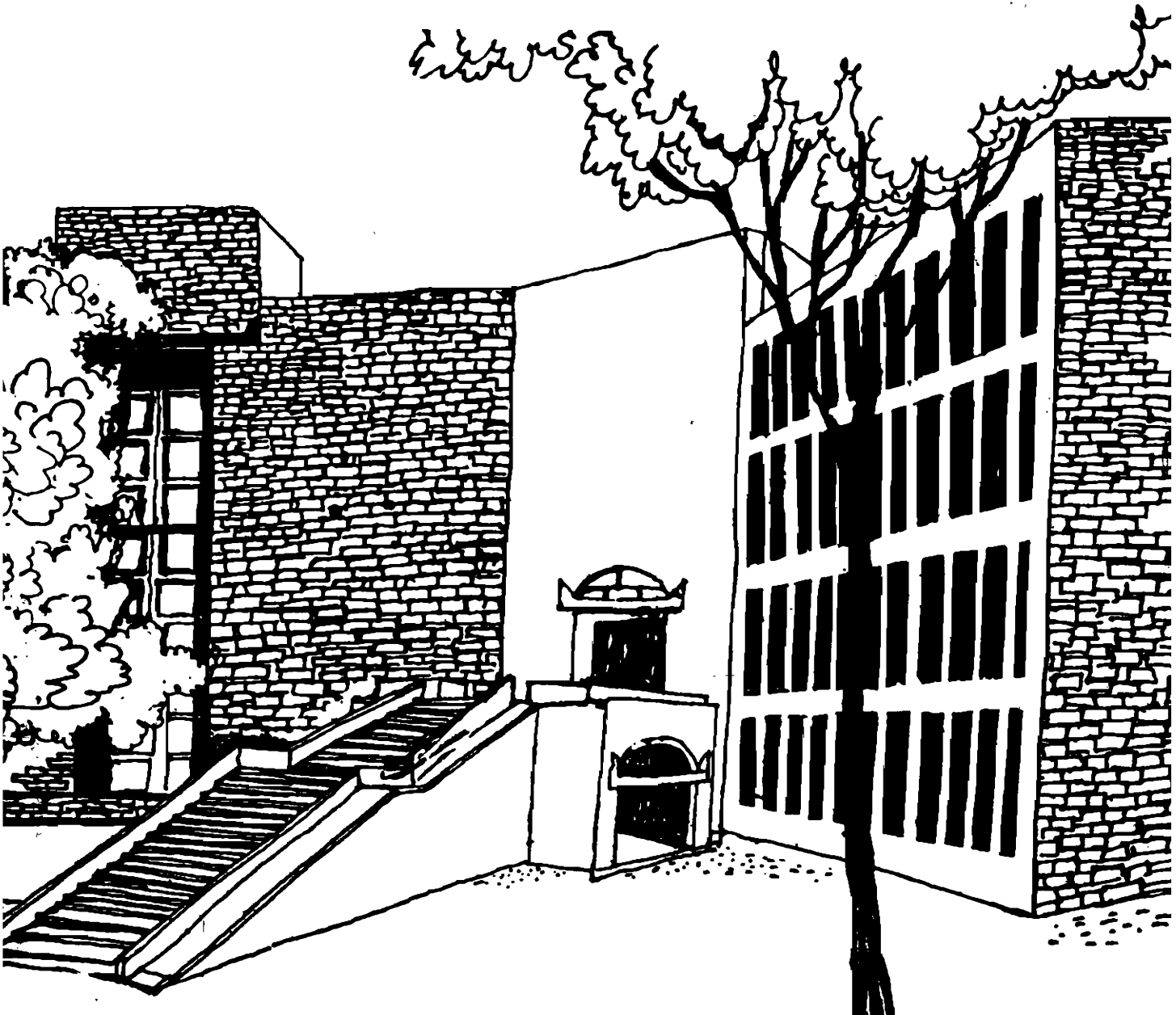




Working Paper



STRUCTURAL DESIGN FOR GREENHOUSE AT
BHUJODI-2

By

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W.P.No.99-02-01 / 1503
February 1999

WP1503

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WP
99-02-01
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Structural Design for Greenhouse at Bhujodi -2

Girja Sharan

Vasant R. Pilare

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 severe 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 slightly high (15 kg/m^2). Conventionally it should not exceed 10 kg/m^2 .

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 a 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 nearly 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.

$$V_z = V_b \cdot K_1 \cdot K_2 \cdot K_3 \quad \dots\dots\dots (1)$$

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

$$WL = P_d \cdot C_p \cdot A \quad \dots\dots\dots (3)$$

IS Wind Code (1987)[4] gives the basic wind speed for Bhuj (15 km from Bhujodi) as 50 m/s.

$$V_b = 50 \text{ m/sec.}$$

IS - 875 Part 3 (1987) gives the external pressure coefficient (C_p) for structures of various forms, sizes 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.

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

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

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

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

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 _o (Walls) | | | | C _o (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,

$$K_1 = 0.90 \text{ for } 50 \text{ m/sec and life } 25 \text{ years (from table 1 of IS Code Catalogue)}$$

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

$$K_3 = 1.13$$

Substituting these, in (3),

$$V_z = 50 \times 0.90 \times 0.98 \times 1.13$$

$$= 49.83 \sim 50 \text{ m/sec}$$

Substituting it, in (2),

$$P_d = 0.6 (50)^2$$

$$= 152.90 \sim 155 \text{ kg/m}^2$$

Bay Size

Bay size refers to spacing between two frames. Closer this spacing, greater the hindrance to 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 Quonse usually have 1 m; commercially available such as Jain Greenhouses 3-4 m; and G.A.U., Navsar 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

$$\begin{aligned}\text{Load on segment AE} &= 0.7 \times 5 \times 155 \\ &= 542.50 \approx 545 \text{ kg}\end{aligned}$$

$$\text{OR} \quad \frac{545}{2.5} = 218 \text{ kg/m}$$

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

$$\begin{aligned}\text{Load on segment BF} &= -0.25 \times 5 \times 155 \\ &= -195 \text{ kg}\end{aligned}$$

$$\text{OR} \quad = -78 \text{ kg/m}$$

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

$$\text{Load on segment EG} = 0$$

$$\begin{aligned}\text{Load on segment GF} &= -0.4 \times 5.8 \times 155 \\ &= -360 \text{ kg}\end{aligned}$$

