Chapter three

Mathematical models

3.1. Introduction

In order to study the effect of bracing types in multi-storey steel braced buildings we studied two different basic models to make two types of comparisons:

- **comparison (1):**

study the effect of bracing types on the stiffnesses of multi-storey steel braced frame buildings in form of the ratio of the maximum deflections at the top of the building to the total height (drift index) and compare these ratios with the drift index of the rigid frame.

- **comparison (2):**

study the effect of bracing types on multi-storey steel braced frame buildings in form of the weights of members and comparing them with the weights of rigid frame members.

3.2. Frames information

Table (3.1): Frame information of models:

<table>
<tr><th colspan="2">Case</th><th>comparison (1)</th><th>comparison (2)</th></tr>
<tr><td colspan="2">Number of stories</td><td>30</td><td>20</td></tr>
<tr><td colspan="2">Storey height(m)</td><td colspan="2">3m for all stories</td></tr>
<tr><td colspan="2">Number of spans (bays)</td><td colspan="2">3 bays in each direction for all bays</td></tr>
<tr><td colspan="2">Length of bay (m)</td><td colspan="2">4m for all bays</td></tr>
<tr><td rowspan="4">Member Sections</td><td>Columns</td><td>I And H</td><td>H</td></tr>
<tr><td>Beams</td><td colspan="2">I</td></tr>
<tr><td>Composite Beams</td><td colspan="2">I And H</td></tr>
<tr><td>Bracing</td><td colspan="2">T</td></tr>
<tr><td rowspan="4">Types of connections</td><td>Columns</td><td>Rigid for all</td><td>Pinned for all</td></tr>
<tr><td>Beams</td><td colspan="2">Rigid for all</td></tr>
<tr><td>Composite beams</td><td colspan="2">Pinned for all</td></tr>
<tr><td>Bracing</td><td colspan="2">Pinned for all types.</td></tr>
</table>

