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FRAME ANALYSIS DUE TO WIND LOAD

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FKAAS
FAKULTI KEJURUTERAAN AWAM DAN ALAM SEKITAR

With Wisdom We Explore

Wind Loading

- Wind forces are variable loads which act directly on the internal and external surfaces of structures.
- The intensity of wind load on a structure is related to the square of the wind velocity and the dimension of the members that are resisting the wind.
- Wind velocity is dependent on:

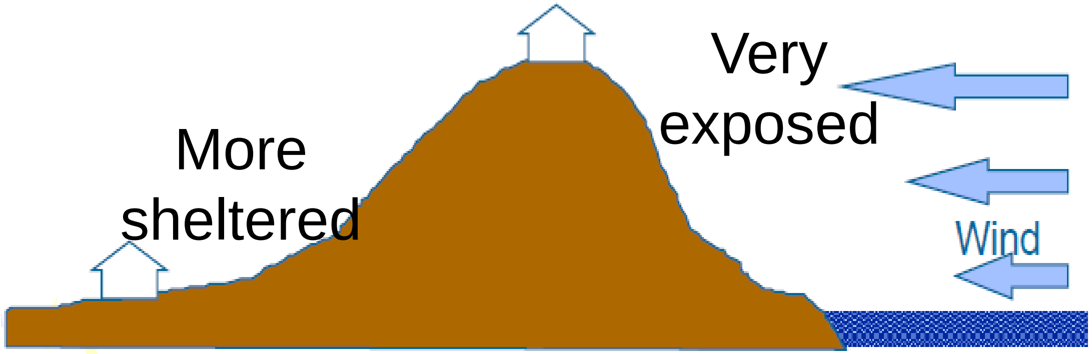
  a) Geographical location

  b) The height of the structure

  c) The topography of the area

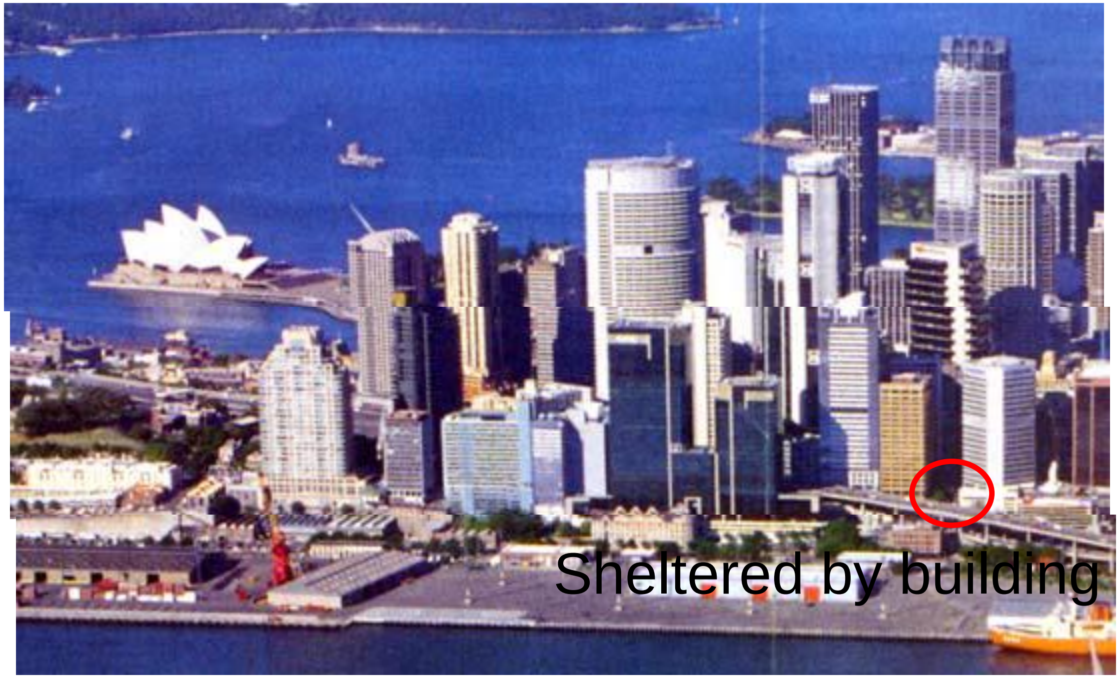
  d) The roughness of the terrain

Wind Loading



Local topography effect wind pattern, wind speed increase with altitude, decrease with terrain roughness

Shelter from any permanents will reduce loads



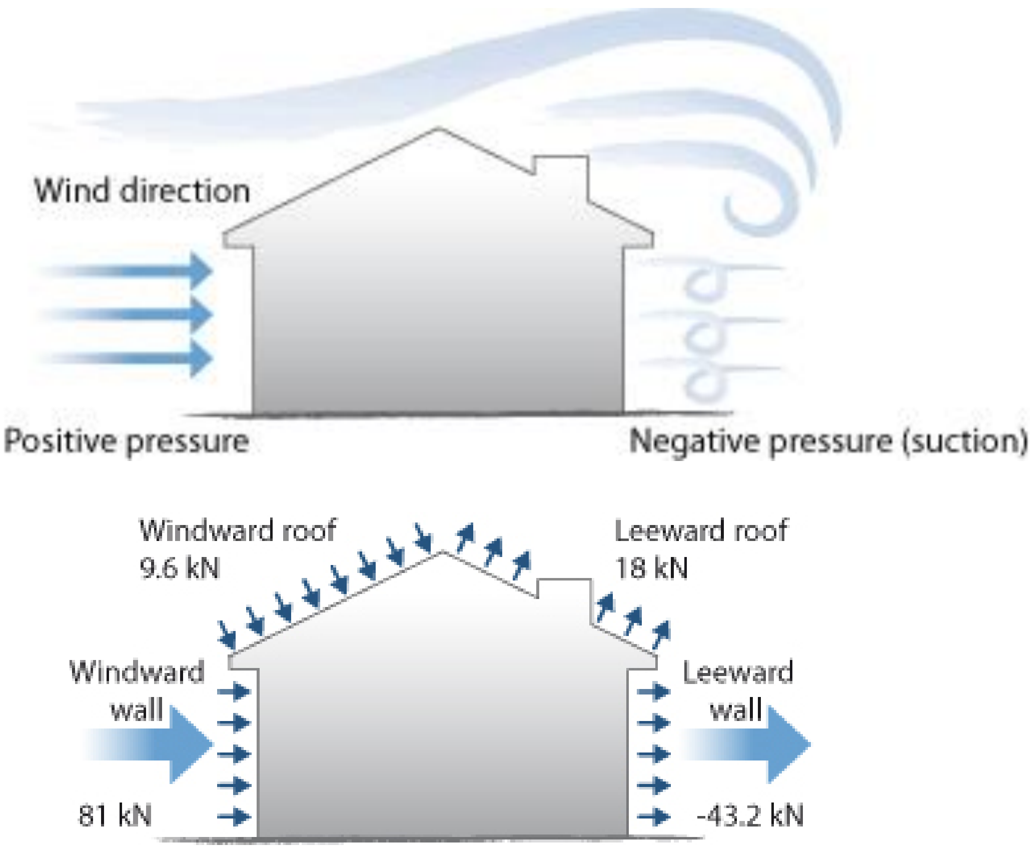
Wind Loading

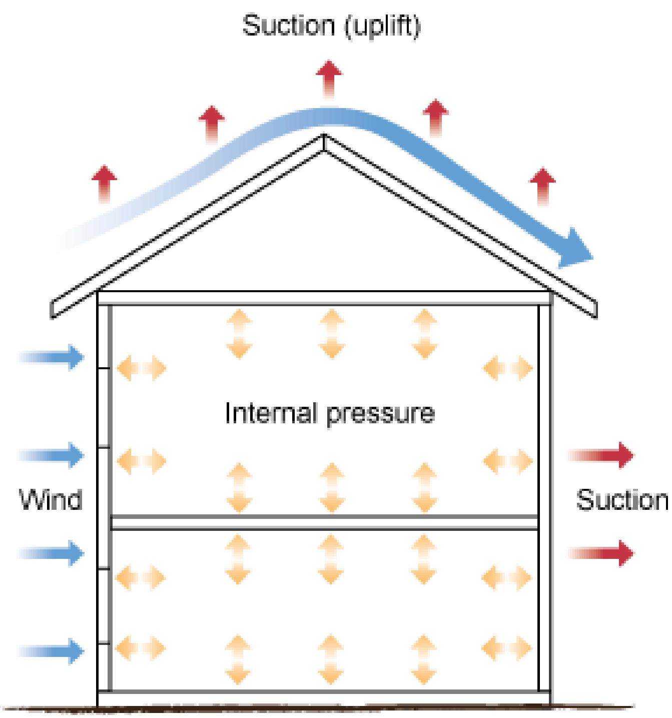
- The response of a structure to the variable action of wind can be separated into 2 components:

Background component	**Resonant component**
- Involves static deflection of the structure under the wind pressure	- Involve dynamic vibration of the structure in response to changes in wind pressure - Relatively small and structural response to wind forces is usually treated using static method of analysis.
- Example: Natural wind	- Example: High-fluctuate wind, hurricane, micro-burst, windblast

Wind Loading

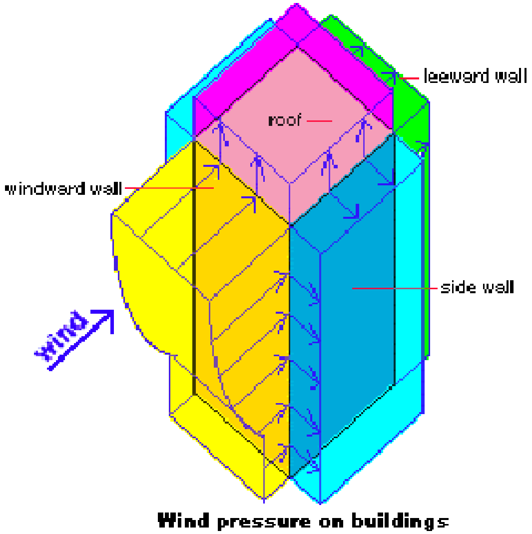
- Wind creates pressure of the windward side of a buildings and suction on three sides.

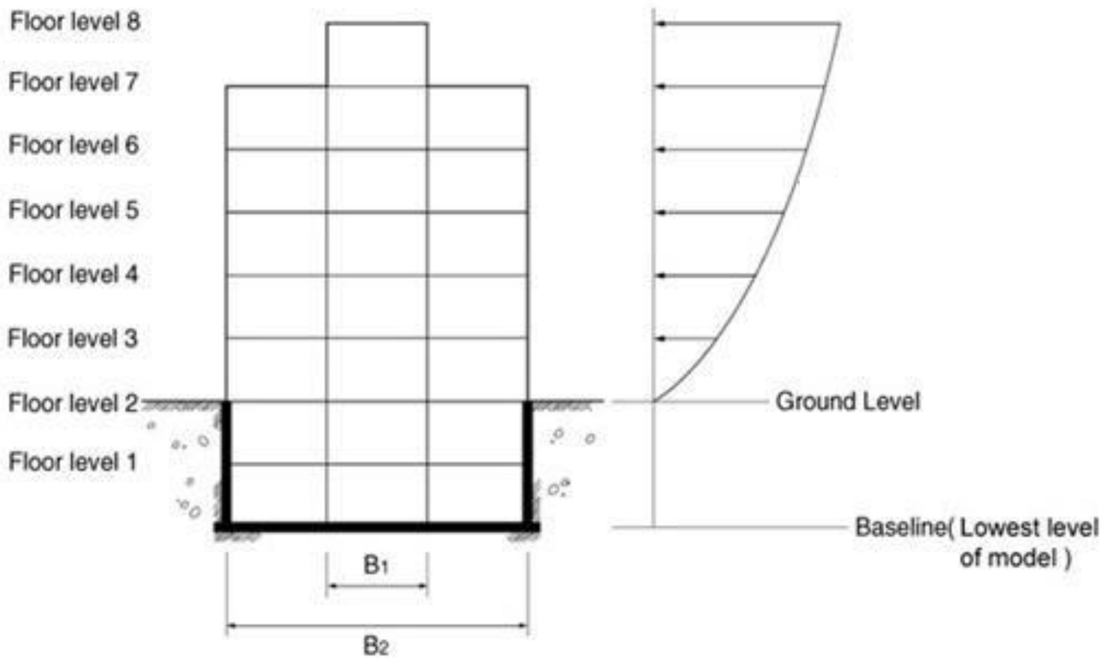


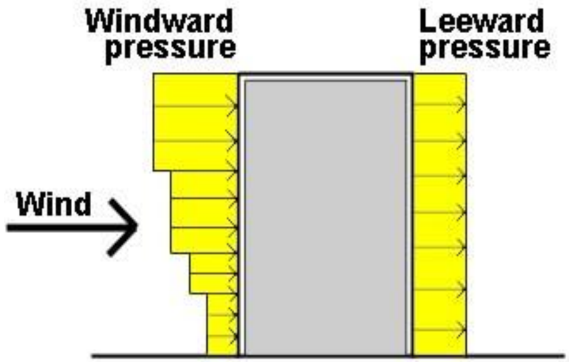


Wind Loading

- Variation of wind pressure on multistory building.
  - Windward : Non-uniform wind pressure
  - Leeward : Uniform wind pressure
  - Sideward : Uniform wind pressure







Effect of Wind Loading

Hurricane Sandy batters New York with howling winds

Building failure due to high pressure wind from Hurricane Katrina

Effect of Wind Loading

Building damage due to high wind
-Cardiff, Wales-

Effect of Wind Loading

High-rise building Insulation peels away and
collapses when the wind picks up.
- China -