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,

$$\text{LL} = 50 \times 10 = 500 \text{ kg or } 100 \text{ kg/m}$$

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.

$$\text{Load on segment EGF} = 9.72 \times 7.32 = 71.15 \approx 75 \text{ kg or } 12.88 \text{ kg/m} \approx 13 \text{ kg/m}$$

$$\text{Load on segment EHF} = 9.72 \times 5 = 48.6 \approx 50 \text{ kg or } 10 \text{ kg/m}$$

(d) Weight of Cladding (CL)

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

$$\text{Total weight of cladding} = 0.4 \times 21.64 = 8.65 \text{ kg}$$

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.

$$\text{SL} = 5 \times 10 = 50 \text{ kg or } 10 \text{ kg/m}$$

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 545 kg or 218 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 (360 kg) and dead load due to self weight(13 kg/m). Vector sum works out to 335 kg or 115 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 HI (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 160 kg(64 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,

| | |
|---------------|--|
| $L_x(i)$ | Applied load in 'X' direction on ' i ' th member |
| $L_y(i)$ | Applied load in 'Y' direction on ' i ' th member |
| $S_{xx}(i,j)$ | Axial force in ' i ' th member at ' j ' th end |
| $S_{xy}(i,j)$ | Shear in ' i ' th member at ' j ' th end |
| $M_{xy}(i,j)$ | Bending moment in ' i ' th member at ' j ' th end |
| $R_x(i,j)$ | Fixed end reaction in ' i ' th member at ' j ' th end in 'X' direction |
| $R_y(i,j)$ | Fixed end reaction in ' i ' th member at ' j ' th end in 'Y' direction |
| $R_m(i,j)$ | 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° and two fixed supports) | | | | | | |
| Member | Axial Force (kg), Sxx | | Shear Force (kg), Sxy | | Bending Moment (kg.m), Mxy | |
| | Jend | Kend | Jend | Kend | Jend | Kend |
| 1 | 148.78 | -148.78 | 535.01 | 9.99 | 521.49 | 134.77 |
| 2 | 13.2 | 6.2 | -42.75 | 75.08 | -150.93 | -21.07 |
| 3 | 38.69 | -51.13 | -168.53 | -160.21 | -48.69 | 39.11 |
| 4 | -23.32 | 23.32 | 178.65 | 121.35 | 16.16 | 55.46 |
| 5 | 63.52 | -63.52 | -24.49 | 324.49 | -115.96 | -320.28 |
| 6 | 213.42 | -213.42 | 189.79 | -384.79 | 281.17 | 437.07 |
| 7 | -96.86 | 96.86 | 86.84 | -86.84 | 69.76 | 60.5 |

| Table 2(b) | | | |
|----------------------------|------------------------------|----------------------------|----------------------------|
| Fixed End Reactions | | | |
| Joint No. | Horizontal Reaction (Rx), kg | Vertical Reaction (Ry), kg | Resisting Moment (Rm),kg-m |
| 1 | -535.00 | -148.78 | 521.49 |
| 6 | -384.79 | -213.41 | 437.06 |

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

Checks

(a) Equilibrium of whole frame

$$\begin{aligned}\sum F_x &= L_x(1) + L_x(3) + L_x(6) + R_x(1,1) + R_x(6,2) \\ &= 545 + 180 + 195 - 535.00 - 384.79 \approx 0\end{aligned}$$

$$\begin{aligned}\sum F_y &= L_y(2) + L_y(3) + L_y(4) + L_y(5) + R_y(1,1) + R_y(6,2) \\ &= -37.83 + 311 - 37.83 - 300 - 300 + 148.78 + 213.41 \approx 0\end{aligned}$$

$$\sum M = M_{xy}(1,1) + M_{xy}(6,2) - R_m(1,1) - R_m(6,2)$$

$$= 521.49 + 437.07 - 521.49 - 437.06 \approx 0$$

Small and obvious rounding-of errors were present.

(b) Equilibrium of Member

Figure 6 is free-body diagram of member 1.

$$\begin{aligned} \Sigma F(1) &= L_x(1) + S_{xy}(1,1) + S_{xy}(1,2) \\ &= -545 + 535.01 + 9.99 \approx 0 \end{aligned}$$

(c) Joint Equilibrium

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

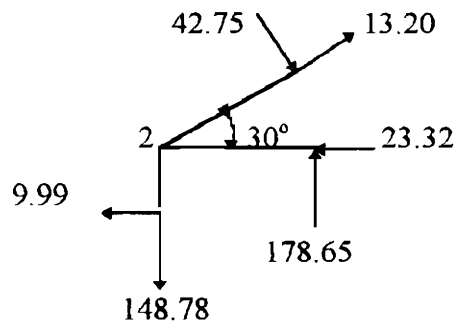


Figure 7: Free Body Diagram of Joint 2

$$\Sigma F_x(2) = 13.20 \cos 30 + 42.75 \cos 60 - 9.99 - 23.32 \approx 0$$

$$\Sigma F_y(2) = 13.20 \sin 30 - 42.75 \sin 60 + 178.65 - 148.78 \approx 0$$

$$\Sigma M(2) = 134.77 - 150.93 + 16.16 \approx 0$$

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 (522 kg-m) occurs at 'J'end of member1. Maximum shear force occurs also at 'J'end of member1 (535 kg). Maximum axial force (tension) occurs in member7 (97 kg). Maximum axial force (compression) occurs in member 6 (214 kg).