3.3. Models

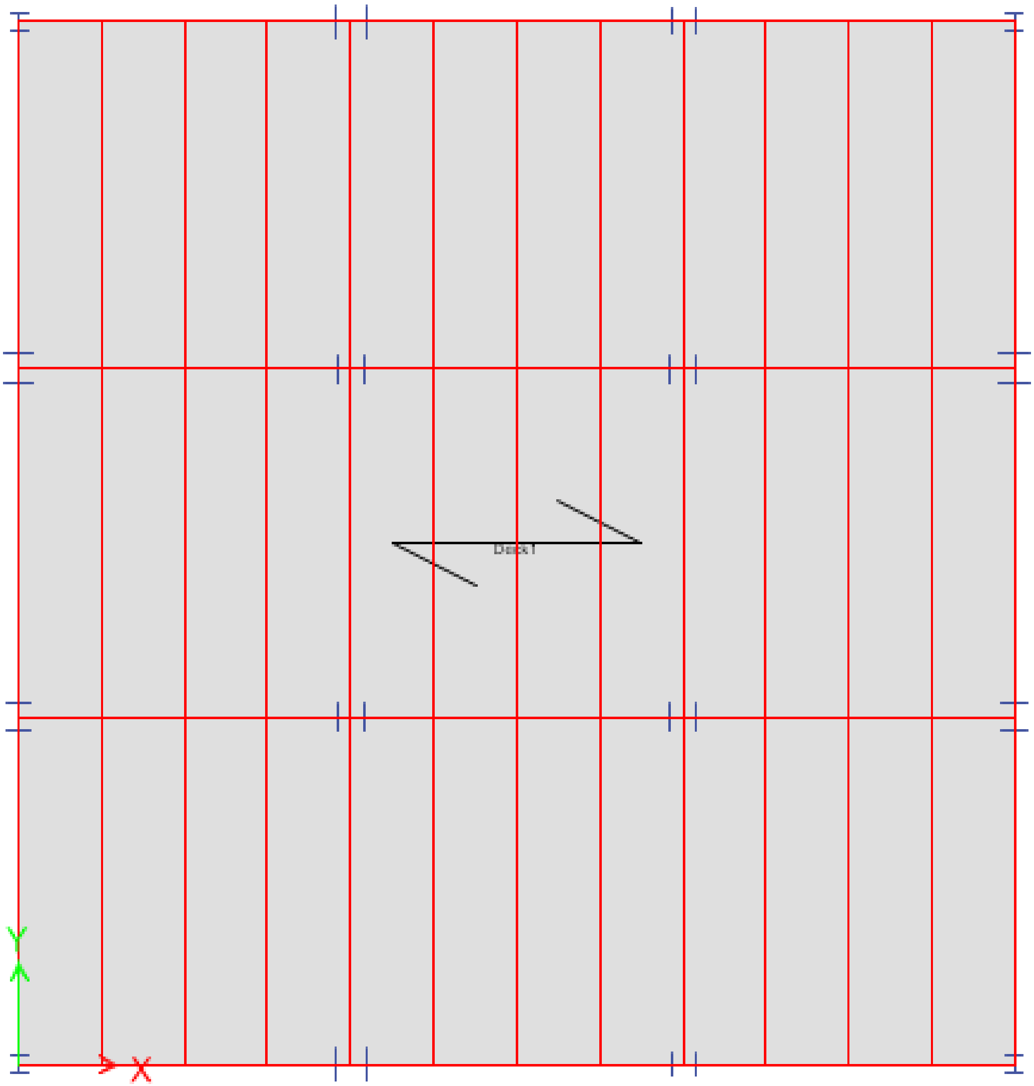

Figure (3.1): Plane of models

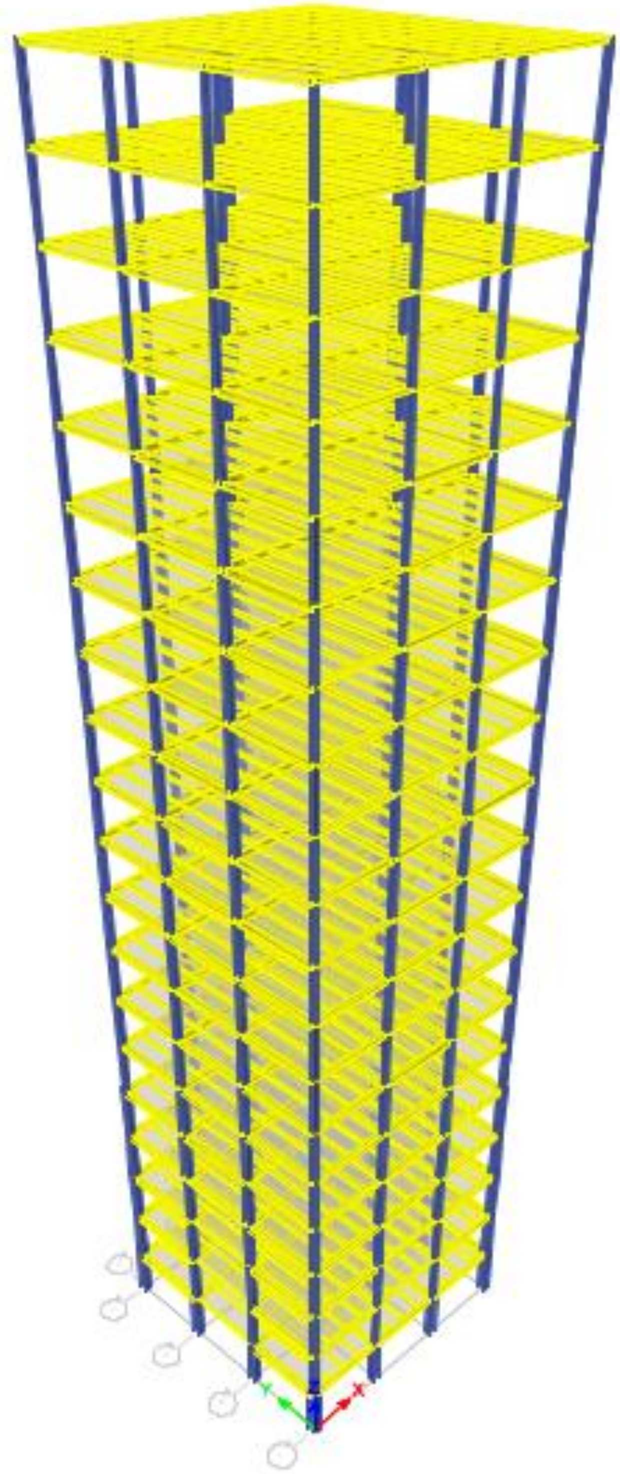

Figure (3.2):3-D rigid frame

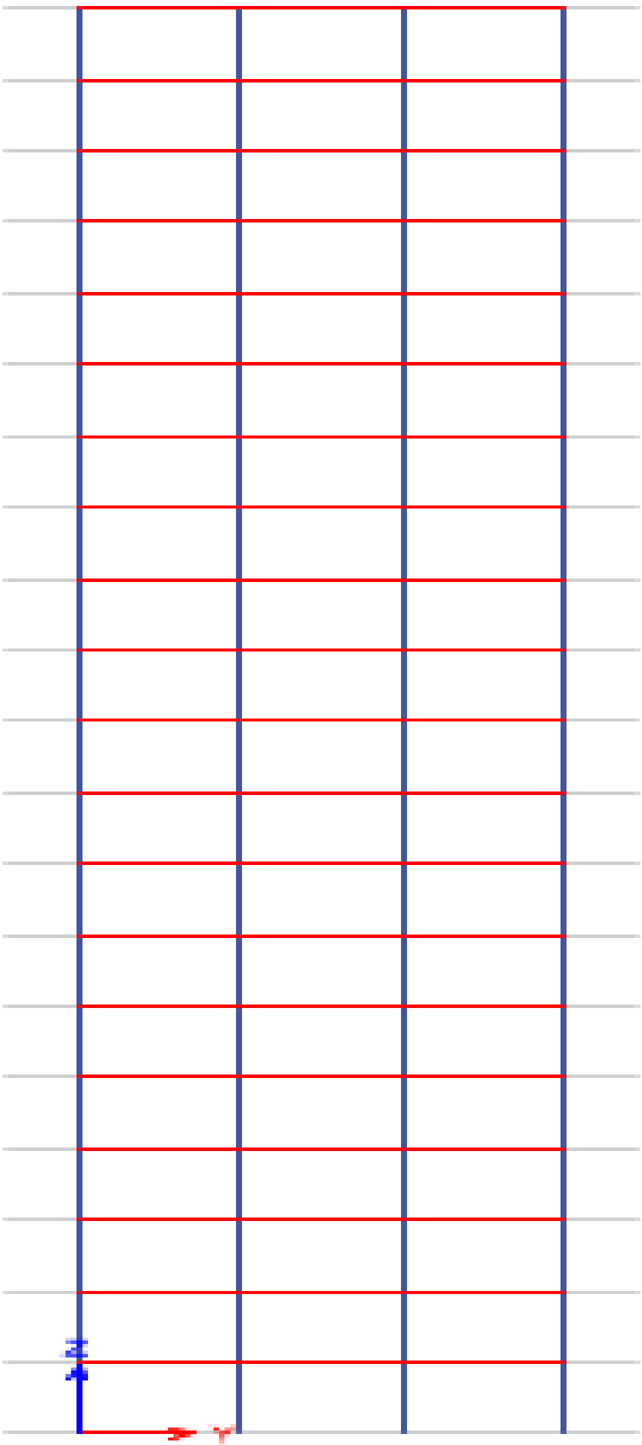

Figure (3.3): Elevation of rigid frame

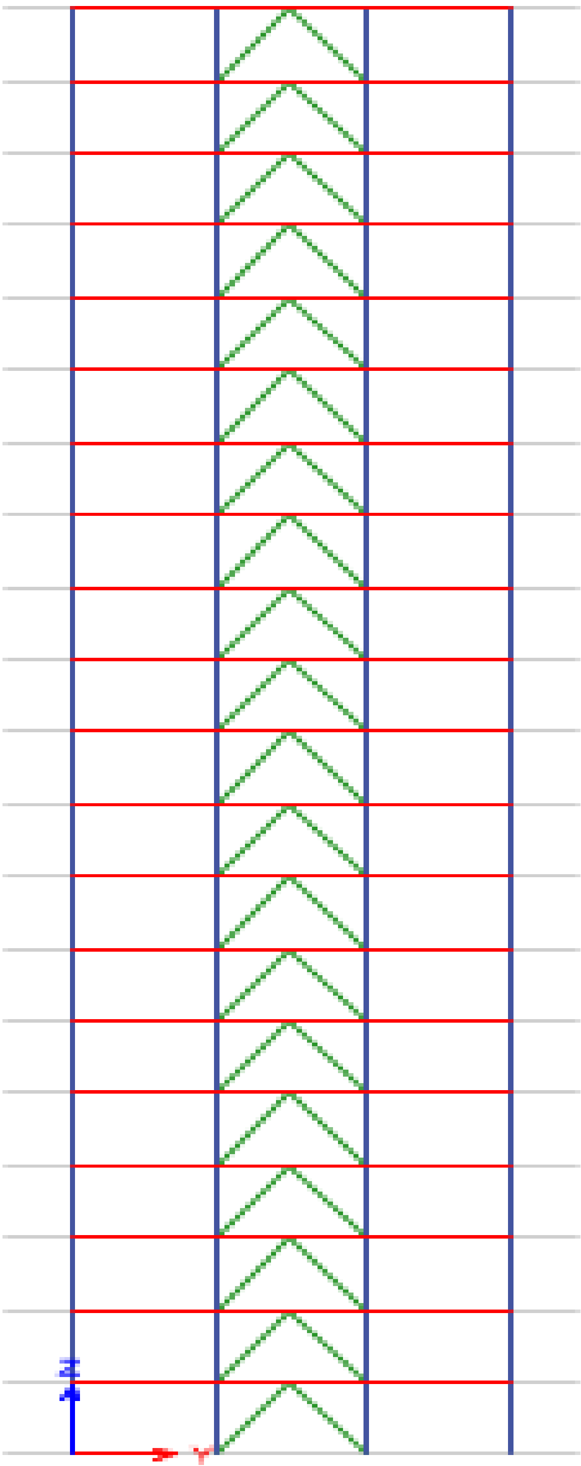

Figure (3.4): Elevation of k braced frame

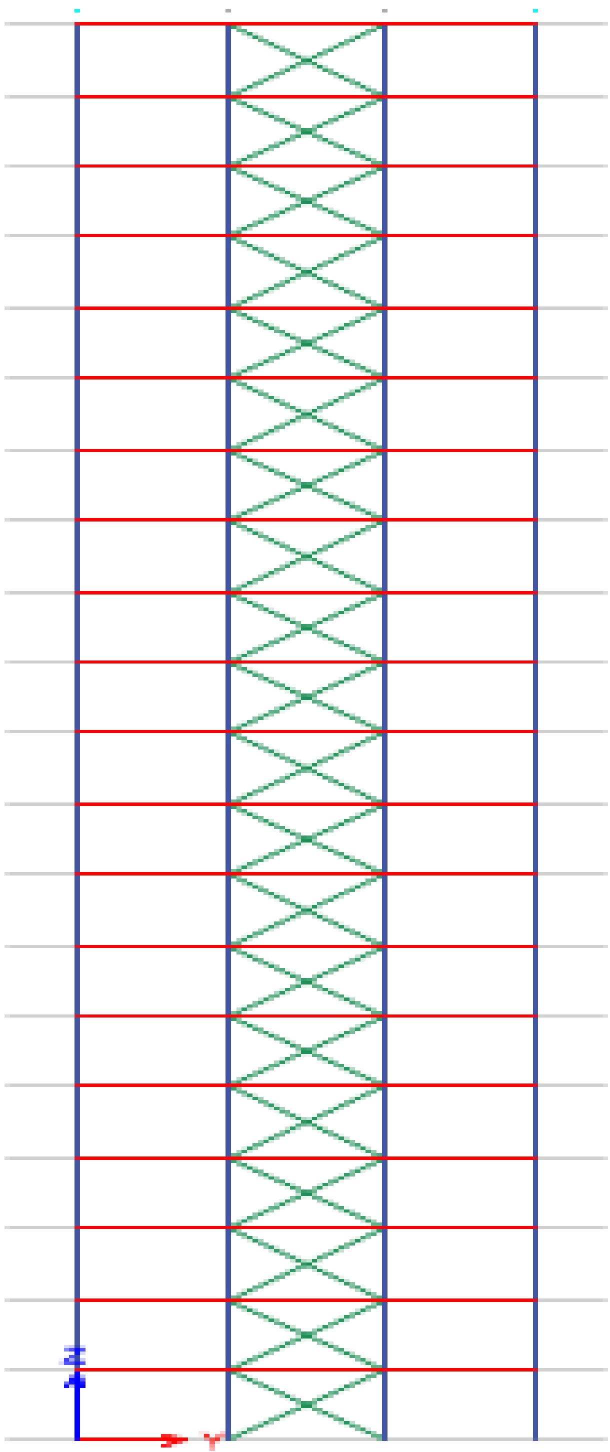