Effect of Wind Loading

Windstorm (13/06/2013 – Menara UMNO)
-Pulau Pinang, Malaysia-

Windstorm (13/10/2014 - Flat Jln Loke Yew)
-Kuala Lumpur, Malaysia-

Effect of Wind Loading

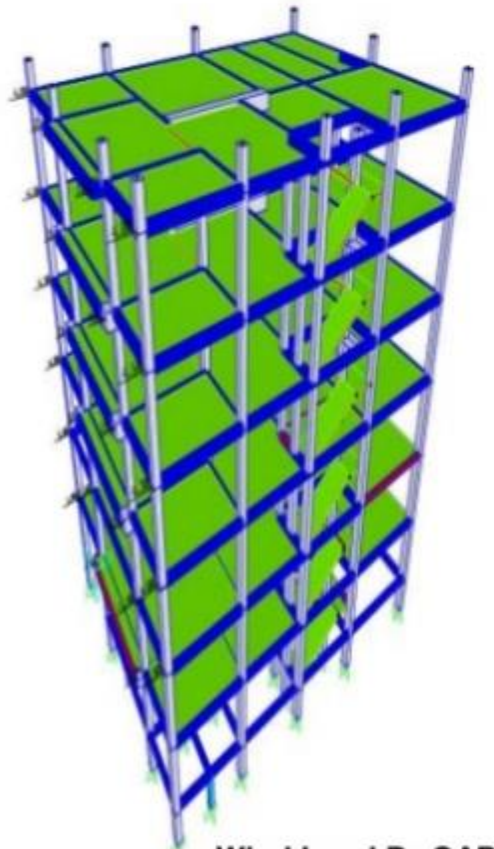
Major failure in uplift damage roof

Effect of Wind Loading

Strong wind events in Malaysia

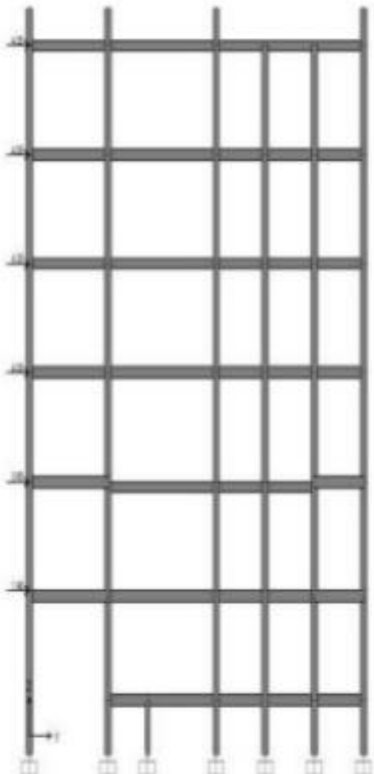
Site, State	Date	Time	Wind Speed	Station
Kuala Perlis , Perlis	8-Oct-08	8.00 pm.		Chuping
Sik, Kedah	28-Mar-09	Evening		Alor Setar Station
Alor Setar, Kedah	25-Mar-09	-	79.92km/hr	Alor Setar Station
Batu Lanchang, Penang	4-Apr-05	4.30 pm		Bayan Lepas
Sungai Dua, Penang	20-Jun-07	1.44 pm	79.636 km/hr	Bayan Lepas
Taiping, Perak	14-Aug-09	5.00 pm.		Hospital Taiping
Putra Jaya , Selangor	4-Apr-08	3.30 pm.		Subang
Kampung Malaysia Raya, Kuala Lumpur	28-Nov-09	4.15pm.	15.9 m/s	Subang
Seremban, Negeri Sembilan	1-Jan-10	5.30 am.		Hospital Seremban
Kota Melaka, Melaka	1-May-07	-		Melaka
Parit Jawa, Muar , Johor	21-Oct-09	1.45 am	48.6km/hr	Senai
Johor Bahru, Johor	19-Jul-07	11.15 am.		Mersing
Rompin, Pahang	28-Sep-09	4.00pm.		Muadzam shah
Kota Bharu, Kelantan	2-Oct-09	-		Kota Bharu
Kota Bharu, Kelantan	22-Nov-09	-		Kota Bharu
Kota Bharu, Kelantan	30-Sep-09	3.30 pm.		Kota Bharu
Besut, Terengganu	24-Apr-09	5.00pm.	52.56km/hr	Kuala Terengganu Airport Station
Kuala Terengganu , Terengganu	21-Nov-09	Noon		Kuala Terengganu
Tawau, Sabah	24-Nov-07	-	50km/hr	Tawau
Lahad Datu, Sabah	19-May-09	Night		Tawau
Papar, Labuan	28-Sep	-	60km/hr	Labuan
Kapit, Sarawak	21-Jun-09	7.30 pm.		Kuching
Kuching, Sarawak	15-Aug-09	-	40.7km/hr	Kuching

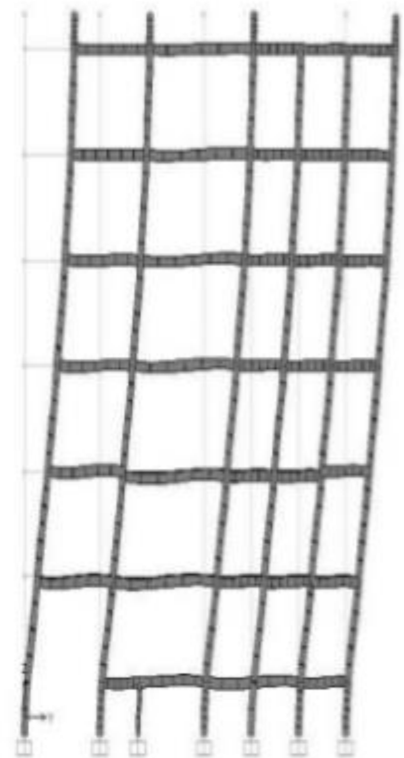
Effect of Wind Loading



Wind Load By SAP 2000

Results Of Static Analysis Of Wind Load by SAP2000





Deflection Due to Wind Load by SAP

Wind Analysis

- Three procedures are specified in MS 1553:2002, Malaysian Standard for the calculation of wind pressures in buildings:
  1) The simplified procedure:

     Limited in application to building of rectangular in plan and not greater than 15 m high

  2) The analytical procedure:

     Limited to regular buildings that are not more than 200 m high and structure with roof spans less than 100 m

  3) The wind tunnel procedure:
     Used for complex building

  4) Simulation procedure
     Practical and for any types of building

Wind Analysis

- Malaysia wind speed map

Table 1: Wind speed description

Beaufort No	Wind speed interval (m/s)	Type of wind	Effect at the turbine
0	0.00-0.39	Calm	No
1	0.40-1.79	Light air	No
2	1.80-3.49	Light Breeze	No
3	3.50-5.79	Gentle Breeze	Low
4	5.80-8.49	Moderate Breeze	Low
5	8.50-10.99	Fresh Breeze	High
6	11.00-13.99	Strong Breeze	High
7	14.00-16.99	Near Gale	Maximum
8	17.00-20.99	Gale	Stop
9	21.00-24.99	Strong Gale	Damage
10,11,12	25.0 >	Storm	Damage

Wind Analysis

- Wind speed analysis for 10, 30, 50 and 100 years return period

Station	10-return period	30-return period	50-return period	100-return period
Chuping	12.63	15.36	16.63	18.35
Alor Setar	13.62	17.65	19.53	22.07
Kota Bharu	13.95	18.07	19.98	22.58
Kuala Terengganu	13.56	16.64	18.07	20.00
Bayan Lepas	13.85	16.26	17.38	18.90
Ipoh	14.37	19.18	21.41	24.44
Cameron	14.19	16.68	17.84	19.42
Kuantan	13.34	16.65	18.18	20.27
Subang	13.64	17.74	19.64	22.23
Mersing	14.13	17.9	19.65	22.04
Senai	13.23	16.25	17.66	19.56
Melaka	13.23	16.25	17.65	19.56

- Simplified procedure (MS1553 Appendix A)

$$p = 0.613(V_s)^2(M_{z,cat})^2(C_{pe} - C_{pi})$$

where:

p = The design wind pressure in Pa

V_s = The basic wind speed (Figure A1)

$M_{z,cat}$ = The terrain/height multiplier (Table A1)

C_{pe} = The external pressure coefficient for surface of enclose building (A2.3 and A2.4)

C_{pi} = The internal pressure coefficient for surface of enclose building which shall be taken as +0.6 or -0.3. The two cases shall be considered to determinate the critical load requirements for the appropriate condition.

- Analytical procedure(MS1553 Section 2)

$$p = 0.613(V_{des})^2 C_{fig} C_{dyn}$$

where:

$V_{des} = V_{sit} I$ = The design wind speed

I = Importance factor (Table 3.2)

$V_{sit} = V_s M_d M_{z,cat} M_s M_h$ = Site wind speed

V_s = Basic wind speed 33.5m/s for zone I and 32.5m/s for zone 2 (refer Figure 3.1)

M_d = Wind directional multiplier = 1.0

$M_{z,cat}$ = Terrain/height multiplier (Table 4.1)

M_s = Shielding multiplier (Table 4.3) equal to 1.0 if the effects of shielding are ignored or not applicable.

M_h = Hill shape multiplier. Shall be taken as 1.0 except that for particular cardinal direction in the local topographic zones.

$C_{fig} = C_{pe} K_a K_c K_1 K_p$ = Aerodynamic shape factor for external pressure.

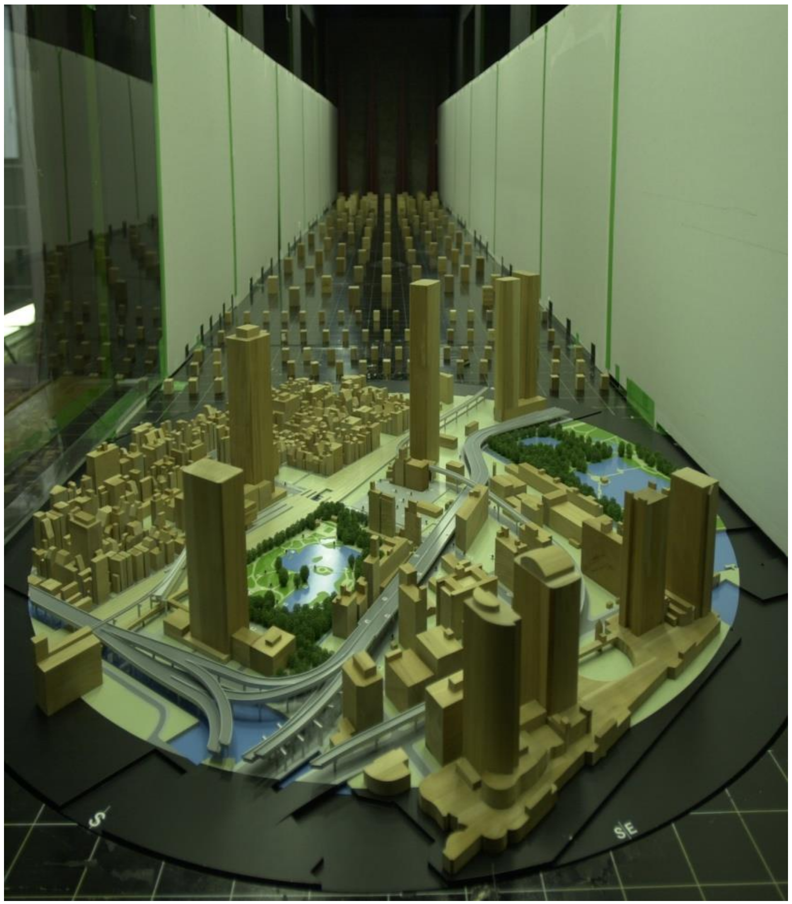
C_{pe} = External pressure coefficient (Table 5.2.a and 5.2.b) for windward and leeward walls respectively for rectangular enclosed building

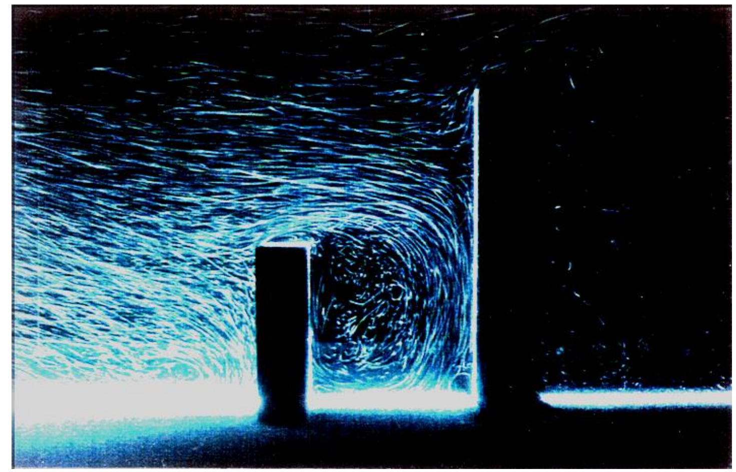
$K_a K_c K_1 K_p$ = Area reduction factor, combination factor, local pressure factor and porous cladding reduction factor respectively. All shall be taken as 1.0 in most cases.

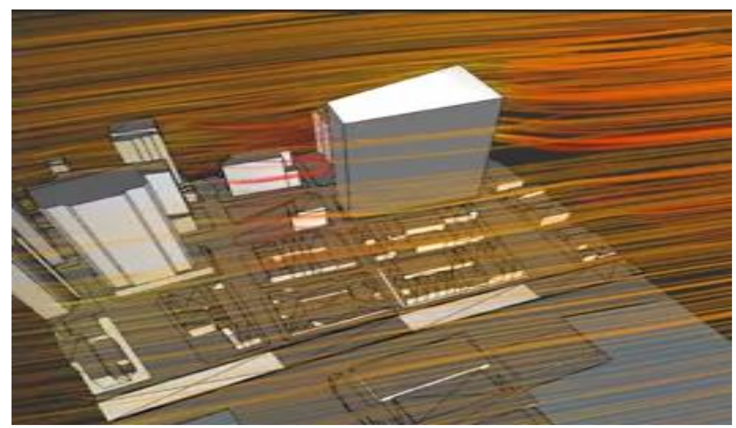
C_{dyn} = Dynamic response factor. Shall be taken as 1.0 unless the structure is wind sensitive.

