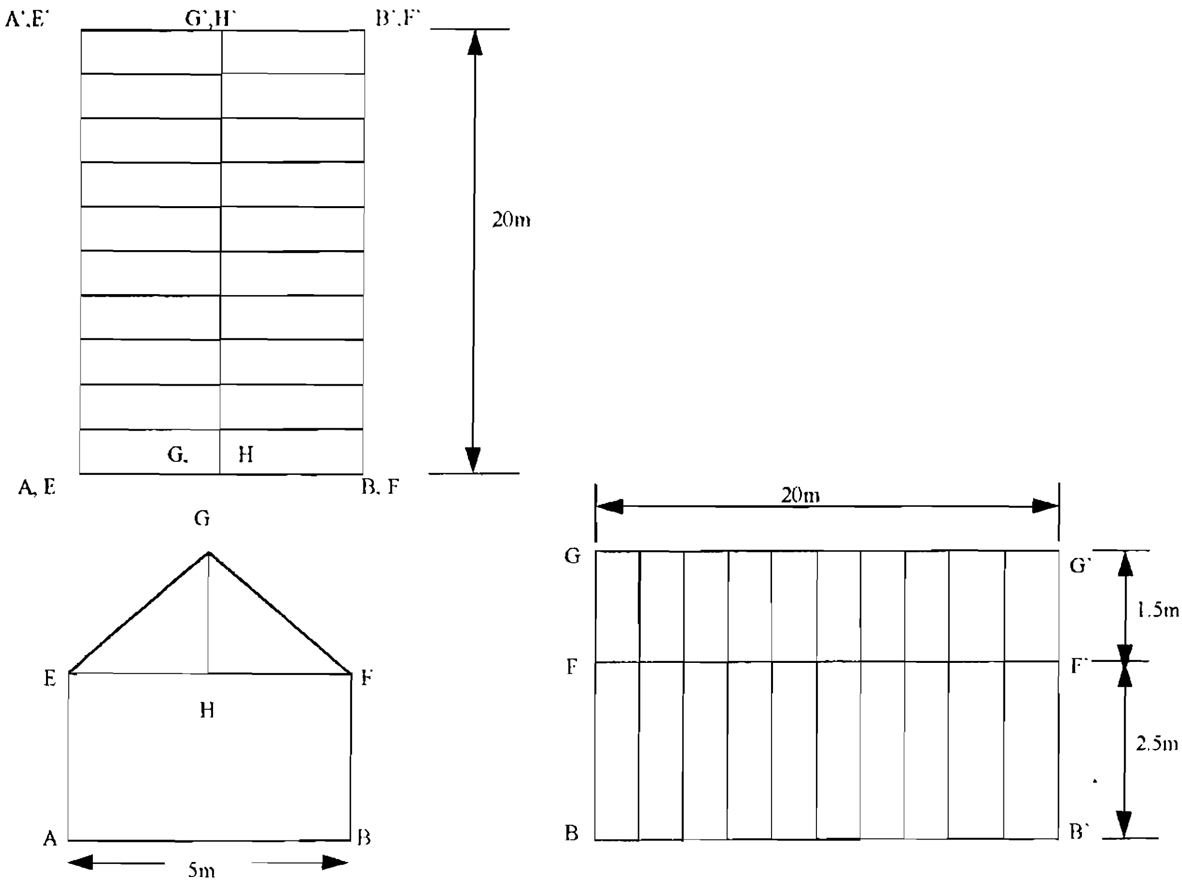


Figure 2 : Straight Wall Gable Roof Structure

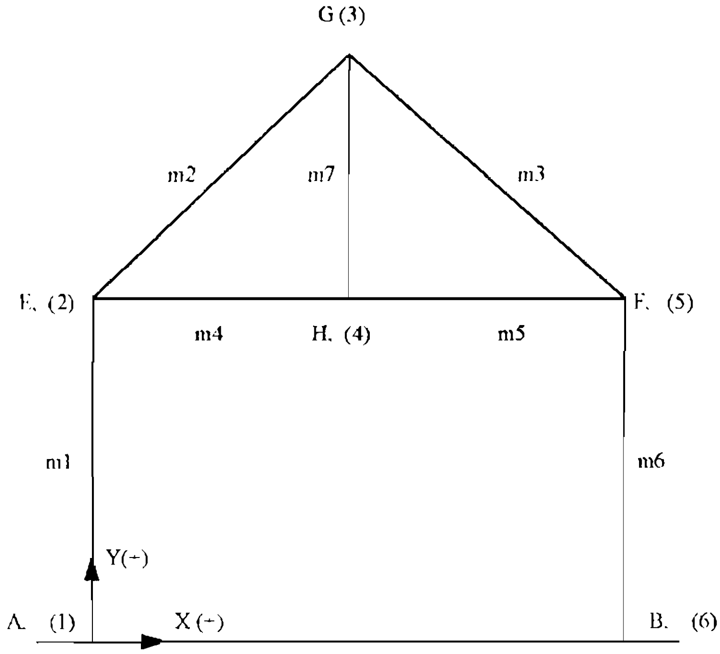


Figure 3 : Nomenculture Diagram