Selection of member size

Let,

| | |
|------------|---|
| F_v | allowable maximum shear stress (kg/m^2) |
| F_t | allowable axial stress in tension (kg/m^2) |
| F_c | allowable axial stress in compression (kg/m^2) |
| F_b | allowable bending stress in tension and compression (kg/m^2) |
| σ_s | 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) |
| P_c | 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 structure

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.

$$F_v = 109 \text{ MPa (1100 kg/cm}^2\text{)}$$

$$F_t = 144 \text{ MPa (1467 kg/cm}^2\text{)}$$

$$F_b = 158 \text{ MPa (1610 kg/cm}^2\text{)}$$

$$\sigma_{st} = 240 \text{ MPa (2445 Kg/cm}^2\text{)}$$

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

The flexural formula [6] ,

$$\frac{M_{xy}}{I} = \frac{F_b}{Y} = \frac{E}{R} \quad \dots\dots\dots (4)$$

$$M_{xy} = \frac{I \times F_b}{Y} \quad \dots\dots\dots (5)$$

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

$$M_{xy(1,1)} = 522$$

$$F_b = 1610 \text{ kg/m}^2$$

From Eq.5,

$$Z = (52200 / 1610) = 32.42 \text{ cm}^3$$

Available commercial section nearest to the required Z is

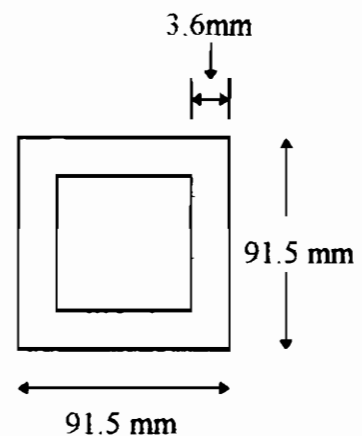
D 91.5 X 91.5 mm,

A 12.32 cm²,

T 3.6 mm,

Z 34.21 cm³,

K 3.56 cm.



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

Shear stress (f_v)

$$f_v = 1.591 \times \frac{S_{xy(1,1)}}{A} \dots\dots\dots(6)$$

As seen earlier, $S_{xy(1,1)} = 535 \text{ kg}$

$$f_v = 1.591 \times (535 / 12.32) = 69.26 \text{ kg/cm}^2 \text{ (say, 70 kg/cm}^2\text{)}$$

Tensile stress (f_t)

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

$$S_{xx(7)} = 97 \text{ kg.}$$

$$\begin{aligned} f_t &= 97 / 12.32 \\ &= 7.87 \text{ kg/cm}^2 \text{ (say, 8 kg/cm}^2\text{)} \end{aligned}$$

Bending Stress (f_b)

$$\text{Maximum bending moment i.e } M_{xy(1,1)} = 522 \text{ kg-m.}$$

$$\text{Section modulus of selected section } Z = 34.21 \text{ cm}^3$$

Using Eq.5,

$$\begin{aligned} f_b &= 52200 / 34.21 \text{ kg/cm}^2 \\ &\approx 1525 \text{ kg/cm}^2 \end{aligned}$$

Axial Compression

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

$$= \frac{250}{3.56}$$

$$= 70.22$$

Allowable stress in compression (F_c) for above slenderness ratio and selected grade of steel (Y_{st} 240) 109 MPa (1110 kg/cm²).

$$P_c = F_c \times A \dots\dots\dots(9)$$

$$= 1110 \times 12.32$$

$$= 13675 \text{ kg}$$

| Stress | Induced | Allowable |
|-------------------------|-------------------------|-------------------------|
| Shear stress | 70 kg/cm ² | 1100 kg/cm ² |
| Tensile stress | 8 kg/cm ² | 1467 kg/cm ² |
| Bending stress | 1525 kg/cm ² | 1610 kg/cm ² |
| Axial compression force | 214 kg | 13675 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. $(f_t / 0.6\sigma_{st} \text{ or } f_a / F_t) + (f_b / F_b) \leq 1.0$ for tension induced by bending
3. $(f_c / F_c) + (f_b / F_b) \leq 1.0$ for compression induced by bending

In the present case,

$$f_t = 8 \text{ kg/cm}^2$$

$$F_t = 1467 \text{ kg/cm}^2$$

$$f_c = 18 \text{ kg/cm}^2$$

$$F_c = 1110 \text{ kg/cm}^2$$

$$f_b = 1525 \text{ kg/cm}^2$$

$$F_b = 1610 \text{ kg/cm}^2$$

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$$L / K = 250 / 3.56$$

$$= 70.22$$

$$(f_a / 0.6F_y) + (f_b / F_b) = (8 / 1467) + (1525 / 1610)$$

$$= 0.945$$

$$(f_c / F_c) + (f_b / F_b) = (18 / 1110) + (1525 / 1610)$$

$$= 0.956$$

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_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' |
| 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 155 kg/m acting in (-) X direction outward from frame. Segment EG(m2) and GF(m3), each is having wind load of 219 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

(155 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° and two fixed supports) | | | | | | |
| Member | Axial Force (kg), Sxx | | Shear Force (kg), Sxy | | Bending Moment (kg.m), Mxy | |
| | Jend | Kend | Jend | Kend | Jend | Kend |
| 1 | -263.56 | 263.56 | 384.414 | 3.086 | 304.257 | 172.402 |
| 2 | -138.431 | 147.88 | -395.373 | -208.902 | -257.643 | -9.508 |
| 3 | -145.379 | 135.93 | -255.491 | -348.784 | -5.948 | 146.62 |
| 4 | -81.628 | 81.628 | 146.692 | 153.308 | 85.241 | -93.511 |
| 5 | -59.802 | 59.803 | 94.025 | 205.975 | 76.228 | -216.166 |
| 6 | -163.04 | 163.04 | 3.086 | -390.586 | 69.545 | 422.545 |
| 7 | -247.333 | 247.333 | 21.826 | -21.826 | 15.456 | 17.283 |

| Table 4(b) Fixed End Reactions | | | |
|---------------------------------------|------------------------------|----------------------------|-----------------------------|
| Joint No. | Horizontal Reaction (Rx), kg | Vertical Reaction (Ry), kg | Resisting Moment (Rm), kg-m |
| 1 | -384.41 | -263.56 | -304.25 |
| 6 | 390.58 | -163.04 | 422.54 |

Equilibrium Checks

(a) Equilibrium of whole frame

$$\sum F_x = L_x(1) + L_x(2) + L_x(3) + L_x(6) + R_x(1,1) + R_x(6,2)$$

$$= -387.5 - 319 + 319 + 387.5 - 384.41 + 390.58 \approx 0$$

$$\sum F_y = L_y(2) + L_y(3) + L_y(4) + L_y(5) + R_y(1,1) + R_y(6,2)$$

$$= 552.9 - 37.83 + 552.9 - 37.83 - 300 - 300 - 263.56 - 163.04 \approx 0$$

$$\sum M = M_{xy}(1,1) + M_{xy}(6,2) - R_m(1,1) - R_m(6,2)$$

$$= 304.25 + 422.54 - 304.25 - 422.54 \approx 0$$

Some obvious rounding of errors were present.