Wind Analysis

- Wind tunnel procedure







Wind Analysis

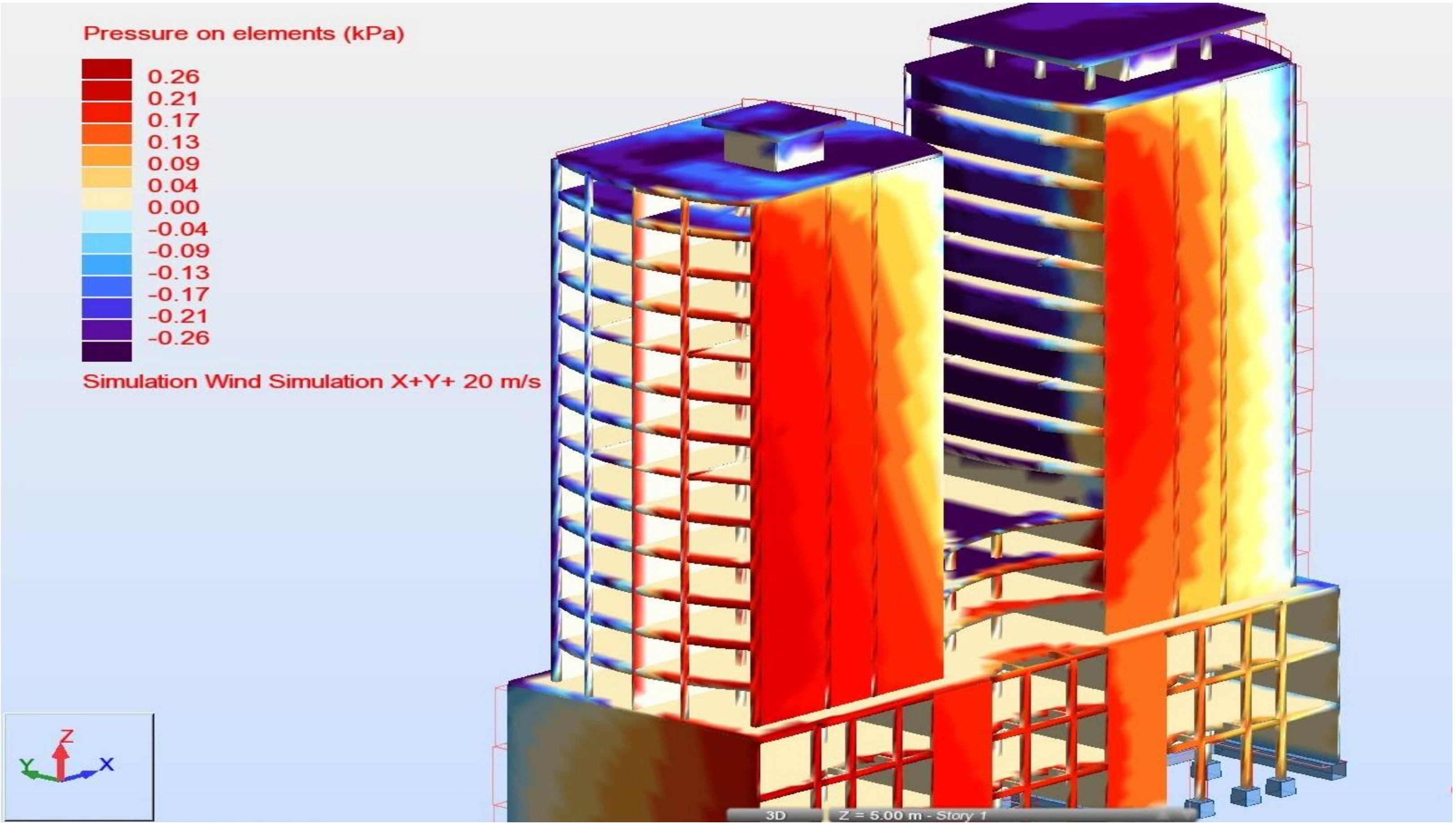
- Wind tunnel procedure

Wind Analysis

- Wind tunnel test >> cladding pressure

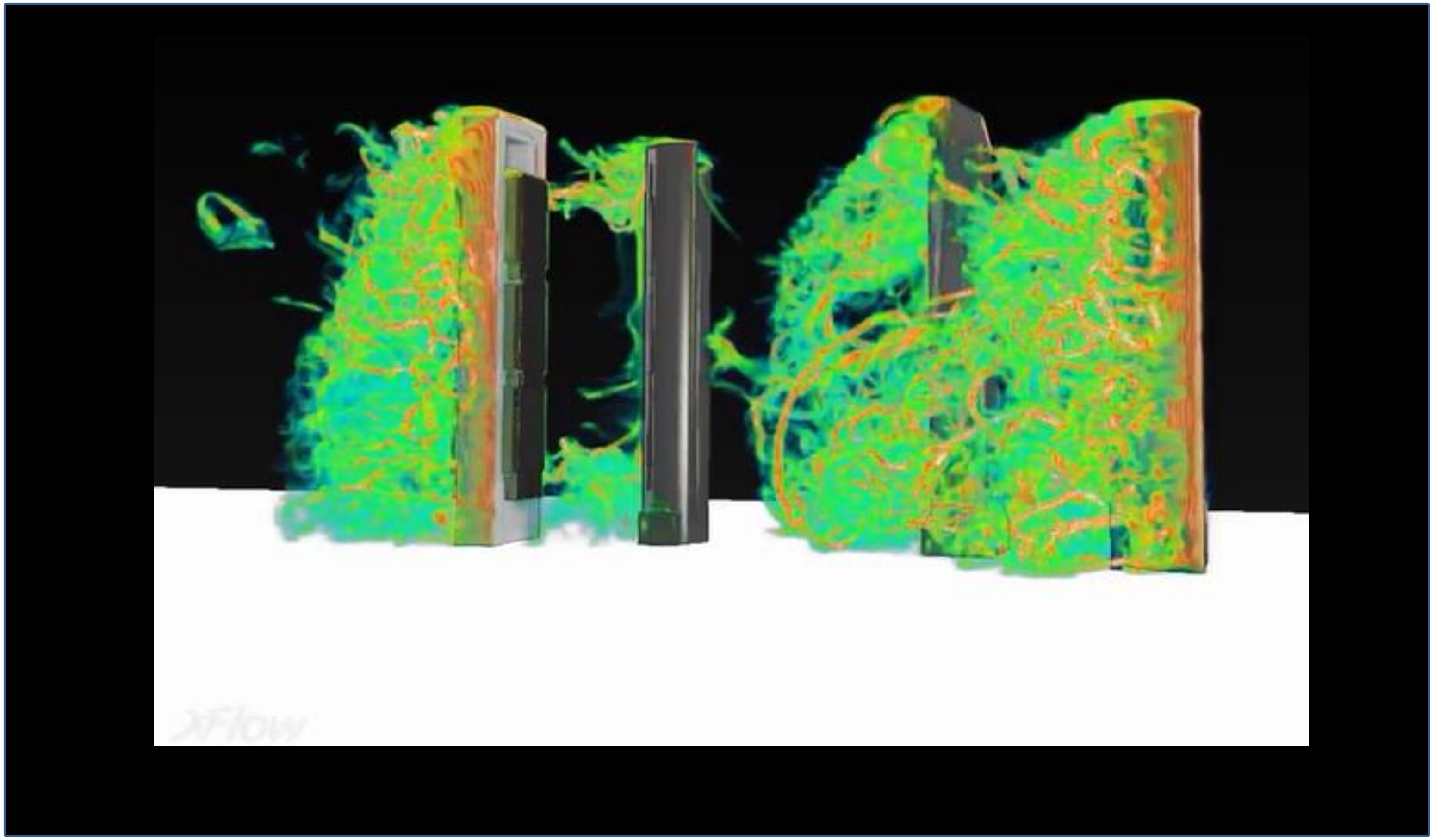
Wind Analysis

- Simulation procedure: Autodesk Robot



Wind Analysis

- Simulation procedure: Computational Fluid Dynamics (CFD)



Analysis of Unbraced Frame

- Procedure:

1. Calculate design wind load, $W_d=1.2W_k$
2. Calculate lateral point load at each level of frame

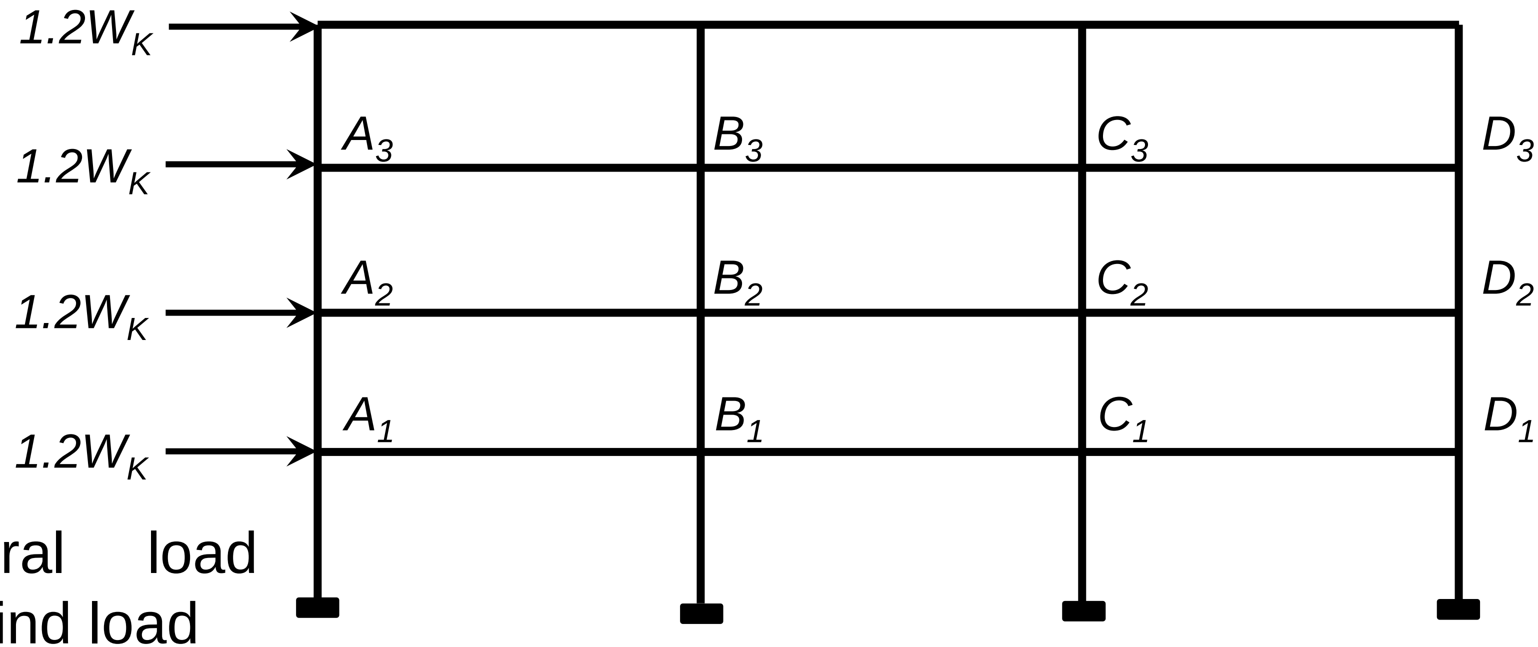
    a) Assume contraflexure point at center of frame

    b) Axial loads in column are in its proportion to distances from the centre of gravity of frame

    c) All columns are equal cross-section area

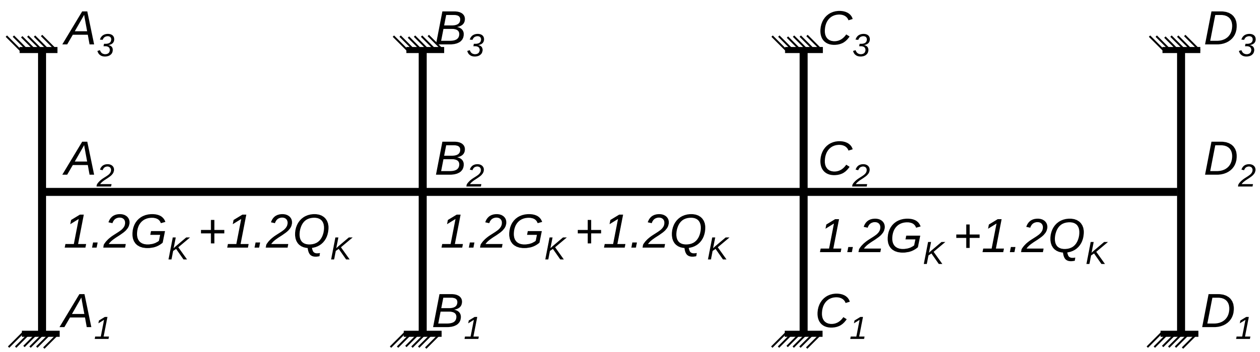
3. Lateral load analysis using Cantilever Method.
   - Calculate axial force in columns, then shear force in beams and columns from top to ground levels.
4. Vertical load analysis due to wind, $1.2\ G_k + 1.2Q_k$
   - analysis of one level sub-frame

Analysis of Unbraced Frame



- Lateral load of wind load

+



- Vertical load due to wind pressure

Example

The framing plans for a multistory building are shown in the figure below. The main dimensions structural features, loads, material, etc. are also set out as at the given data.