Note m1, m2 .. .. m7 are member notations
Number in bracket indicates joint notations of the member

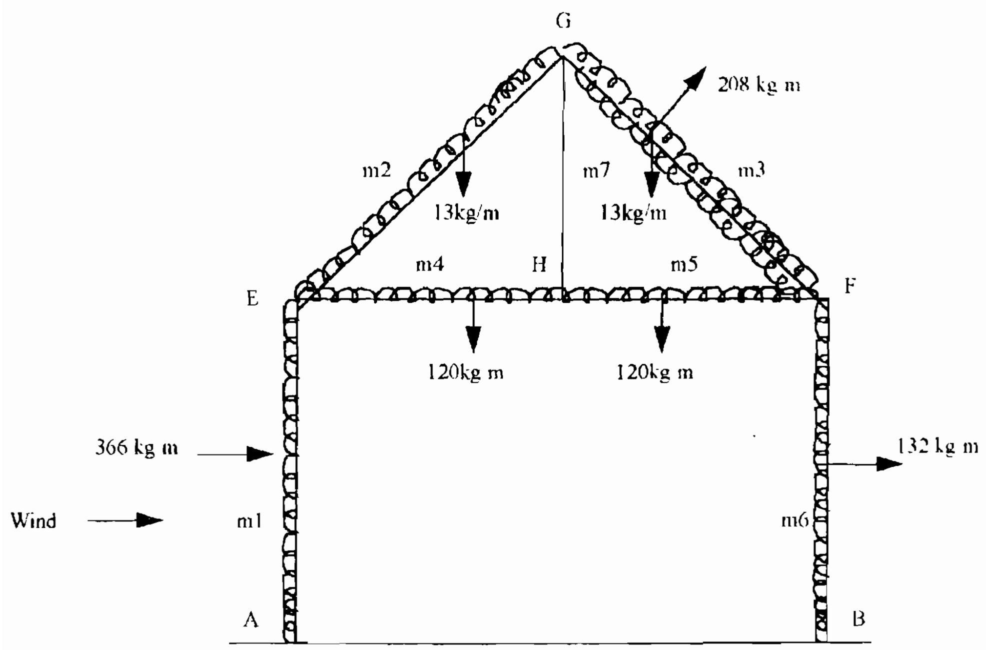


Figure 4 : A Loaded Frame (W0^0)