b) Equilibrium of member

Figure 10 is free body diagram of member 1.

$$\begin{aligned}\Sigma F(1) &= L_x(1) + S_{xy}(1,1) + S_{xy}(1,2) \\ &= 387.5 - 384.41 - 3.08 \approx 0\end{aligned}$$

(c) Joint Equilibrium

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

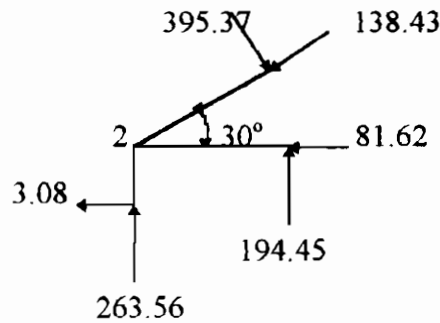


Figure 11: Free Body Diagram for Joint 2

$$\Sigma F_x(2) = -138.43 \cos 30 + 395.37 \cos 60 - 3.08 - 81.62 \approx 0$$

$$\Sigma F_y(2) = -138.43 \sin 30 - 395.37 \sin 60 + 194.45 + 263.56 \approx 0.$$

$$\Sigma M(2) = 172.40 - 257.64 + 85.24 \approx 0$$

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) | 522 kg-m, Mxy(1,1) | 423 kg-m, Mxy(6,2) |
| Maximum shear force (Sxy) | 535 kg, Sxy(1,1) | 396 kg, Sxy(2,1) |
| Maximum Axial force in Tension (Sxx) | 97 kg, Sxx (7) | 264 kg, Sxx(1) |
| Maximum axial force in Compression (Sxx) | 214 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°)

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° to such open structure.

External and internal pressure coefficients created because of wind flowing at 0° 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 at 0° and left wall open) | | | | | | |
| Member | Axial Force (kg), Sxx | | Shear Force (kg), Sxy | | Bending Moment (kg.m), Mxy | |
| | Jend | Kend | Jend | Kend | Jend | Kend |
| 1 | -32.166 | 32.166 | 98.045 | -98.045 | 166.505 | 78.607 |
| 2 | -96.551 | 112.963 | -186.117 | -124.724 | -144.943 | 57.853 |
| 3 | -107.067 | 92.644 | -197.27 | -139.433 | -81.506 | -0.2 |
| 4 | -111.01 | 111.01 | 177.103 | 122.897 | 66.336 | 1.423 |
| 5 | -78.741 | 78.741 | 40.007 | 259.993 | -26.172 | -248.811 |
| 6 | 92.768 | -92.768 | -86.445 | -921.055 | 249.011 | 794.251 |
| 7 | -162.903 | 162.903 | 32.268 | -32.268 | 23.653 | 24.749 |

| Table 7(b) | | | |
|----------------------------|-----------------------------|----------------------------|----------------------------|
| Fixed End Reactions | | | |
| Joint No. | Horizontal Reaction (Rx),kg | Vertical Reaction (Ry), kg | Resisting Moment (Rm),kg-m |
| 1 | -98.04 | -32.16 | 166.50 |
| 6 | -921.05 | 92.76 | 794.25 |

Equilibrium Check for Whole Frame

$$\begin{aligned}\Sigma F_x &= L_x (2) + L_x (3) + L_x (6) + R_x (1,1) + R_x (6,2) \\ &= -174 + 186 + 1008 - 98.04 - 921.05 \approx 0\end{aligned}$$

$$\begin{aligned}\Sigma F_y &= L_y (2) + L_y (3) + L_y (4) + R_y (5) + R_y (1,1) + R_y (6,2) \\ &= 295.8 - 37.83 + 319 - 37.83 - 300 - 300 - 32.16 + 92.76 \approx 0\end{aligned}$$

$$\begin{aligned}\Sigma M &= M_{xy} (1,1) + M_{xy} (6,2) - R_m (1,1) - R_m (6,2) \\ &= 166.50 + 794.25 - 166.50 - 794.25 \approx 0\end{aligned}$$

Some obvious rounding of errors are present.

Selection of Member Size

Maximum bending moment occurs at 'k' end of 6th member i.e. $M_{xy} (6,2) = 795 \text{ kg-m}$.

Using Eq.5,

$$Z = \frac{79500}{1610} = 49.37$$

Available cross section close to this requirement is

| | |
|---|-----------------------|
| D | 113.5 x 113.5 mm |
| A | 20.28 cm ² |
| t | 4.80 mm |
| Z | 69.30 cm ³ |
| K | 4.40 cm |

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

Shear Stress (fv)

Maximum shear force i.e. $S_{xy}(6,2) = 922 \text{ kg}$

Using Eq.6,

$$f_v = 72.51 \text{ kg/cm}^2 \quad \text{say, } 75 \text{ kg/cm}^2$$

Tensile Stress (ft)

Maximum tensile force i.e. $S_{xx}(7) = 163 \text{ kg}$

Using Eq.7,

$$f_t = 8 \text{ kg/cm}^2$$

Bending Stress (fb)

Maximum bending moment i.e. $M_{xy}(6,2) = 795 \text{ kg-m}$.