- Permanent office building (Design life = 50 years)
- Location: Near sub-urban (Zone 1)
- Topography: Flat area–slope<0.05 (Building around within 1 KM radius)
- Beam in grid line 1,2,3…12 : 250 x 600 mm ; Beam in grid line A, B, C & D : 250 x 500 mm
- Slab thickness = 150 mm ; Columns : 300 x 400 mm
- Imposed load : 4.0 kN/m^2 ;
- Finishes, ceiling, services etc. : 0.75 kN/m^2 ;
- Partitions : 0.5 kN/m^2

Example

For the multistory building:

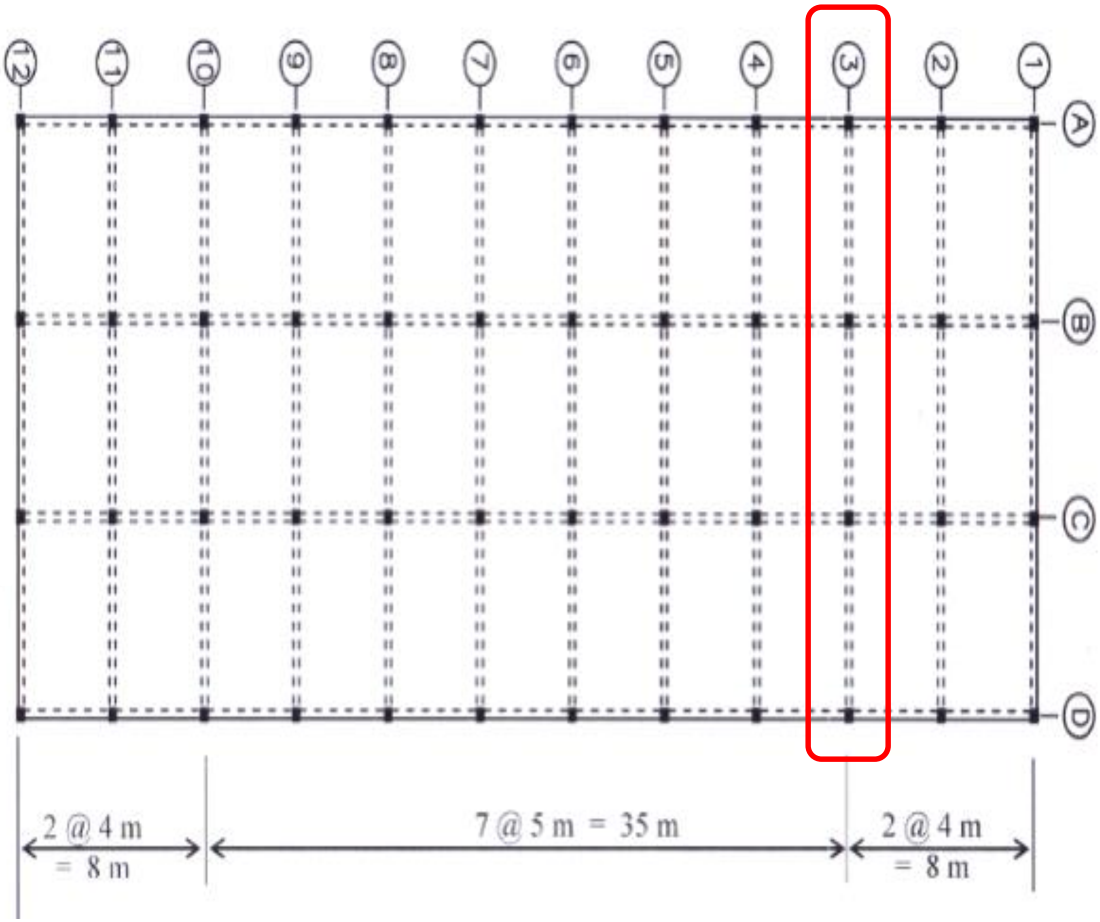
a) Calculate the wind load on the building

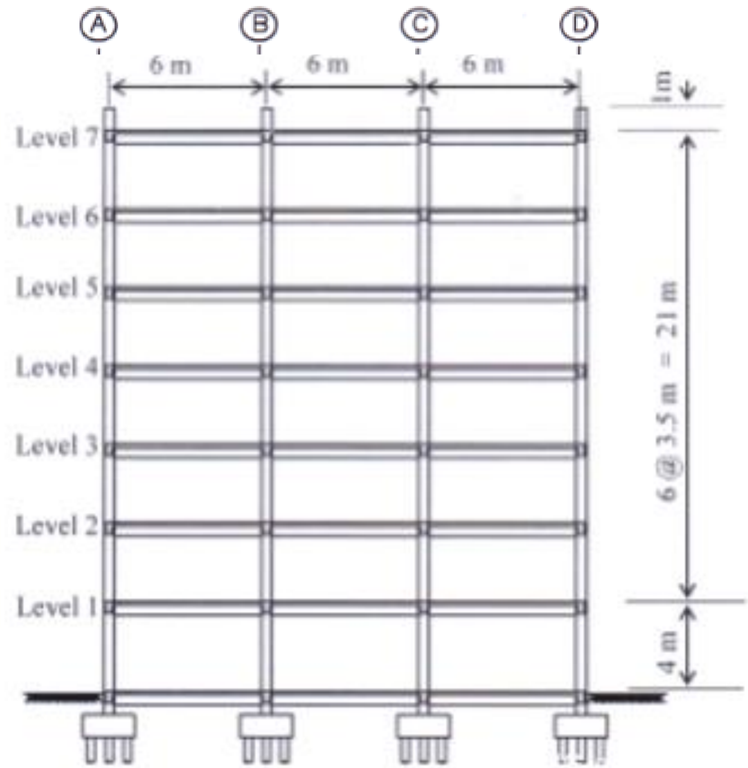
b) Calculate the bending moments for all beams and columns, due to wind load

c) Analyse the subframe consisting Beam 3/A-D, Level 1 with the column above and below then, subjected to vertical load only

d) Sketch the bending moment diagrams for each loadings lateral and vertical, and the combined loadings

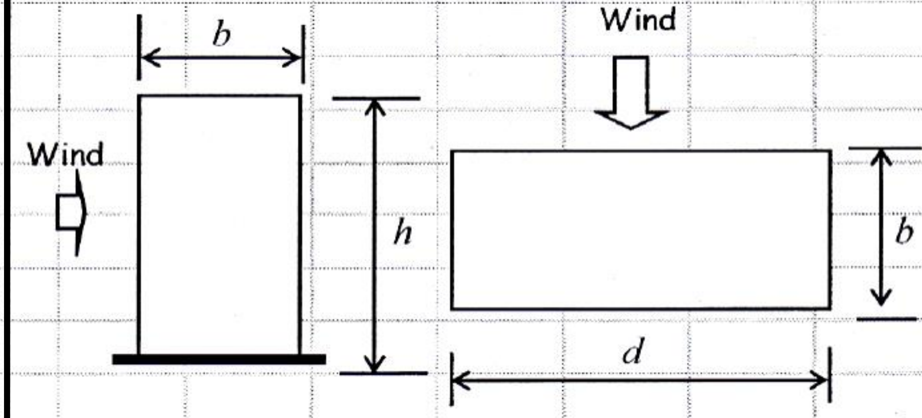
Example


12
11
10
9
8
7
6
5
4
3
2
1
A
B
C
D
2 @ 4 m = 8 m
7 @ 5 m = 35 m
2 @ 4 m = 8 m


A
B
C
D
6 m
6 m
6 m
1m
Level 7
Level 6
Level 5
Level 4
Level 3
Level 2
Level 1
6 @ 3.5 m = 21 m
4 m

Example

Specification



Side elevation   Plan

Building dimensions,

Height, h	=	26	m
Width, b	=	18	m
Length, d	=	51	m

Building usage & location,

Permanent office

Sub-urban, Zone 1

Flat area, building around

Example

	Design wind pressure	
	p = $0.613\,[V_{des}]^2\,C_{fig}\,C_{dyn}$ Pa	2.8333
	V_{des} = design wind speed	
	= $V_{sit}\,I$	
Table 3.2	I = importance factor = 1.0	
	V_{sit} = $V_s\,M_d\,M_{z,cat}\,M_s\,M_h$	
Fig. 3.1	V_s = basic wind speed = 33.5 m/s	
2.2	M_d = wind directional multiplier = 1.00	
Table 4.1	$M_{z,cat}$ = terrain/height multiplier = 1.00	
4.3.1	M_s = shielding multiplier = 1.00	
4.4	M_h = hill shape multiplier = 1.00	
	V_{sit} = 33.5 x 1.00 x 1.00 x 1.00 x 1.00	
	= 33.50 m/s	
	V_{des} = 33.50 x 1.0 = 33.50 m/s	
	C_{fig} = aerodynamic shape factor	
	= $C_{p,e}\,K_a K_c K_l K_p$ for external pressure	
Table 5.2(a)	$C_{p,e}$ = external pressure coefficient =	
Table 5.2(b)	: windward wall = 0.70	
	: leeward wall = -0.25	

Example

5.4.2	K_a = area reduction factor =	1.00
5.4.3	K_c = combination factor =	1.00
5.4.4	K_l = local pressure factor =	1.00
5.4.5	K_p = porous cladding reduction factor =	1.00
6.1	C_{fig} = (0.70 - -0.25) x 1.00 x 1.00 x 1.00 x 1.00	
	= = 0.95	
	C_{dyn} = dynamic response factor = 1.00	

Design wind pressure

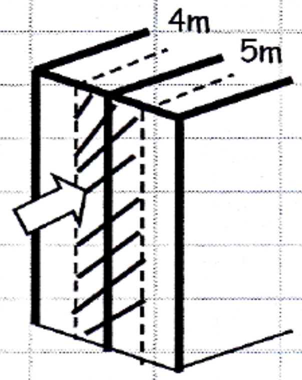
p = 0.613 x 33.5^2 x 0.95 x 1.00

= 653.54 N/m^2 = 0.654 kN/m^2

Characteristic wind load for each sub-frame,

= 0.65 x [(4+5)/2]

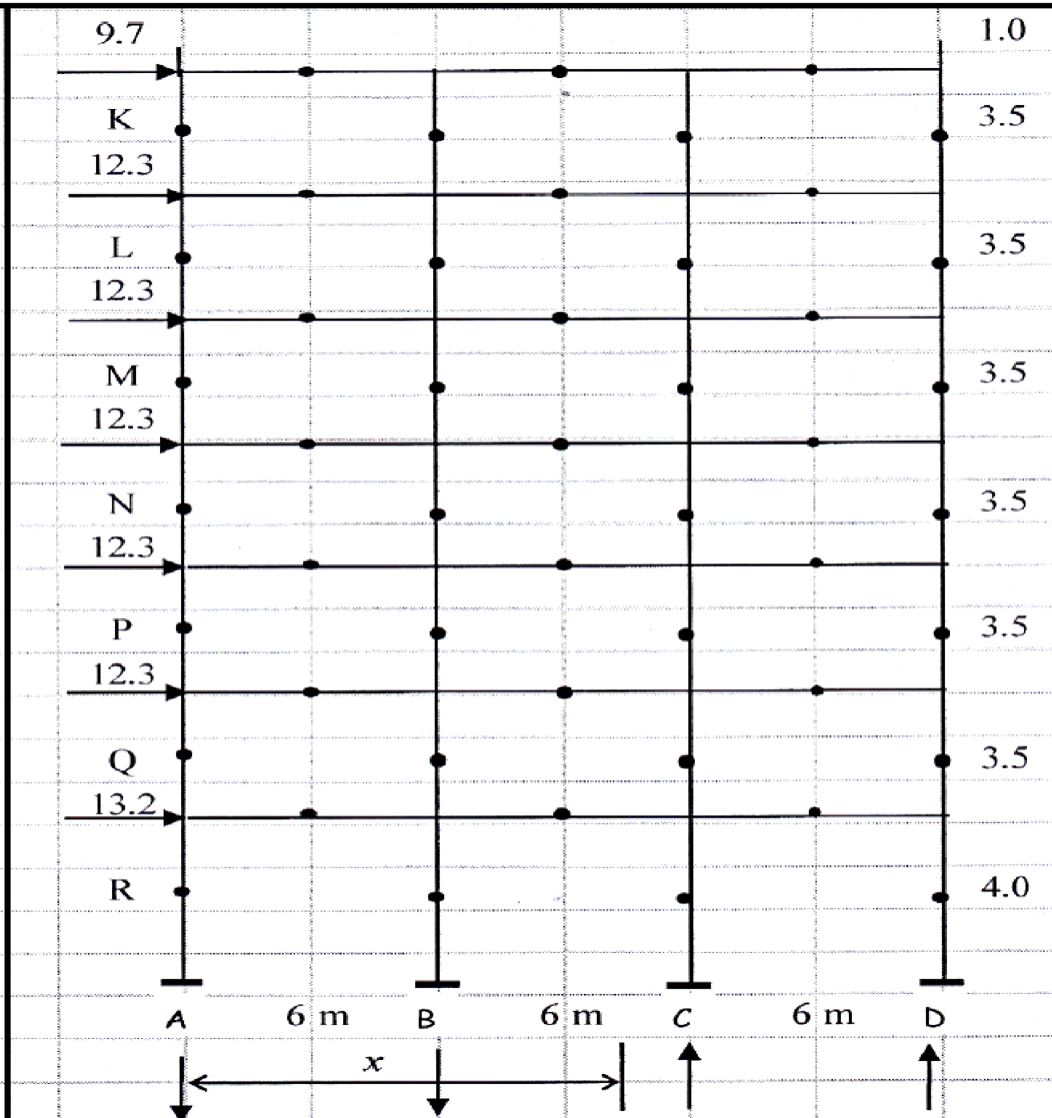
= 2.94 kN/m height



Example

Characteristic wind load, W_k =				2.94	kN/m height	
Design wind load, W_d =		1.20	W_k =	3.53	kN/m height	
Point load for each floor level :						
Roof level :	3.5	(1.00 +	1.75)	=	9.70	kN
Level 2 - 6 :	3.5	(1.75 +	1.75)	=	12.35	kN
Level 1 :	3.5	(1.75 +	2.00)	=	13.23	kN
Centre of gravity of the structure,						
x = (6.0N	+ 12N	+ 18N)	/ 4 N	=	9	m
Column :		A :	B :	C :	D	
Distance from centroid:		9.00 :	3.00 :	3.00 :	9.00	
Column axial load:		3.0P :	1.0P :	1.0P :	3.0P :	

Example

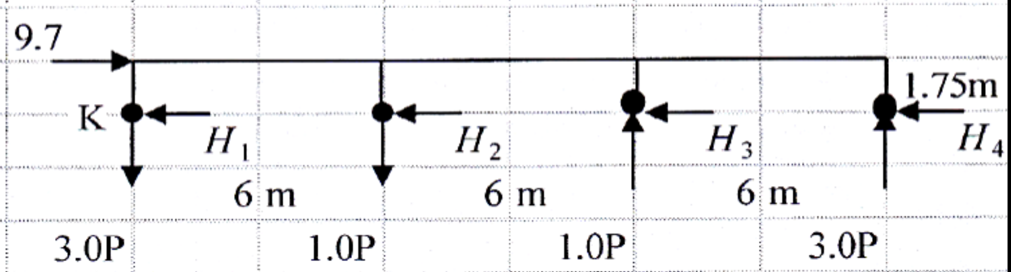


* Assumptions,

1. Point of contraflexure are located at the mid-points of all columns and beams.
2. The direct axial loads in the columns are in propotion to their distances from the centre of gravity of the frame.
3. All the column in a storey are of equal cross-sectional area.