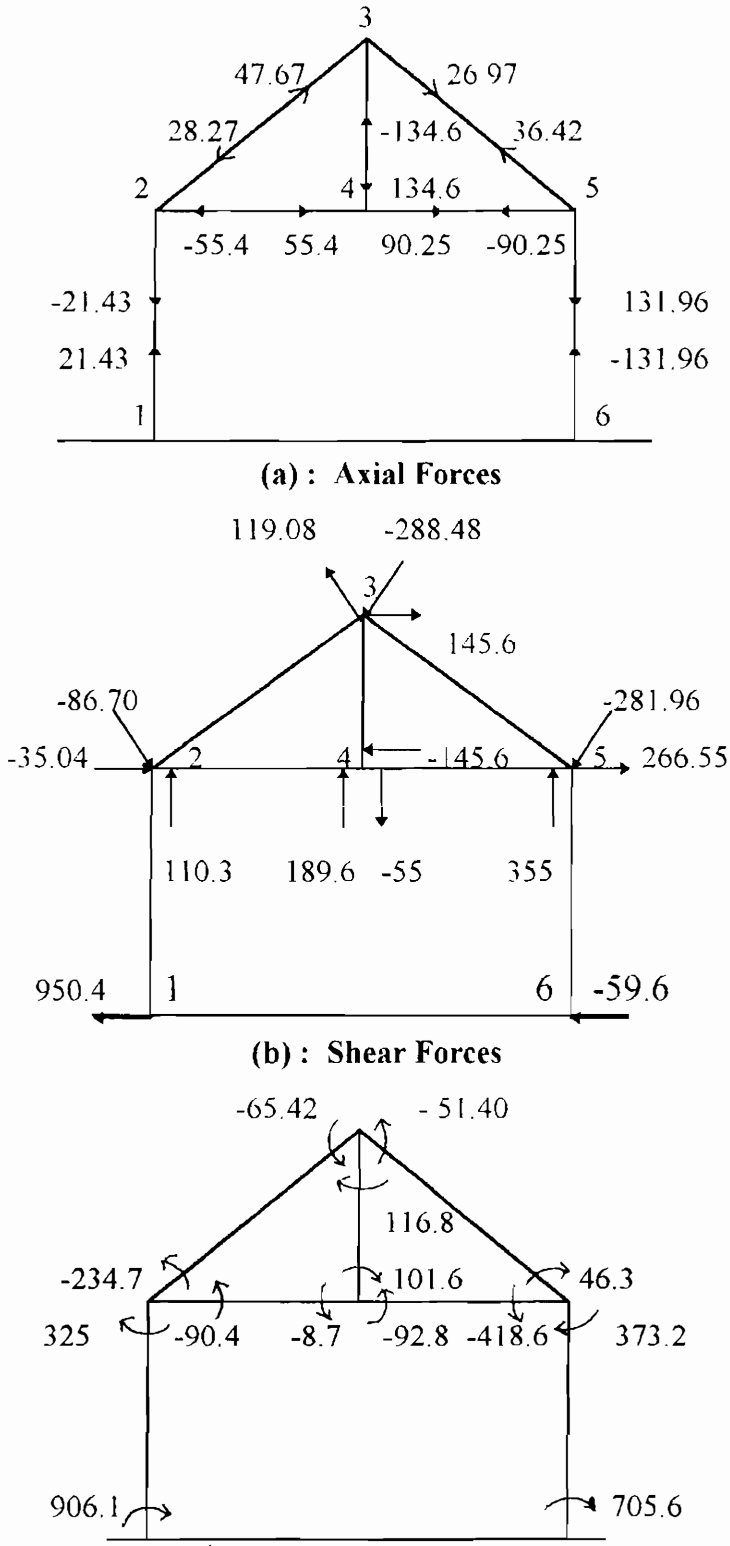


Figure 5: Force Response of Plane Frame with Rigid Joints

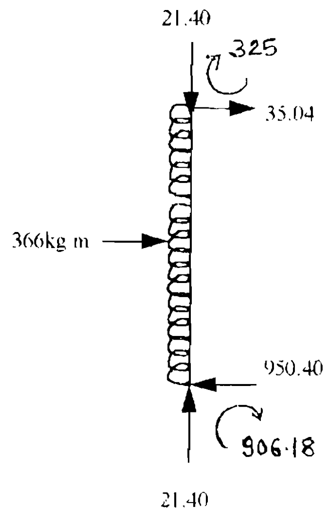


Figure 6. Free body diagram (member1)