Section modulus of selected section $Z = 69.30 \text{ cm}^3$

Using Eq.5,

$$\begin{aligned} f_b &= 1147 \text{ kg/cm}^2 \\ &\approx 1150 \text{ kg/cm}^2 \end{aligned}$$

Axial Compression

$$\begin{aligned} \text{From Eq.8, } S &= \frac{250}{4.40} \\ &= 56.81 \end{aligned}$$

Allowable stresses in compression for above slenderness ratio is 107 MP (1090 kg/cm²)

$$\text{i.e. } f_c = 1212 \text{ kg/cm}^2$$

Using Eq.9,

$$\begin{aligned} P_c &= 1212 \times 20.28 \\ &= 24580 \text{ kg} \end{aligned}$$

| Stresses | Induced | Allowable |
|-------------------|-------------------------|-------------------------|
| Shear stress | 75 kg/cm ² | 1100 kg/cm ² |
| Tensile stress | 8 kg/cm ² | 1467 kg/cm ² |
| Bending stress | 1150 kg/cm ² | 1610 kg/cm ² |
| Compressive force | - | 24580 kg |

Checks for AISC Conditions

1. $L/K = 56.81$
2. $(f_a / 0.6F_y) + (f_b / F_b) = 0.719$
3. No induced compressive force

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

Steel Requirement of greenhouse

As estimated earlier, column section of greenhouse is of size 91.5mm x 91.5mm. Forces developed in roof section are of lower magnitude. Maximum bending moment in the roof is at Kend of fifth memebr with value 320 kg-m. A square crosssection of size 72mm x 72 mm is suitable to resist induced bending moment in roof section. Based on these steel requirement of greenhouse are as follows.

| | |
|---------------------------|---|
| Steel in column section | = length x weight/ unit length |
| | = 5 x 9.67 = 48.35 kg. |
| Steel in roof members | = 12.32 x 8.22 = 101.27kg. |
| Unit requiremnet of steel | = 149.62 / 10 = 14.96 kg / m ² of floor area |
| Total steel requirement | = 11 x 149.62 = 1645 kg (1.6 tons) |

Summary and Conclusions

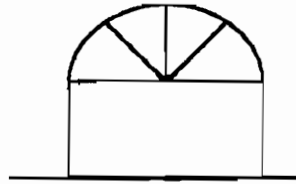
Design of structural members was carried out for straight wall gable roof form of greenhouse for a wind velocity of 180 km/hr. Various loads(wind, live, dead, cladding and system) were estimated. A structural analysis was carried out using STASS package. Effect of wind at 0° was found to be more serve on the structure than wind at 90°. Size of the members that will constitute the columns and roof are 91.5mm and 72 mm respectively (square cross-section).

Further effect of wind at 0° 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 (27 kg/m²) besides making the structure expensive and disturbs the microclimate.