Example

Level K and above



Axial force in columns,

$\Sigma M @ K = 0$

$(9.7 \times 1.75) + (1.0P \times 6.0) - (1.0P \times 12.0)$

$-(3.0P \times 18.0) = 0$

$60.0P = 17.0$ kN

$P = 17.0 / 60.0 = 0.28$ kN

$3.0P = 0.85$ kN

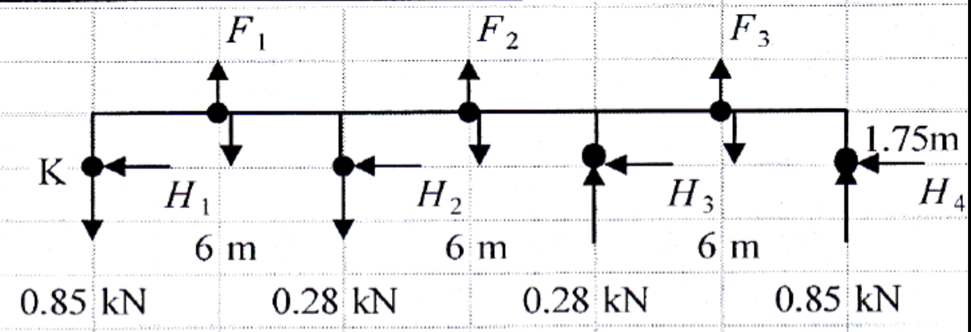
$1.0P = 0.28$ kN

$1.0P = 0.28$ kN

$3.0P = 0.85$ kN

Example

Shear force in beams and columns,



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$: $F_1 - 0.85 = 0$ — $F_1 = 0.85$ kN

$\Sigma M@F_1 = 0$: $(H_1 \times 1.75) - (0.85 \times 3.00) = 0$ — $H_1 = 1.46$ kN

Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$: $F_2 - 0.85 - 0.28 = 0$ — $F_2 = 1.13$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2) \times 1.75 - (0.85 \times 9.0) - (0.28 \times 3.0) = 0$ — $H_2 = 3.40$ kN

Consider sub-frame to the left of F_3 :

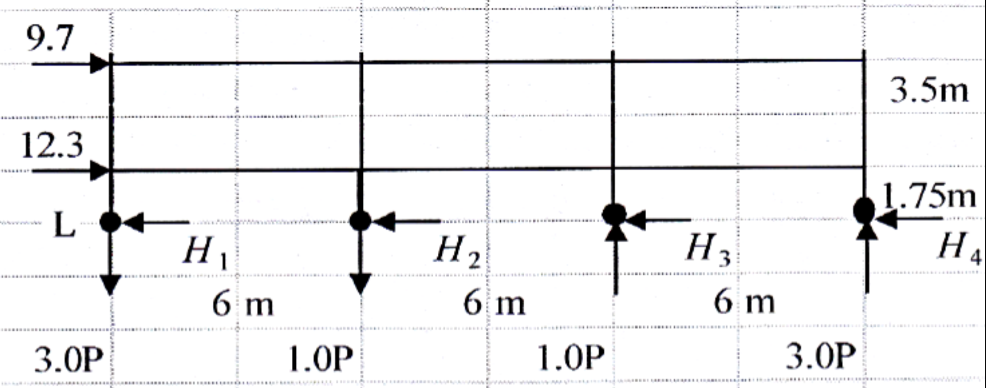
$\Sigma F_v = 0$: $F_3 - 0.85 - 0.28 + 0.28 = 0$ — $F_3 = 0.85$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)\,1.75 - (0.85 \times 15.00) - (0.28 \times 9.0) + (0.28 \times 3.0) = 0$ — $H_3 = 3.40$ kN

$\Sigma F_H = 0$: $9.7 - H_1 - H_2 - H_3 - H_4 = 0$ — $H_4 = 1.46$ kN

Example

Level L and above



Axial force in columns,

ΣM @ L = 0

$(9.7 \times 5.25) + (12.3 \times 1.75) + (1.0P \times 6.0)$

$- (1.0P \times 12.0) - (3.0P \times 18.0) = 0$

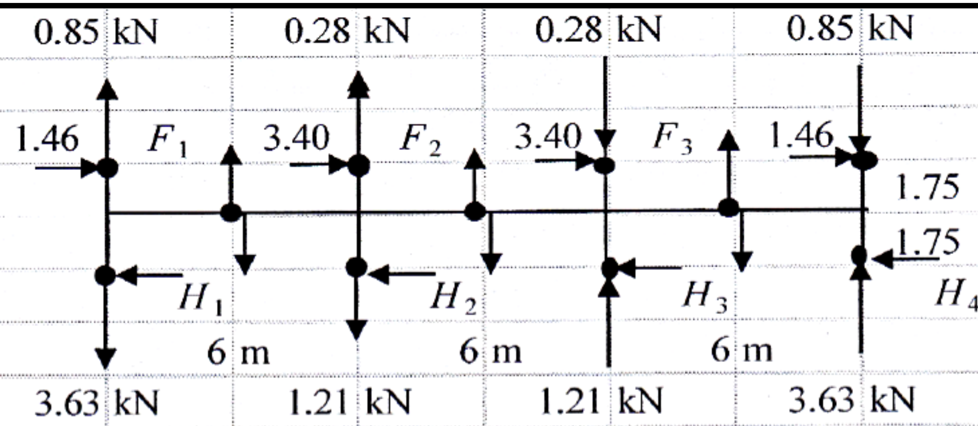
$60.0P = 72.5$ kN

$P = 72.5 / 60.0 = 1.21$ kN

3.0P =	3.63	kN
1.0P =	1.21	kN
1.0P =	1.21	kN
3.0P =	3.63	kN

Example

Shear force in beams and columns



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$: $F_1 - 3.63 + 0.85 = 0$ → $F_1 = 2.78$ kN

$\Sigma M@F_1 = 0$: $(H_1 + 1.46) \times 1.75 - (2.78 \times 3.00) = 0$ → $H_1 = 3.31$ kN

Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$: $F_2 - 2.78 - 0.93 = 0$ → $F_2 = 3.70$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2) \times 1.75 + (4.85 \times 1.75) - (2.78 \times 9.0) - (0.93 \times 3.0) = 0$ → $H_2 = 7.72$ kN

Consider sub-frame to the left of F_3 :

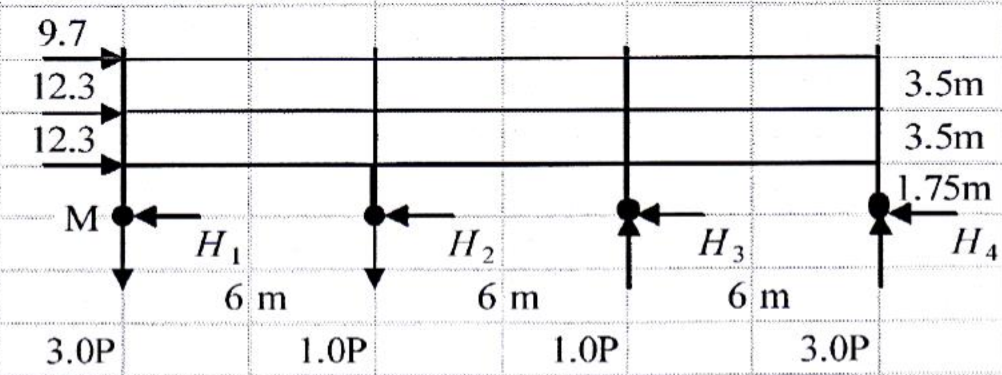
$\Sigma F_v = 0$: $F_3 - 2.78 - 0.93 + 0.93 = 0$ → $F_3 = 2.78$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)\ 1.75 + (8.25 \times 1.75) - (2.78 \times 15.00) - (0.93 \times 9.0) + (0.93 \times 3.0) = 0$ → $H_3 = 7.72$ kN

$\Sigma F_H = 0$: $22.1 - H_1 - H_2 - H_3 - H_4 = 0$ → $H_4 = 3.31$ kN

Example

Level M and above



<u>Axial force in columns,</u>

ΣM @ M = 0

(9.7 x 8.75) + (12.3 x 5.25) + (12.3 x 1.75) +

(1.0P x 6.0) - (1.0P x 12.0) -(3.0P x 18.0) = 0

60.0P = 171.3 kN

P = 171.3 / 60.0 = 2.86 kN

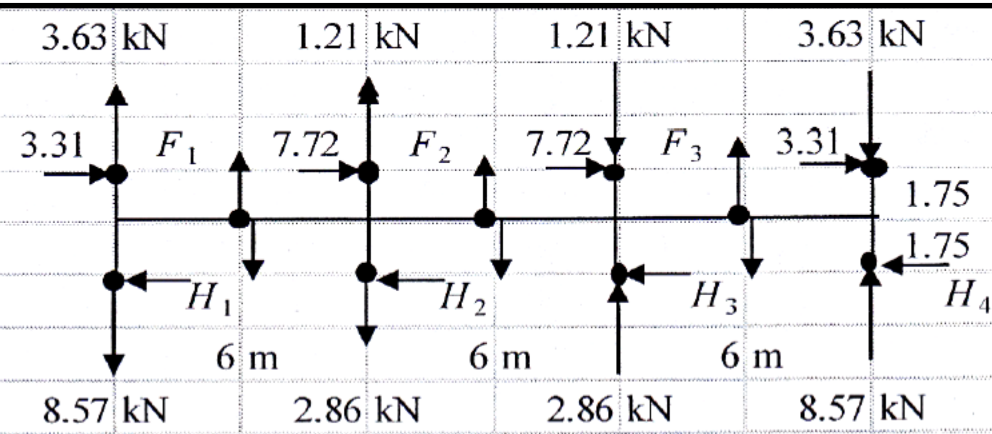
3.0P = 8.57 kN

1.0P = 2.86 kN

1.0P = 2.86 kN

3.0P = 8.57 kN

Example



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$: $F_1 - 8.57 + 3.63 = 0$ $\qquad F_1 = 4.94$ kN

$\Sigma M@F_1 = 0$: $(H_1 + 3.31) \times 1.75 - (4.94 \times 3.00) = 0$ $\qquad H_1 = 5.16$ kN

Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$: $F_2 - 4.94 - 1.65 = 0$ $\qquad F_2 = 6.59$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2) \times 1.75 + (11.03 \times 1.75) - (4.94 \times 9.0) - (1.65 \times 3.0) = 0$ $\qquad H_2 = 12.04$ kN

Consider sub-frame to the left of F_3 :

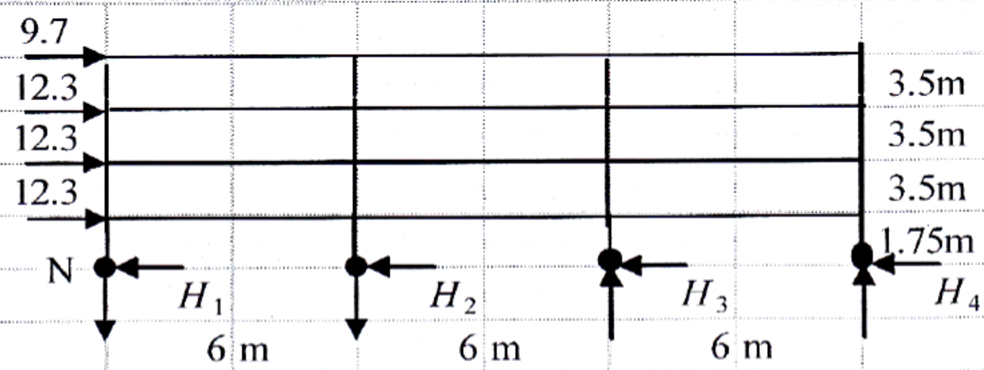
$\Sigma F_v = 0$: $F_3 - 4.94 - 1.65 + 1.65 = 0$ $\qquad F_3 = 4.94$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)\ 1.75 + (18.74 \times 1.75) - (4.94 \times 15.00) - (1.65 \times 9.0) + (1.65 \times 3.0) = 0$ $\qquad H_3 = 12.04$ kN

$\Sigma F_H = 0$: $34.4 - H_1 - H_2 - H_3 - H_4 = 0$ $\qquad H_4 = 5.16$ kN

Example

Level N and above



3.0P 1.0P 1.0P 3.0P

<u>Axial force in columns,</u>

ΣM @ M = 0

(9.7 x 12.3)+ (12.3 x 8.75) + (12.3 x 5.25) + (12.3 x 1.75) +

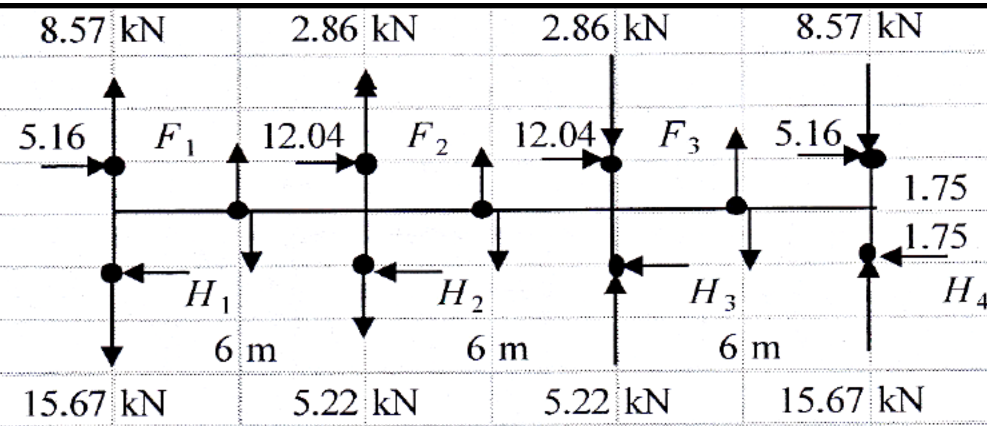
(1.0P x 6.0) - (1.0P x 12.0) -(3.0P x 18.0) = 0