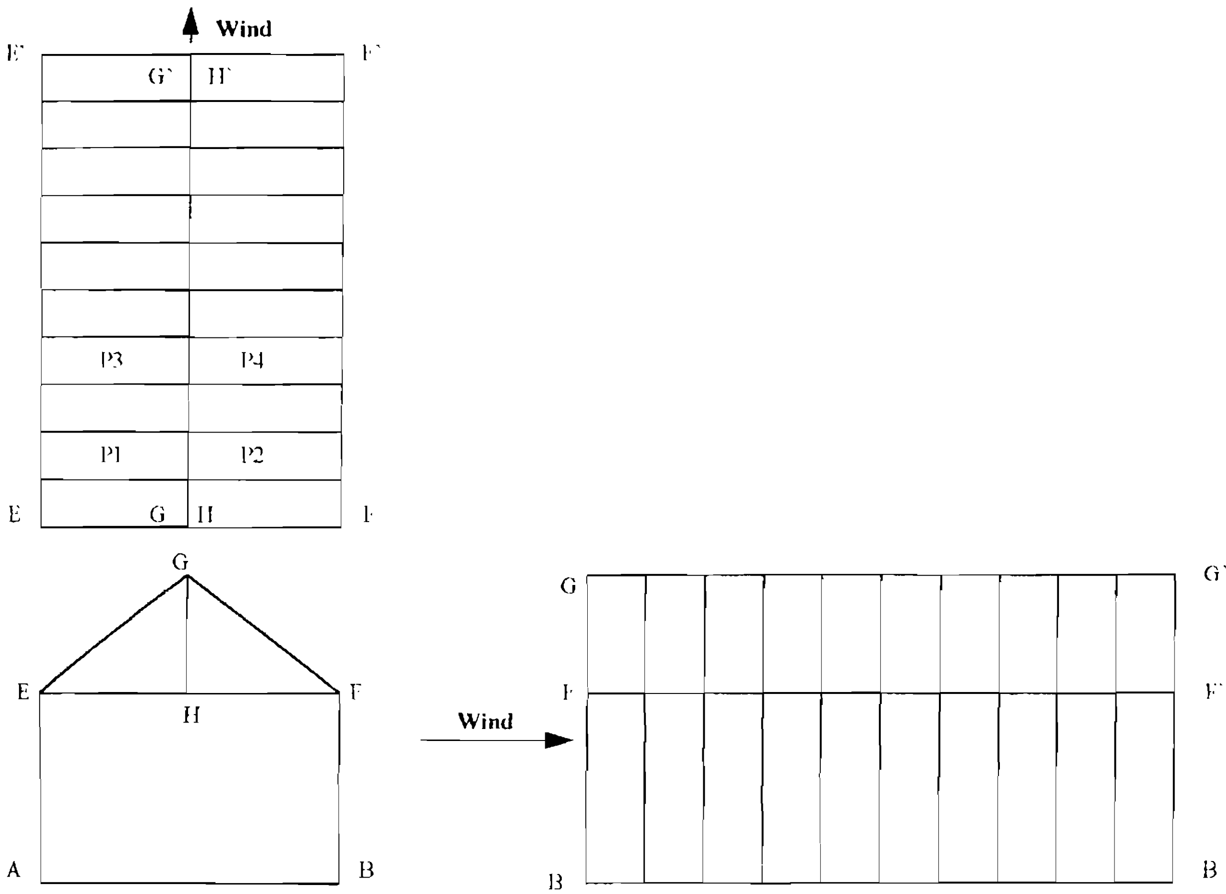


Fig.8 Wind at 90° to the Structure

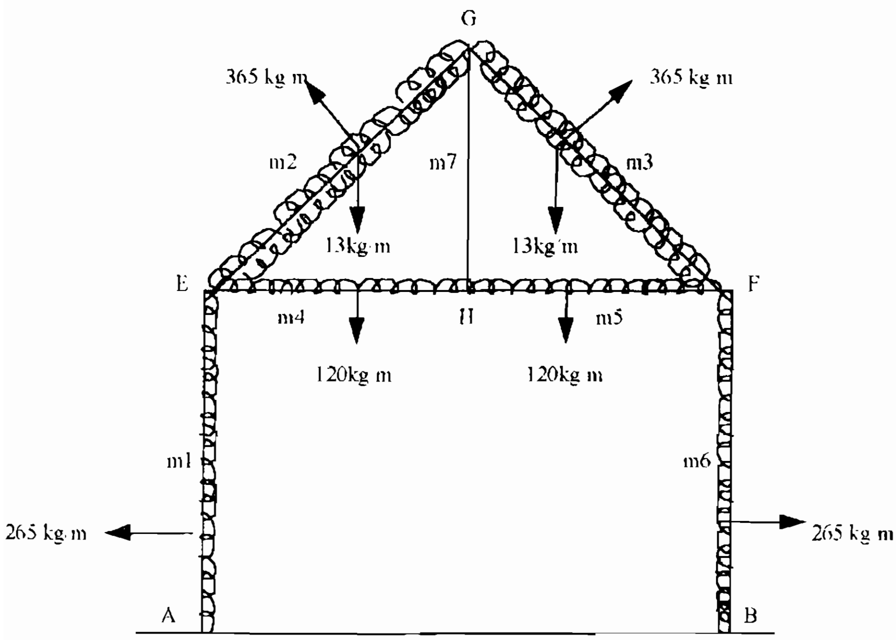


Figure 9 : A Loaded Frame (W90^{0})