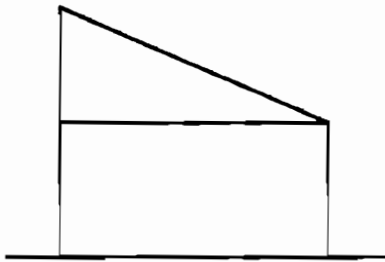
1. Quonset



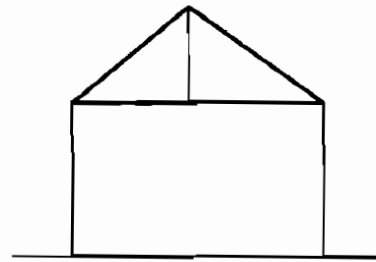
2. Straight wall arch roof



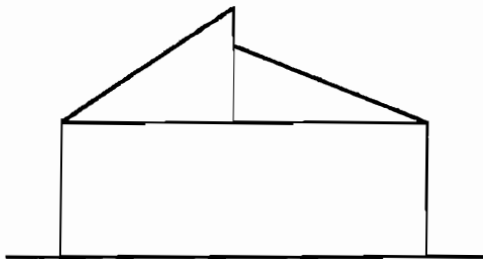
3. Straight wall single slope



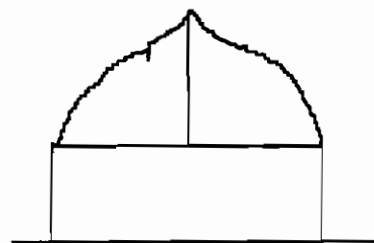
4. Straight wall gable



5. Saw tooth



6. Gothic arch

**Figure 1: Free Standing Greenhouse - Examples**

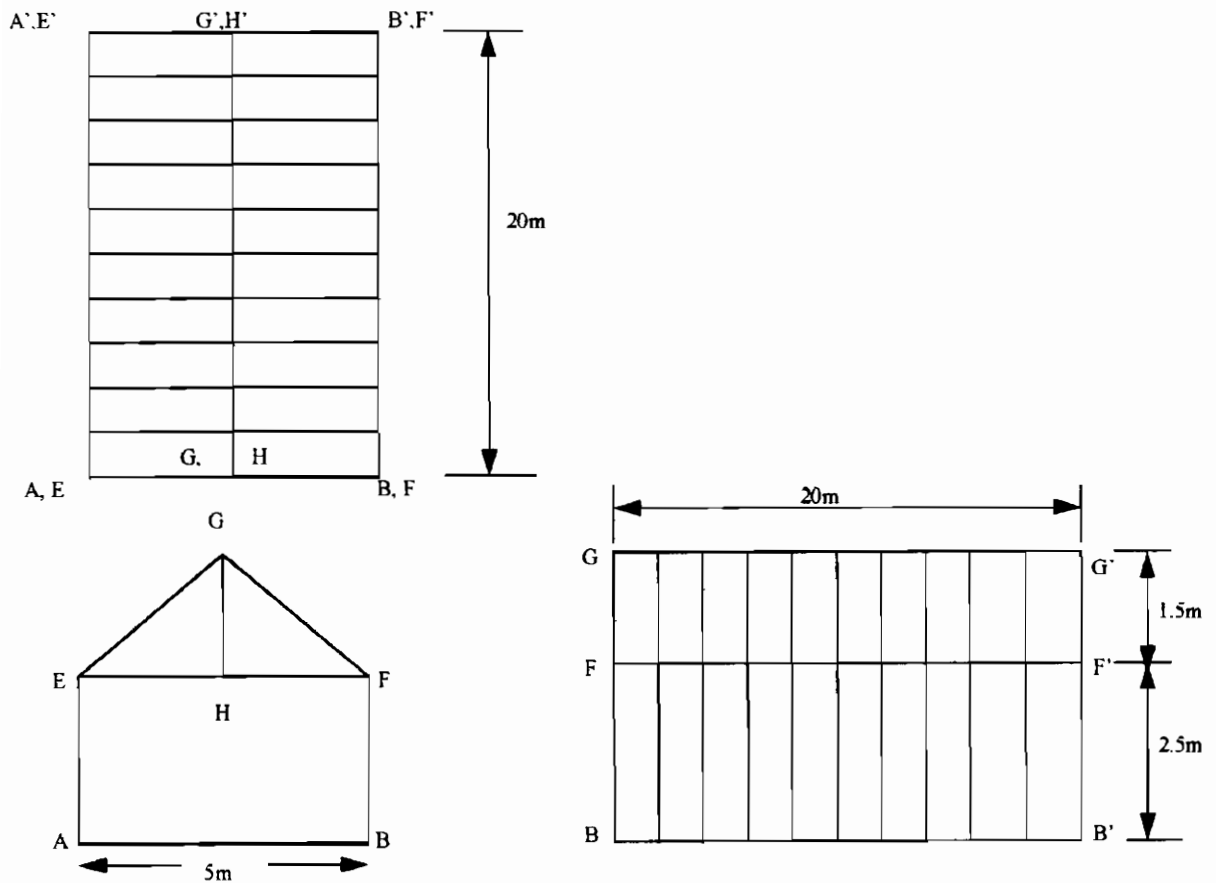


Figure 2 : Straight Wall Gable Roof Structure

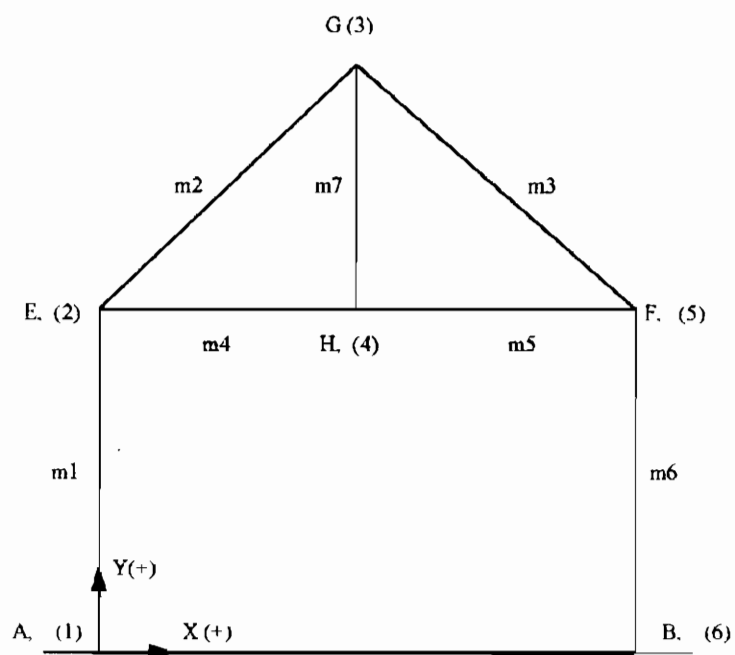


Figure 3 : Nomenclature Diagram

Note : m1, m2 m7 are member notations

Number in bracket indicates joint notations of the member

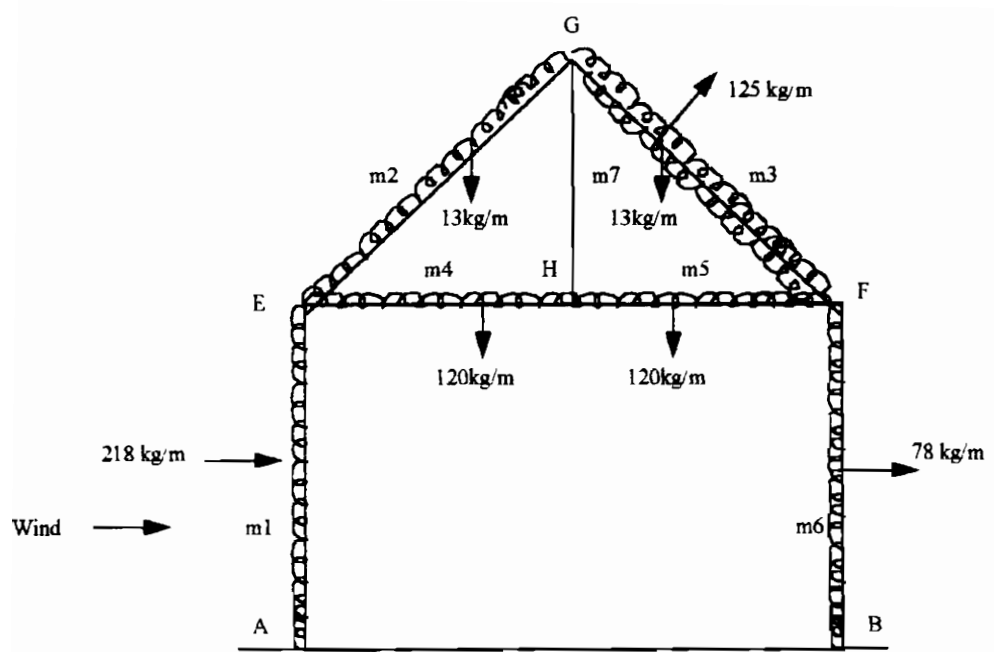
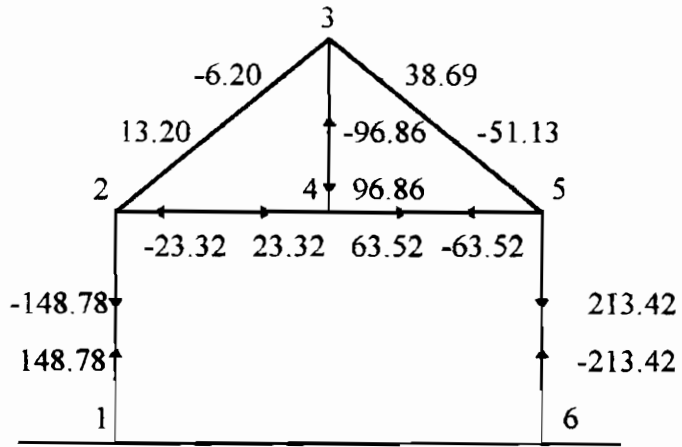
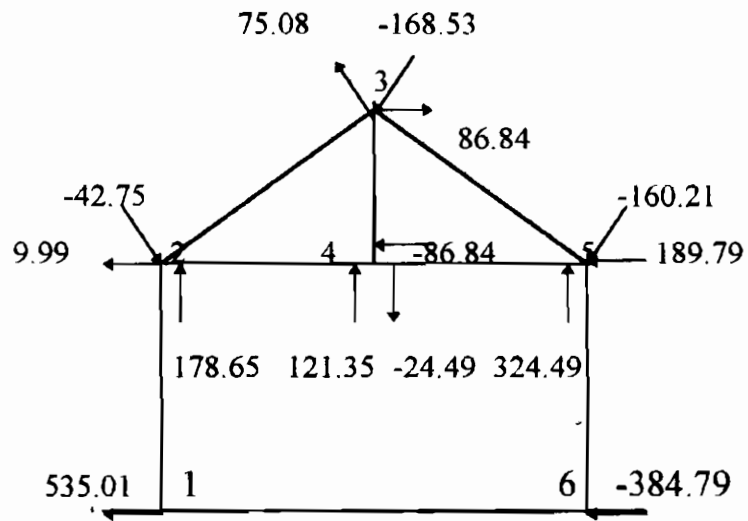