60.0P = 313.3 kN

P = 313.3 / 60.0 = 5.22 kN

3.0P =	15.67 kN
1.0P =	5.22 kN
1.0P =	5.22 kN
3.0P =	15.67 kN

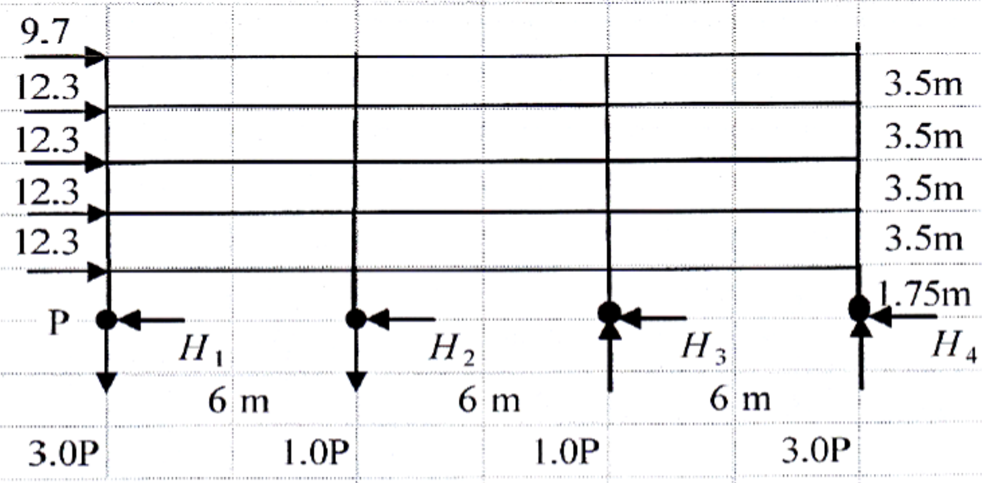
Example



Consider sub-frame to the left of F_1 :	
$\Sigma F_v = 0$: F_1 - 15.67 +8.57 = 0	F_1 = 7.10 kN
$\Sigma M@F_1 = 0$: $(H_1 + 5.16)$ x 1.75 - (7.10 x 3.00) = 0	H_1 = 7.01 kN
Consider sub-frame to the left of F_2 :	
$\Sigma F_v = 0$: F_2 - 7.10 - 2.37 = 0	F_2 = 9.47 kN
$\Sigma M@F_2 = 0$: $(H_1 + H_2)$ x 1.75 + (17.20 x 1.75)	H_2 = 16.36 kN
- (7.10 x 9.0) - (2.37 x 3.0) = 0	
Consider sub-frame to the left of F_3 :	
$\Sigma F_v = 0$: F_3 - 7.10 - 2.37 + 2.37 = 0	F_3 = 7.10 kN
$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)$ 1.75 + (29.24 x 1.75)	H_3 = 16.36 kN
- (7.10 x 15.00) - (2.37 x 9.0) + (2.37 x 3.0) = 0	
$\Sigma F_H = 0$: 46.7 - H_1 - H_2 - H_3 - H_4 = 0	H_4 = 7.01 kN

Example

Level P and above



<u>Axial force in columns,</u>

$\Sigma M @ P = 0$

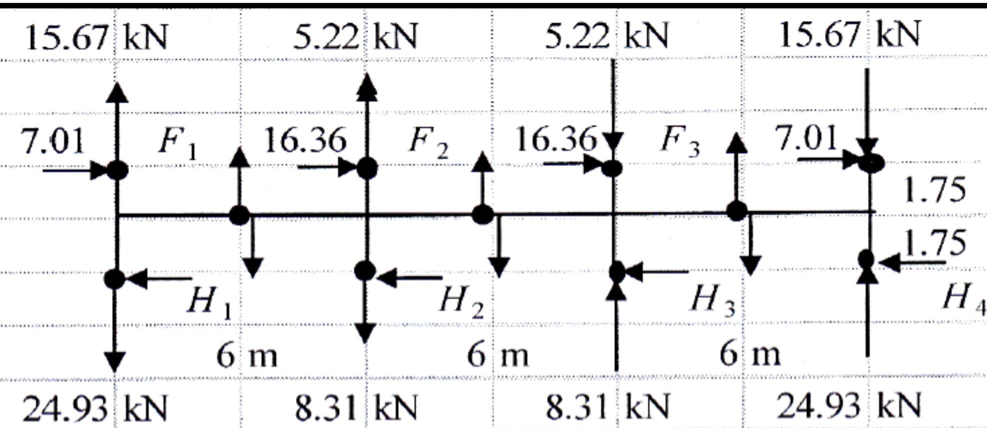
(9.7 x 15.8)+ (12.3 x 12.3)+ (12.3 x 8.75) + (12.3 x 5.25) + (12.3 x 1.75)+ (1.0P x 6.0) - (1.0P x 12.0) -(3.0P x 18.0) = 0

60.0P = 498.6 kN

P = 498.6 / 60.0 = 8.31 kN

3.0P = 24.9 kN
1.0P = 8.3 kN
1.0P = 8.3 kN
3.0P = 24.9 kN

Example



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$: $F_1 - 24.93 + 15.67 = 0$ — $F_1 = 9.3$ kN

$\Sigma M@F_1 = 0$: $(H_1 + 7.01) \times 1.75 - (9.3 \times 3.00) = 0$ — $H_1 = 8.9$ kN

Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$: $F_2 - 9.26 - 3.09 = 0$ — $F_2 = 12.3$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2) \times 1.75 + (23.37 \times 1.75) - (9.3 \times 9.0) - (3.09 \times 3.0) = 0$ — $H_2 = 20.7$ kN

Consider sub-frame to the left of F_3 :

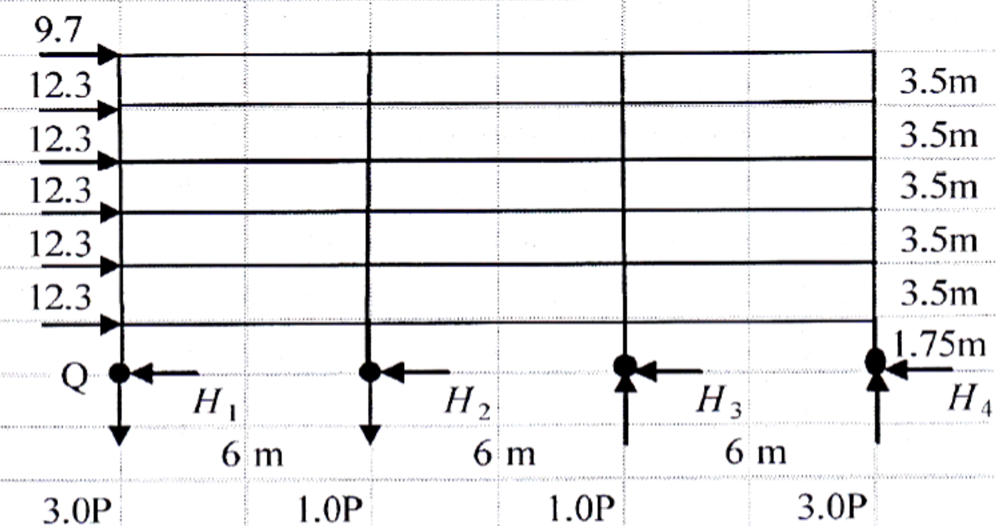
$\Sigma F_v = 0$: $F_3 - 9.26 - 3.09 + 3.09 = 0$ — $F_3 = 9.3$ kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)\, 1.75 + (39.73 \times 1.75) - (9.3 \times 15.00) - (3.09 \times 9.0) + (3.09 \times 3.0) = 0$ — $H_3 = 20.7$ kN

$\Sigma F_H = 0$: $59.1 - H_1 - H_2 - H_3 - H_4 = 0$ — $H_4 = 8.9$ kN

Example

Level Q and above



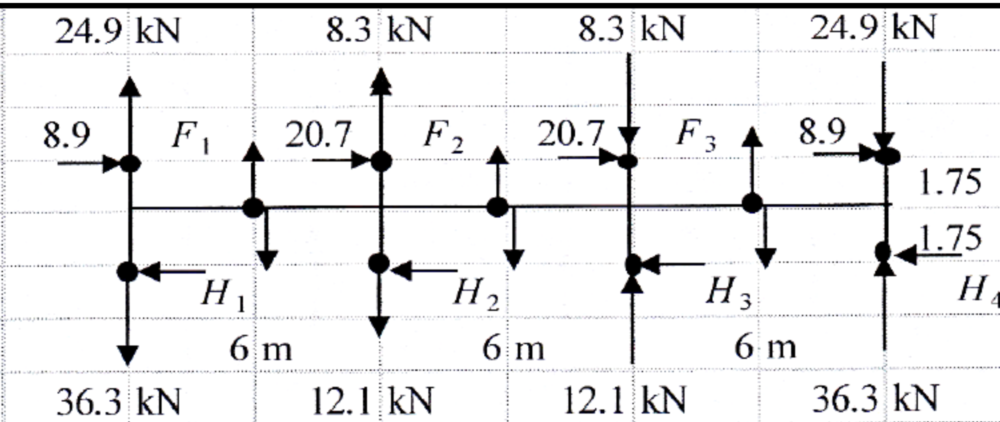
<u>Axial force in columns,</u>

ΣM @ P = 0

(9.7 x 19.3)+ (12.3 x 15.8)+ (12.3 x 12.3) + (12.3 x 8.75) +
(12.3 x 5.25)+ (12.3 x 1.75)+ (1.0P x 6.0) - (1.0P x 12.0)
-(3.0P x 18.0) = 0
60.0P = 727.0 kN
P = 727.0 / 60.0 = 12.12 kN

3.0P = 36.3 kN
1.0P = 12.1 kN
1.0P = 12.1 kN
3.0P = 36.3 kN

Example



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$: F_1 - 36.35 +24.93 = 0 — F_1 = 11.4 kN

$\Sigma M@F_1 = 0$: $(H_1 + 8.9) \times 1.75 - (11.4 \times 3.00) = 0$ — H_1 = 10.7 kN

Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$: F_2 - 11.42 - 3.81 = 0 — F_2 = 15.2 kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2) \times 1.75 + (29.55 \times 1.75) - (11.4 \times 9.0) - (3.81 \times 3.0) = 0$ — H_2 = 25.0 kN

Consider sub-frame to the left of F_3 :

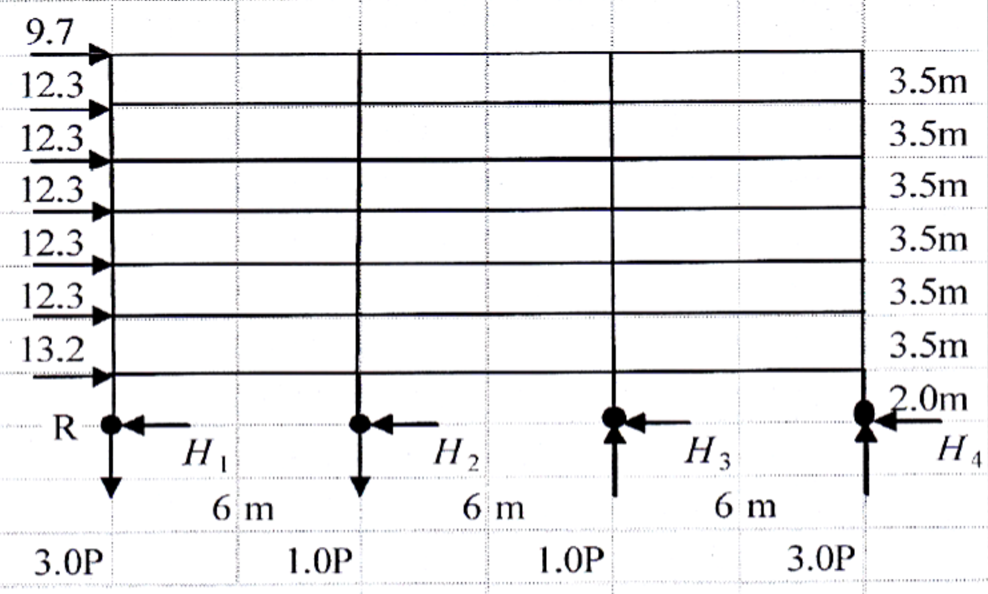
$\Sigma F_v = 0$: F_3 - 11.42 - 3.81 + 3.81 = 0 — F_3 = 11.4 kN

$\Sigma M@F_2 = 0$: $(H_1 + H_2 + H_3)\ 1.75 + (50.23 \times 1.75) - (11.4 \times 15.00) - (3.81 \times 9.0) + (3.81 \times 3.0) = 0$ — H_3 = 25.0 kN