Figure (3.5): Elevation of x braced frame

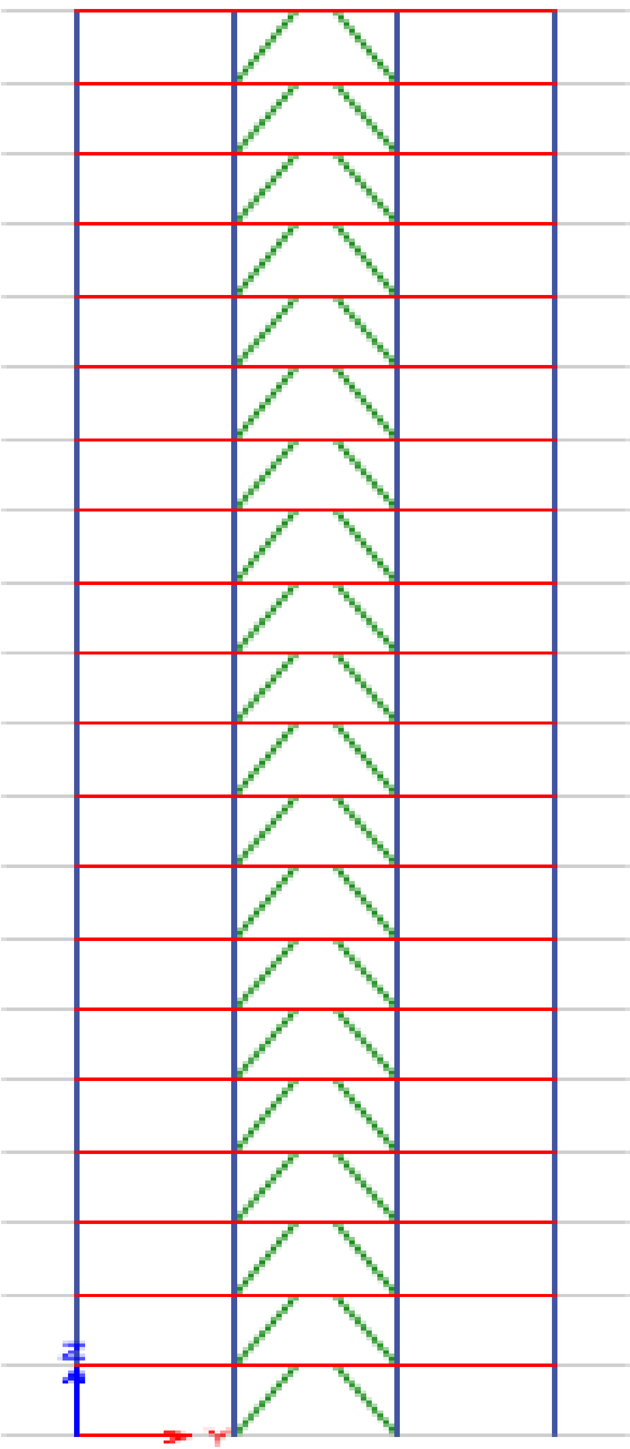

Figure (3.6): Elevation of eccentric frame{eccentric is equal to 1 m}

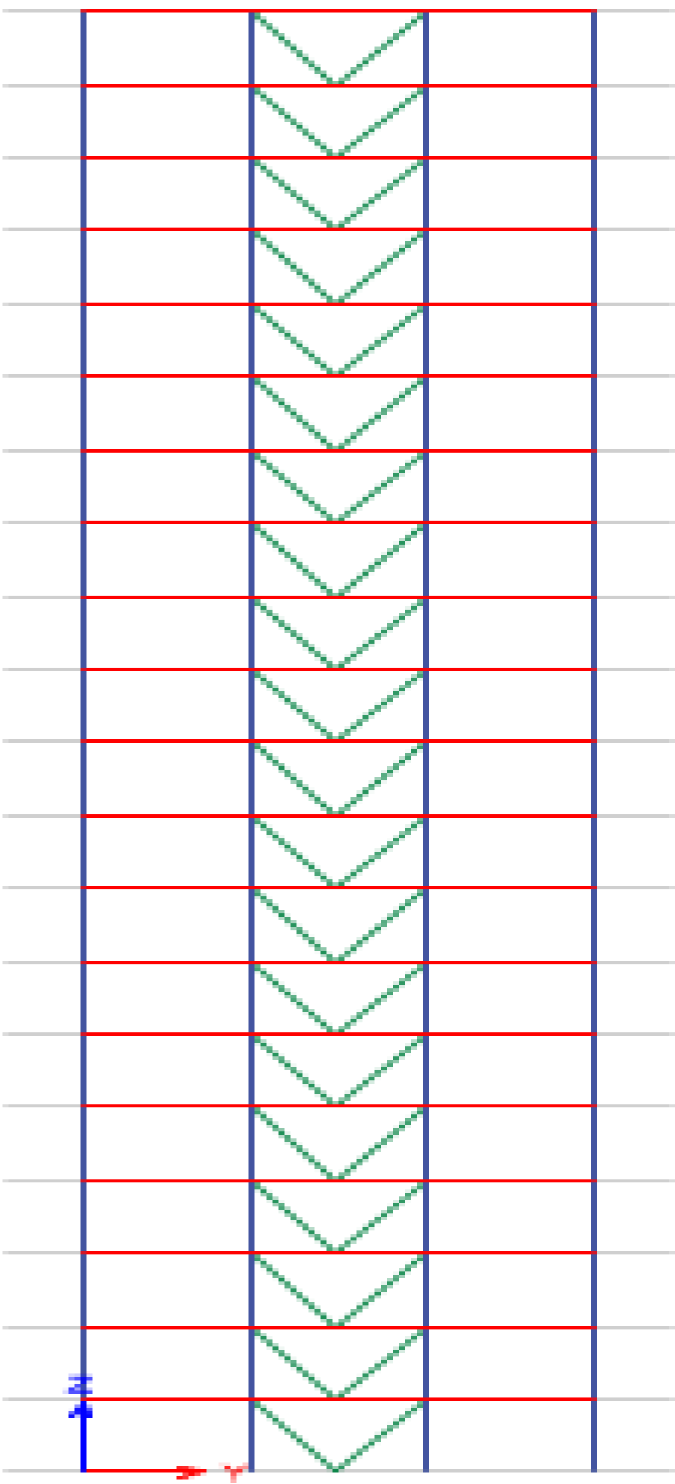

Figure (3.7): Elevation of v braced frame

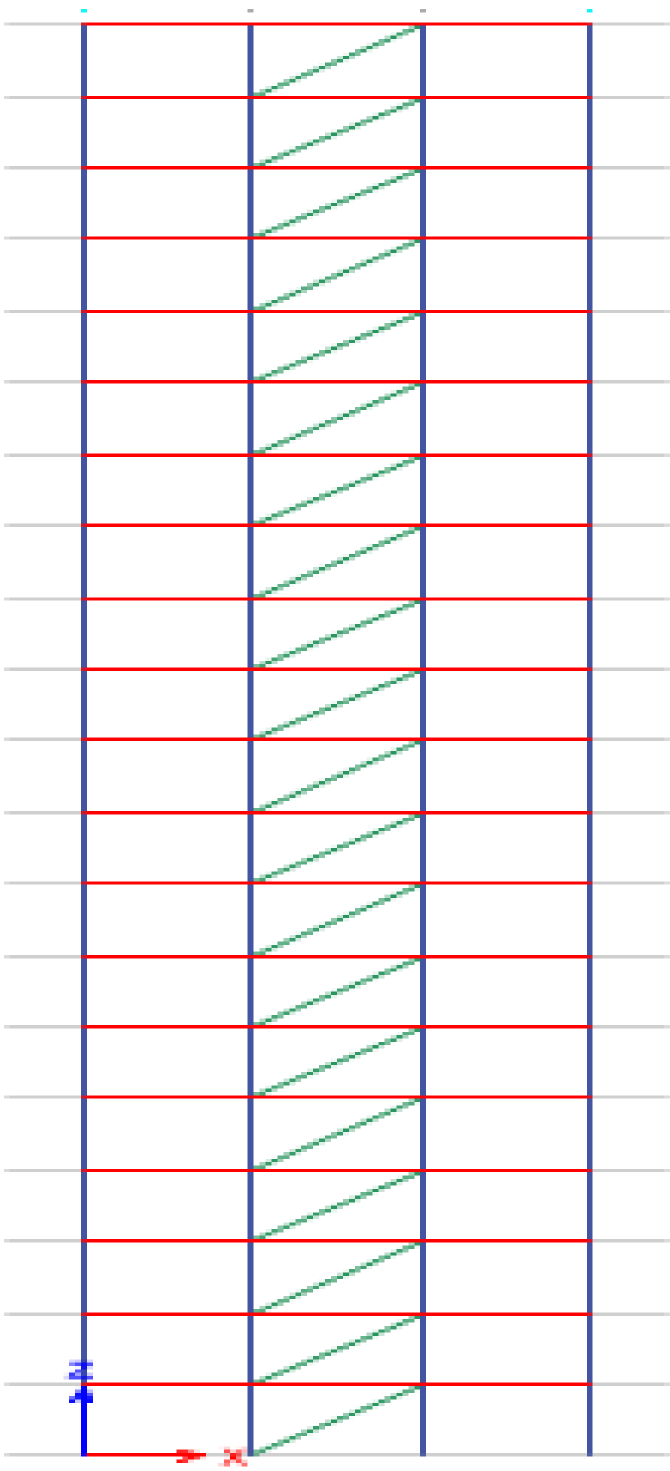

Figure (3.8): Elevation of single diagonal braced frame