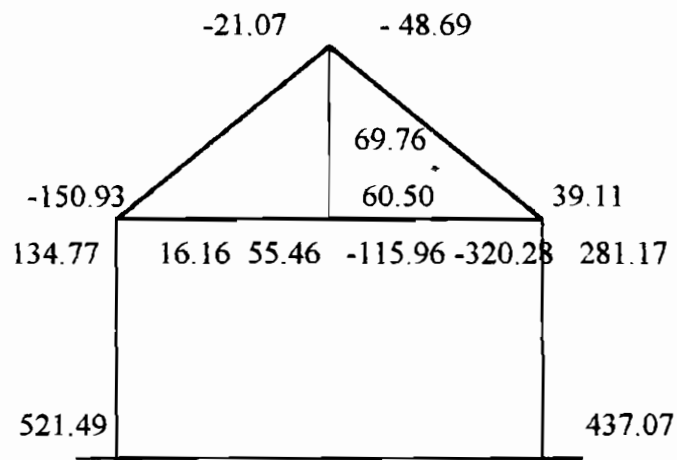
Figure 4 : A Loaded Frame ($W0^0$)



(a) : Axial Forces



(b) : Shear Forces



(c) : Bending Moments

Figure 5: Force Response of Plane Frame with Rigid Joints

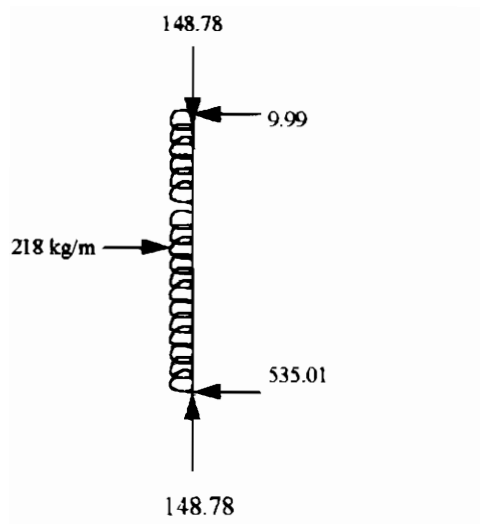


Figure 6. Free body diagram (member1)