$\Sigma F_H = 0$: $71.4 - H_1 - H_2 - H_3 - H_4 = 0$ — H_4 = 10.7 kN

Example

Level R and above



Axial force in columns,

ΣM @ P = 0

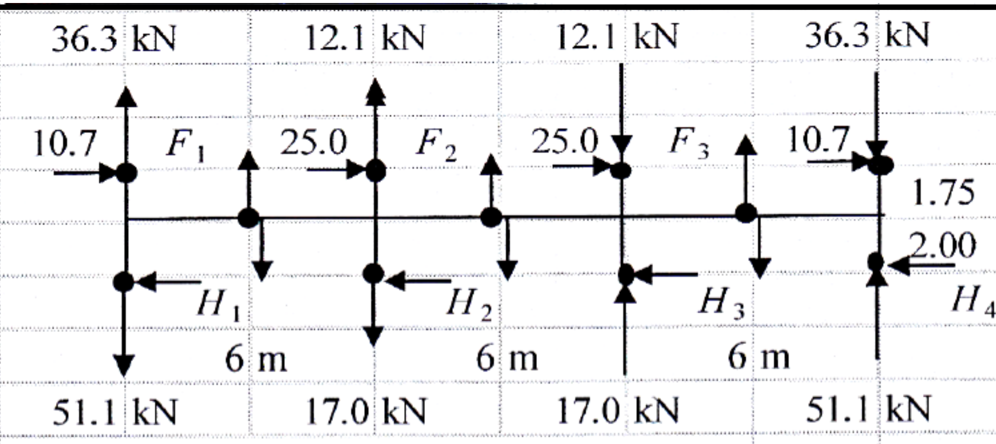
(9.7 x 23.0)+ (12.3 x 19.5)+ (12.3 x 16.0) + (12.3 x 12.5) +
(12.3 x 9.00)+ (12.3 x 5.50)+ (13.2 x 2.00)+ (1.0P x 6.0)
- (1.0P x 12.0) -(3.0P x 18.0) = 0

60.0P = 1021.4 kN

P = 1021 / 60.0 = 17.02 kN

3.0P =	51.1 kN
1.0P =	17.0 kN
1.0P =	17.0 kN
3.0P =	51.1 kN

Example



Consider sub-frame to the left of F_1 :

$\Sigma F_v = 0$:	$F_1 - 51.07 + 36.35 = 0$	$F_1 = 14.7$ kN
$\Sigma M@F_1 = 0$:	$(H_1 \times 2.00) + (10.7 \times 1.75) - (14.7 \times 3.0) = 0$	$H_1 = 12.7$ kN

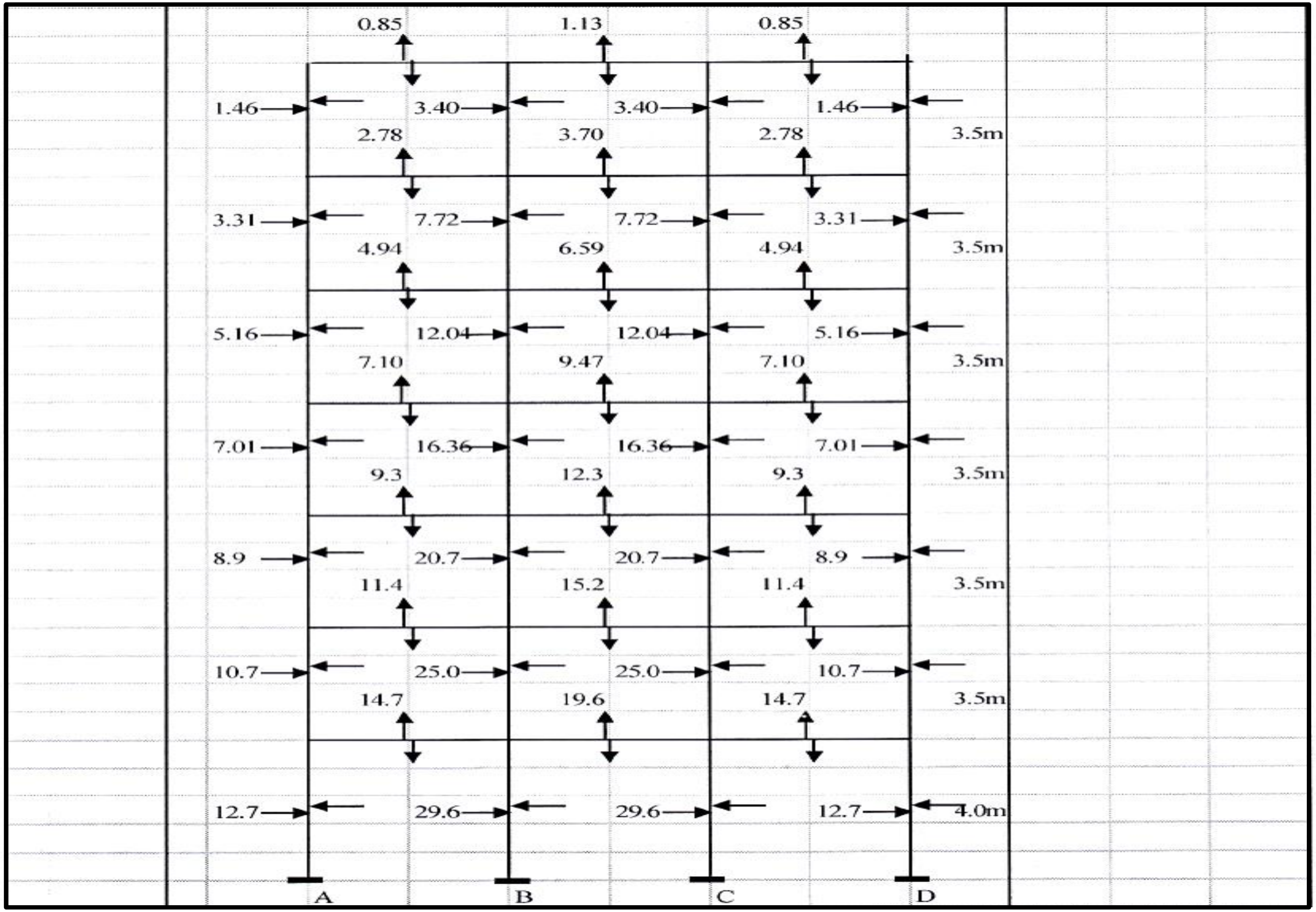
Consider sub-frame to the left of F_2 :

$\Sigma F_v = 0$:	$F_2 - 14.72 - 4.91 = 0$	$F_2 = 19.6$ kN
$\Sigma M@F_2 = 0$:	$(H_1 + H_2) \times 2.00 + (35.72 \times 1.75)$	$H_2 = 29.6$ kN
	$- (14.7 \times 9.0) - (4.91 \times 3.0) = 0$	

Consider sub-frame to the left of F_3 :

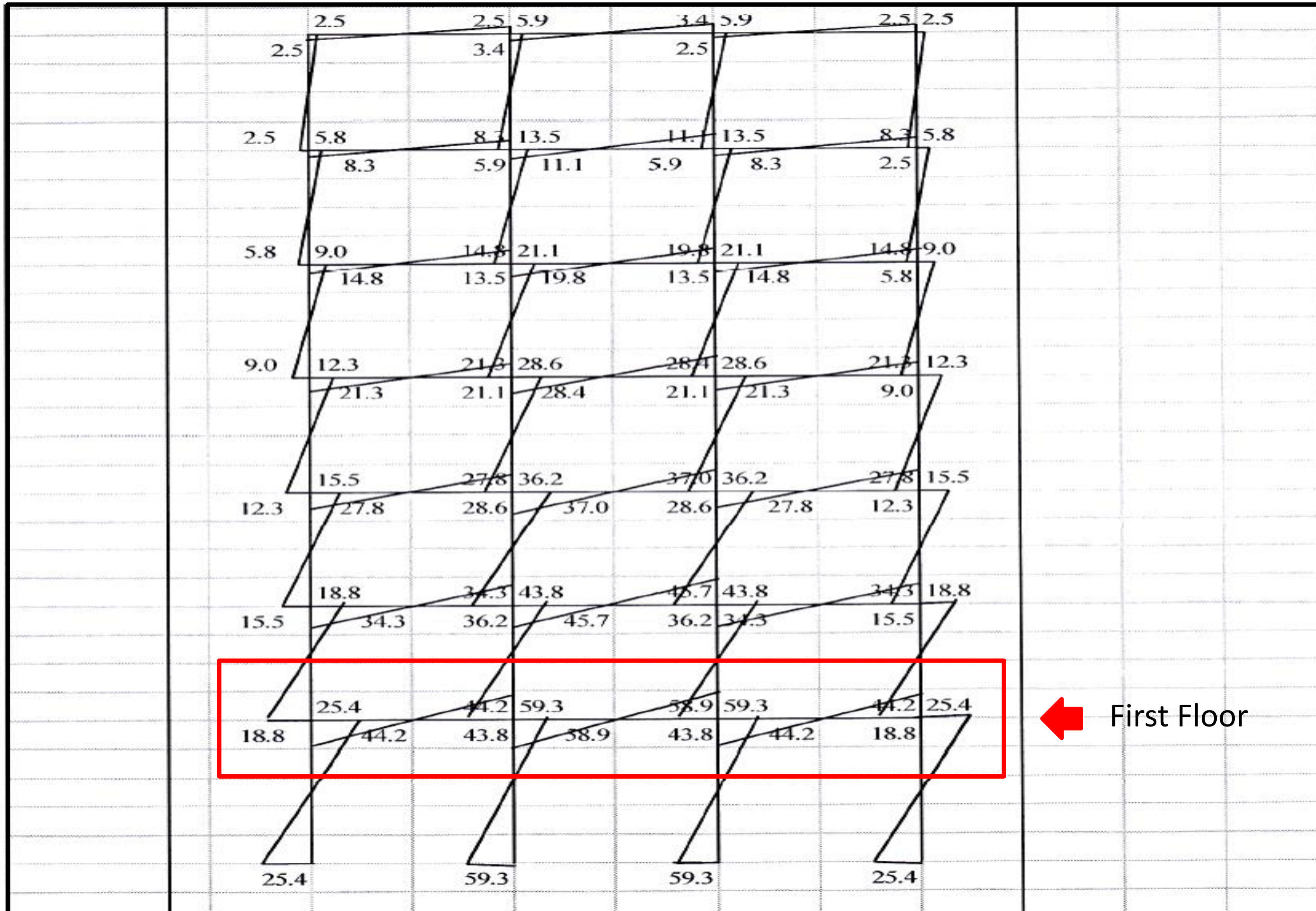
$\Sigma F_v = 0$:	$F_3 - 14.72 - 4.91 + 4.91 = 0$	$F_3 = 14.7$ kN
$\Sigma M@F_2 = 0$:	$(H_1 + H_2 + H_3)\, 2.00 + (60.73 \times 1.75)$	$H_3 = 29.6$ kN
	$- (14.7 \times 15.00) - (4.91 \times 9.0) + (4.91 \times 3.0) = 0$	
$\Sigma F_H = 0$:	$84.7 - H_1 - H_2 - H_3 - H_4 = 0$	$H_4 = 12.7$ kN

Example



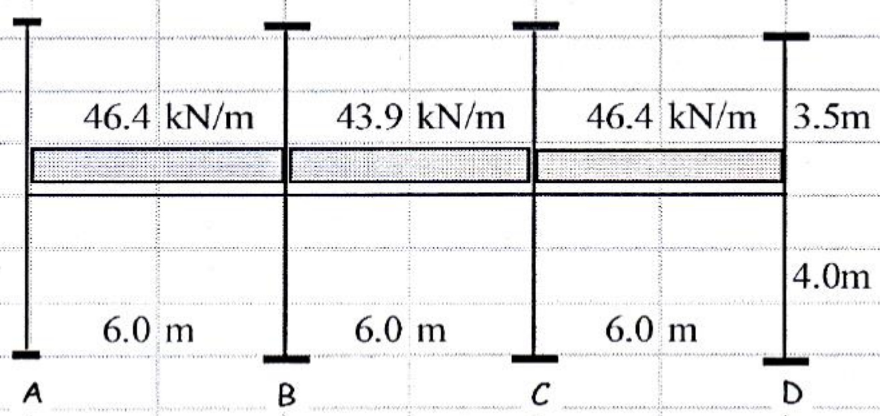
0.85
1.13
0.85
1.46
3.40
3.40
1.46
2.78
3.70
2.78
3.5m
3.31
7.72
7.72
3.31
4.94
6.59
4.94
3.5m
5.16
12.04
12.04
5.16
7.10
9.47
7.10
3.5m
7.01
16.36
16.36
7.01
9.3
12.3
9.3
3.5m
8.9
20.7
20.7
8.9
11.4
15.2
11.4
3.5m
10.7
25.0
25.0
10.7
14.7
19.6
14.7
3.5m
12.7
29.6
29.6
12.7
4.0m
A
B
C
D

Example



Example

Case 1 : All spans design permanent & variable loads $1.2G_k + 1.2Q_k$



Fixed end moment :

$-M_{AB} = M_{BA} = w_1 L_1^2/12$

$= 46.4 \times 6.0^2/12$

$= 139.1$ kNm

$-M_{BC} = M_{CB} = w_2 L_2^2/12$

$= 43.9 \times 6.0^2/12$

$= 131.6$ kNm

$-M_{CD} = M_{DC} = w_1 L_1^2/12$

$= 46.4 \times 6.0^2/12$

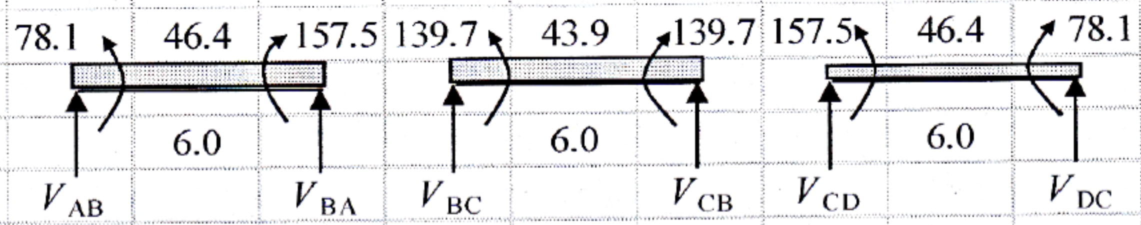
$= 139.1$ kNm

Example

41.67				-9.48				9.48				-41.67
0.25				-0.42				0.42				-0.25
1.52				-1.09				1.09				-1.52
0.34				-6.52				6.52				-0.34
39.56				-1.45				1.45				-39.56
0.28	A		B	0.19			C	0.19			D	0.28
0.25	0.47		0.32	0.17	0.32		0.32	0.17	0.32		0.47	0.25
	-139.1		139.1		-131.6		131.6		-139.1		139.1	
34.6	64.9		-2.4	-1.3	-2.4		2.4	1.3	2.4		-64.9	-34.6
	-1.2		32.5		1.2		-1.2		-32.5		1.2	
0.3	0.6		-10.7	-5.7	-10.7		10.7	5.7	10.7		-0.6	-0.3
	-5.4		0.3		5.4		-5.4		-0.3		5.4	
1.3	2.5		-1.8	-1.0	-1.8		1.8	1.0	1.8		-2.5	-1.3
	-0.9		1.2		0.9		-0.9		-1.2		0.9	
0.2	0.4		-0.7	-0.4	-0.7		0.7	0.4	0.7		-0.4	-0.2
36.5	-78.1		157.5	-8.3	-139.7		139.7	8.3	-157.5		78.1	-36.5