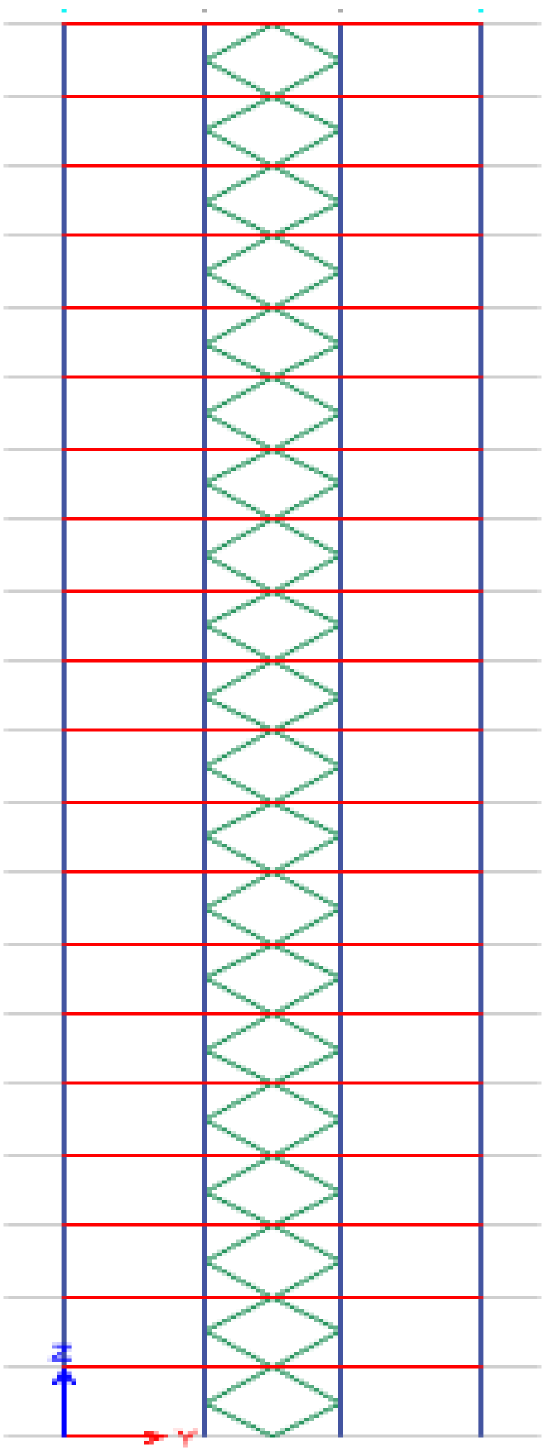

Figure (3.9): Elevation of quadrangular braced frame

3.4. Analysis information

3.4.1. Loading

3.4.1.1. Dead and imposed load

- **Dead load:**

$\mathrm{DL} = 1.5\ \mathrm{kN/m^2}$ {Ceilings, partitions and finishing}

$\text{Deck self} - \text{weight} = 0.11\ \mathrm{kN/m^2}$

- **Imposed load:**