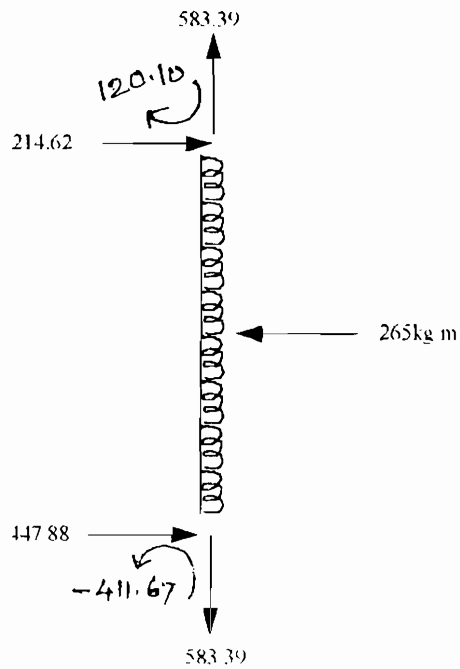


Figure.10 Free Body Diagram of Member1

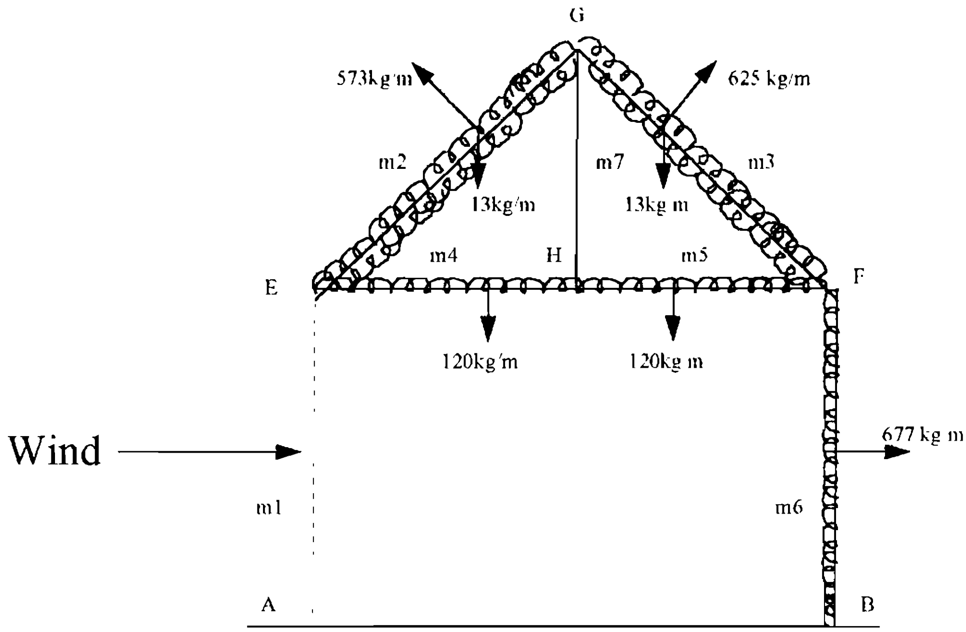


Figure 12 : A Loading Diagram (W angle 0^0 and left wall open)

References

1. Christian von Zabeltitz (1990). Appropriate greenhouse constructions for mild climates. Proceedings of XI International Congress on Use of Plastic in Agriculture, New Delhi, PP:F117-F126.

2. Chandra Pitam (1996). Greenhouse design consideration for hot arid areas. Symposium on Controlled Environment Agriculture in Arid Areas, Bhaikaka Bhavan, Law College Road, Ahmedabad.

3. Jension Merle H and Alan. J. Malter (1994). Protected agriculture. World Bank technical paper no.253, Washington D.C.

4. Indian Standard code of practice for design loads (other than earthquake) for buildings and structures, Part 3 Wind Loads (Second revision), 1987

5. Tata steel, Catalogue of closed structures (RHS/SHS).

6. Eugene A. Avallone and Theodore Baumeister (1997). Marks standard handbook for mechanical engineers. 10th edition, Mc-Graw Hill International Edition.

7. Bresler Boris, Lin.T.Y and John .B.Scalzi (1970). Design of steel structures. 2nd edition, Wiley Eastern Pvt. Ltd., PP:413-414.