Example

Shear force :



ΣM @ B = 0

$6.0\,V_{AB} - (46.4 \times 6.0 \times 3.0) + 157.5 - 78.1 = 0$

$V_{AB} = (834.46 - 157.5 + 78.1)\,/\,6.0 = 125.8$ kN

$V_{BA} = (46.4 \times 6.0) - 125.8 = 152.3$ kN

ΣM @ C = 0

$6.0\,V_{BC} - (43.9 \times 6.0 \times 3.0) + 139.7 - 139.7 = 0$

$V_{BC} = (789.75 - 139.7 + 139.7)\,/\,6.0 = 131.6$ kN

$V_{CB} = (43.9 \times 6.0) - 131.6 = 131.6$ kN

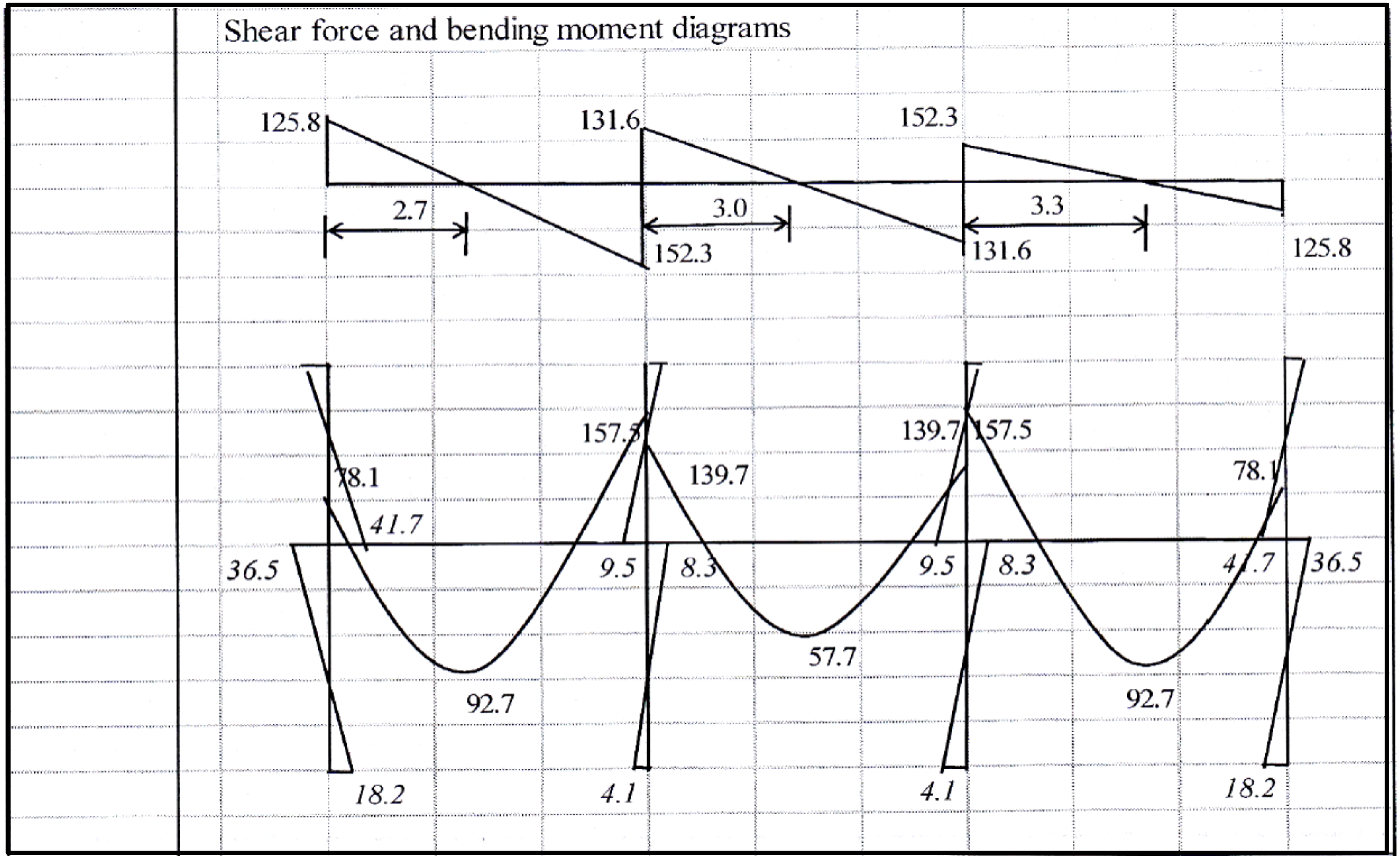
ΣM @ D = 0

$6.0\,V_{CD} - (46.4 \times 6.0 \times 3.0) - 157.5 + 78.1 = 0$

$V_{CD} = (834.46 + 157.5 - 78.1)\,/\,6.0 = 152.3$ kN

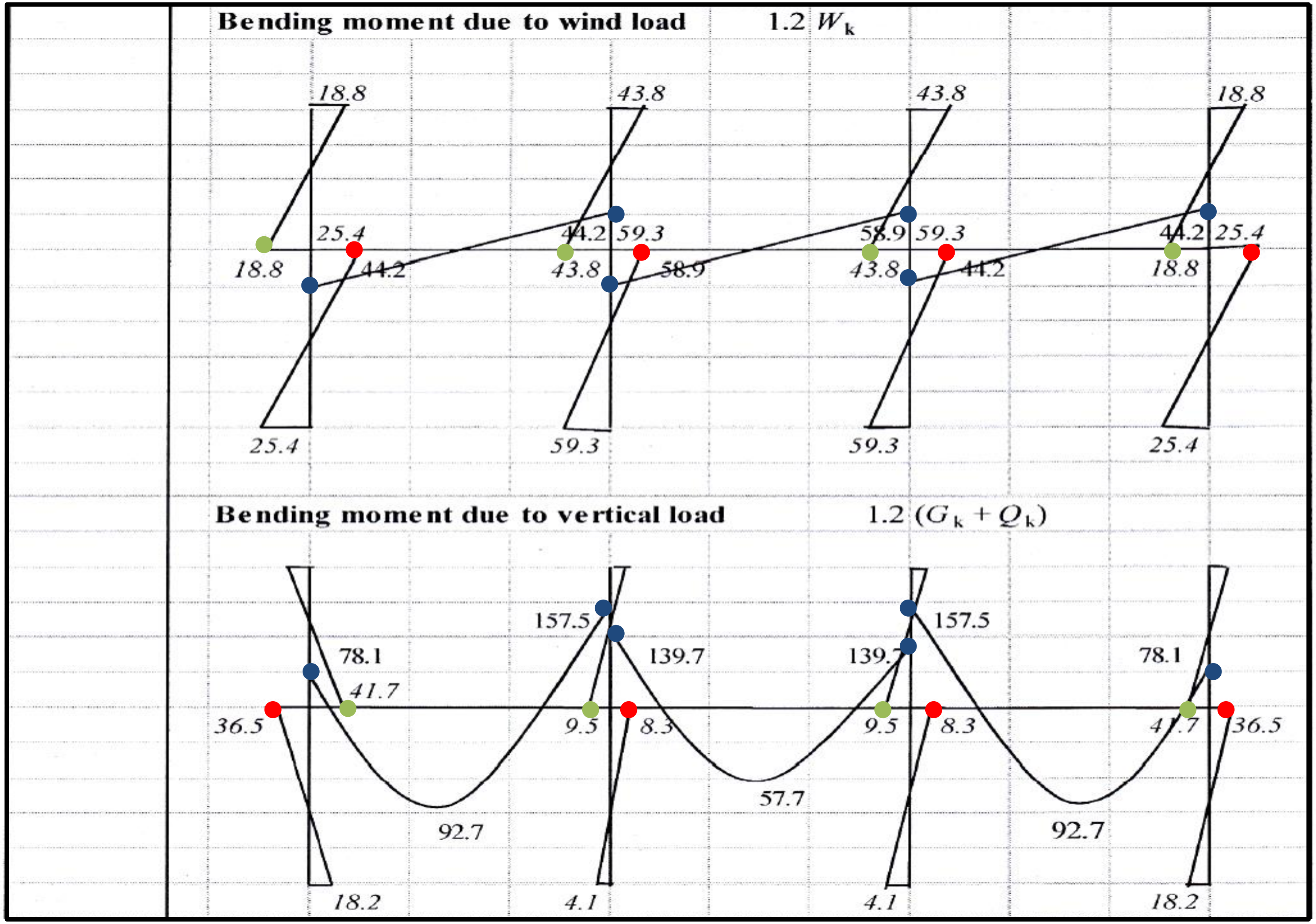
$V_{DC} = (46.4 \times 6.0) - 152.3 = 125.8$ kN

Example

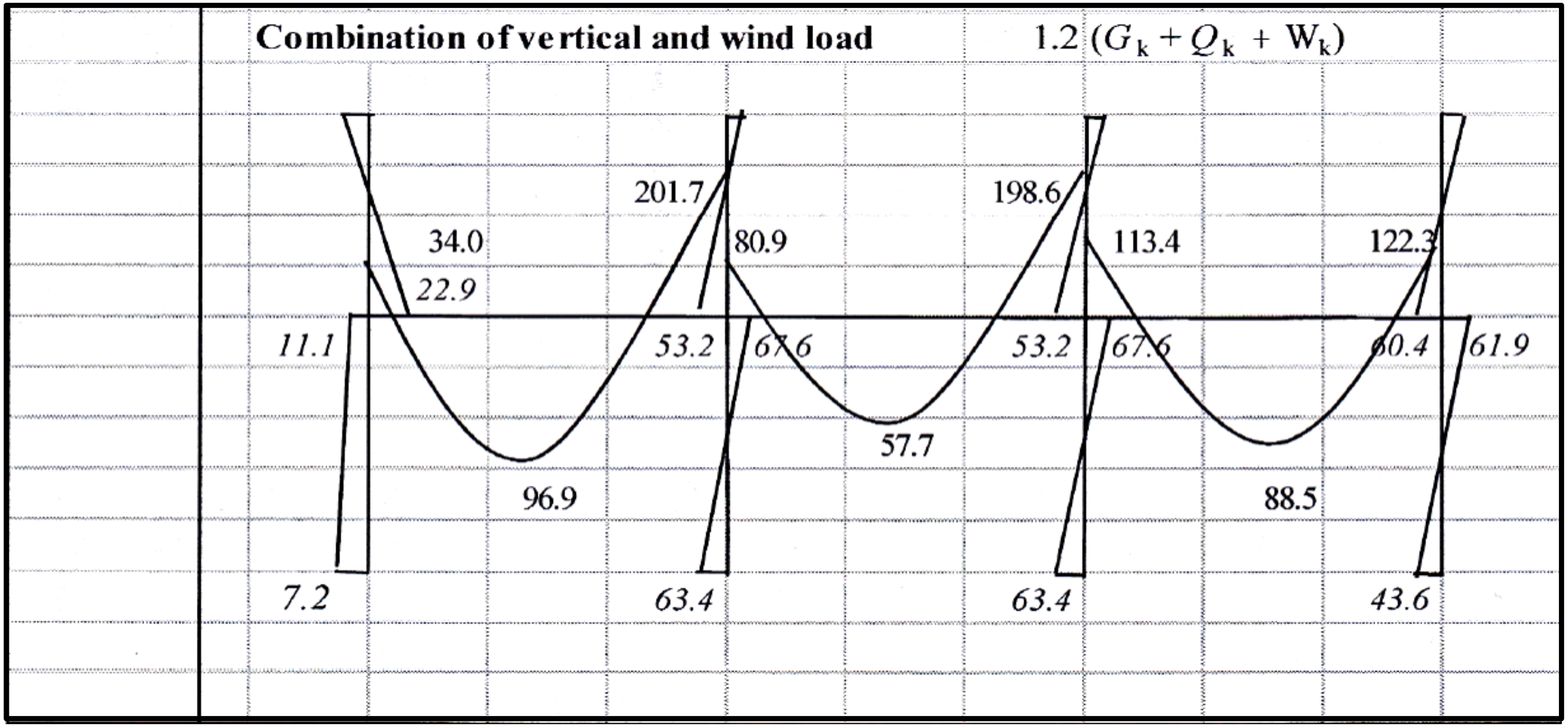


Shear force and bending moment diagrams
125.8
131.6
152.3
2.7
3.0
3.3
152.3
131.6
125.8
157.5
139.7
157.5
139.7
78.1
78.1
41.7
41.7
36.5
36.5
9.5
8.3
9.5
8.3
92.7
57.7
92.7
18.2
4.1
4.1
18.2

Example


Bending moment due to wind load
1.2 W_k
18.8
43.8
43.8
18.8
25.4
44.2
59.3
58.9
59.3
44.2
25.4
18.8
44.2
43.8
58.9
43.8
44.2
18.8
25.4
59.3
59.3
25.4
Bending moment due to vertical load
1.2 $(G_k + Q_k)$
157.5
157.5
78.1
139.7
139.7
78.1
41.7
36.5
9.5
8.3
9.5
8.3
41.7
36.5
57.7
92.7
92.7
18.2
4.1
4.1
18.2

Example


Combination of vertical and wind load
1.2 (G k + Q k + W k)
201.7
198.6
34.0
80.9
113.4
122.3
22.9
11.1
53.2
67.6
53.2
67.6
60.4
61.9
57.7
96.9
88.5
7.2
63.4
63.4
43.6