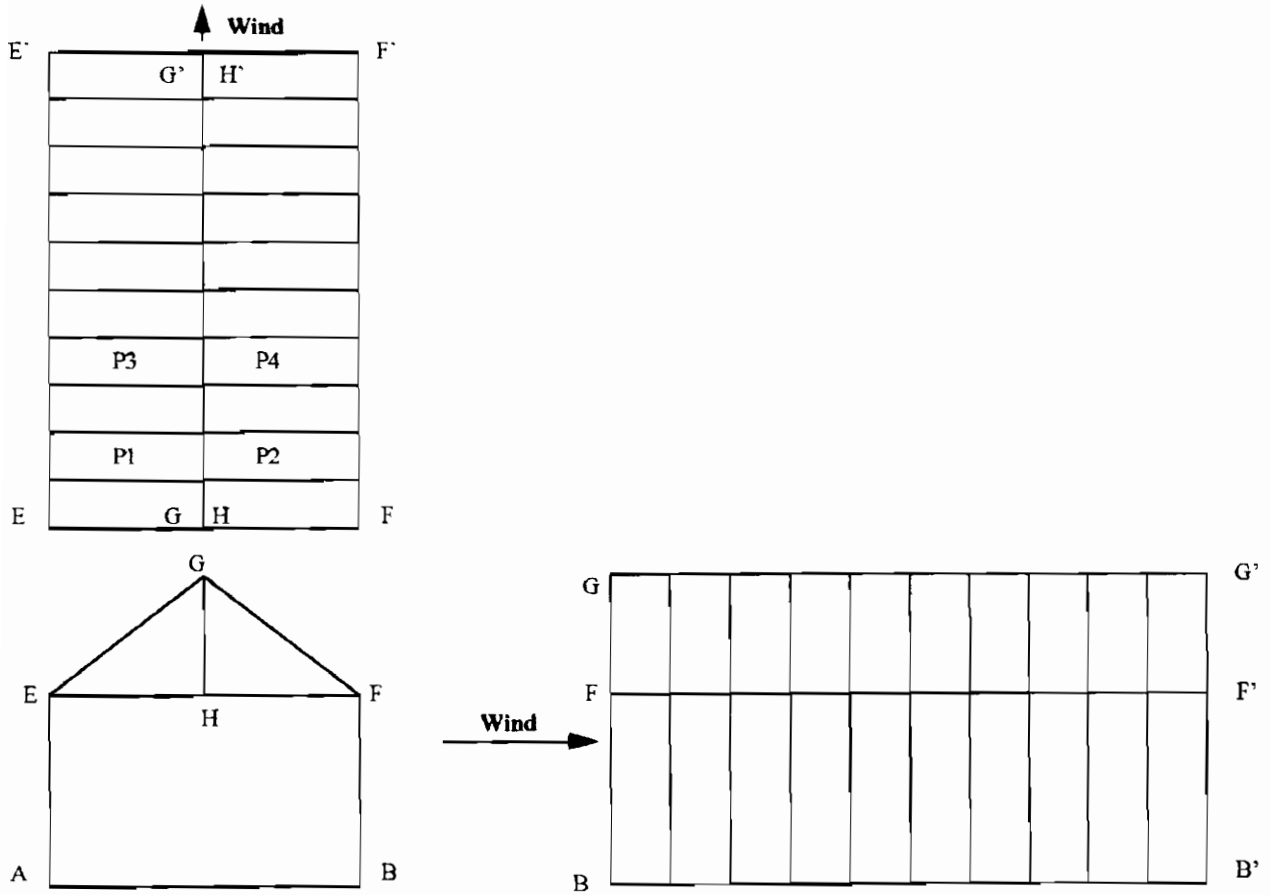


Fig.8 Wind at 90° to the Structure

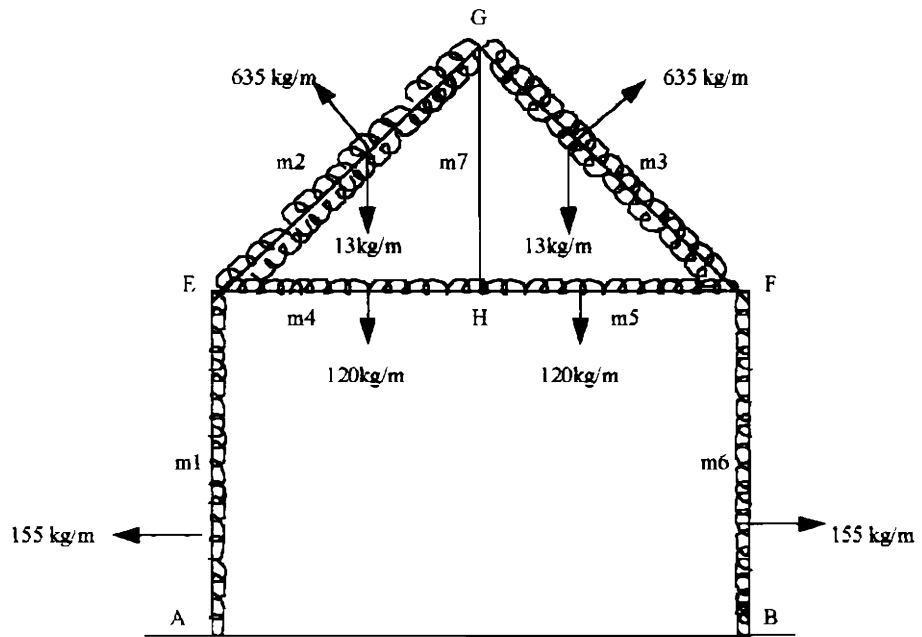


Figure 9 : A Loaded Frame (W90⁰)

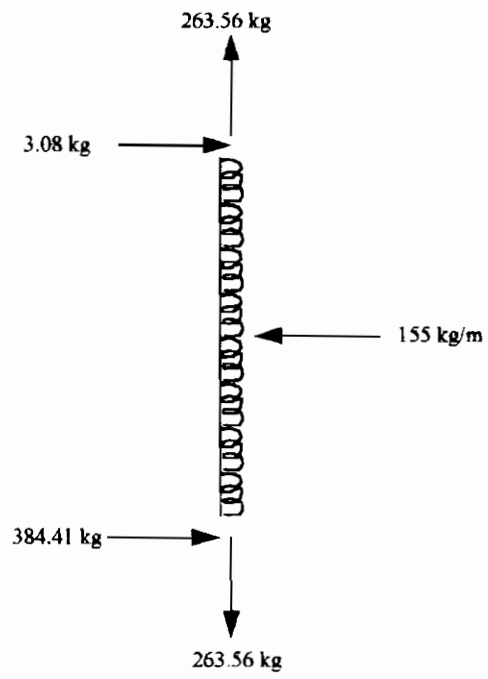


Figure.10 Free Body Diagram of Member1

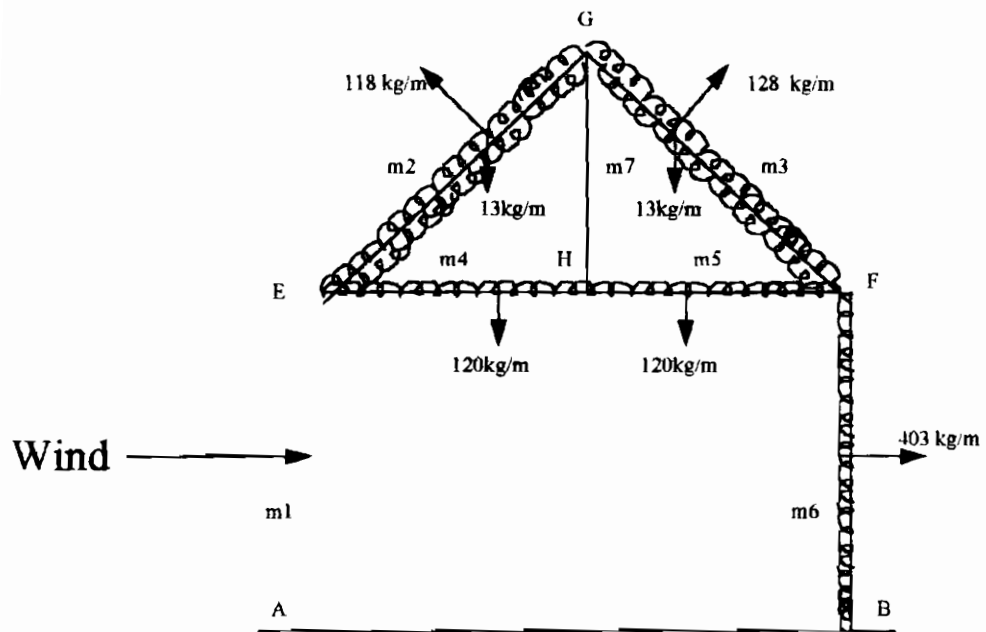


Figure 12 : A Loading Diagram (W angle 0° and left wall open)

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