$\mathrm{LL} = 2\ \mathrm{kN/m^2}$ {BS 6399 Part -1:1996 Table:1 (specific use is public)}

3.4.1.2. Wind load calculations: {accordance with B.S 6399-2:1997}

- Building location: KHARTOUM – ALSAHAFA.
- Basic wind speed (v_b): $v_b = 45\ m/s$ (Khartoum city).
- site altitude in meters above mean sea level (Δ):

$\Delta = 412.090\mathrm{m}$ [In Khartoum city].

Ref.	Calculations	Output
	Wind load calculations :	
	Standard method :	
	Stage 1 :	
Cl:1.6.1	Dynamic augmentation factor(c_r) :	
T :1	Building type factor (k_b)	
	→ Type of building :	
	Light structure with few internal walls.	
	$\rightarrow k_b = 2$	$k_b = 2$
	→ Building height H=90 m	H=90 m
Figure :3	Dynamic augmentation factor	
	$c_r = .15$	$c_r = .15$
	Stage 2:	
Cl:1.6.2	Check limits of applicability	
Figure :3	$c_r = .15 < 0.25, H = 90 < 300 \rightarrow ok$	
	Stage 3:	
Cl:2.2.1	Basic wind speed (v_b):	
	$v_b = 45\ m/s$ (Khartoum city)	$v_b = 45\ m/s$
	Stage 4:	
Cl:2.2.2	Site wind speed:	
Eq:8	$(v_s = v_b \times s_a \times s_d \times s_s \times s_p)$	
	$v_b = 45\ m/s$	
Cl:2.2.2.2	**Altitude factor(s_a):**	
Cl:2.2.2.2.2	Topography is not considered significant.	
Eq:9	$s_a = 1 + 0.001\Delta$	

	Δ= site altitude in meters above mean sea level Δ = 412.090 m [Khartoum city] $s_a = 1 + 0.001 * 412.090$ $= 1.412$	$s_a = 1.412$
Cl:2.2.2.3	**Directional factor (s_d)** Direction(Ø)→0° North	
T:3	$\therefore S_d = .78$	$S_d = .78$
Cl:2.2.2.4	**Seasonal factor (S_s)** Permanent buildings → S_s=1	$S_s = 1$
Cl:2.2.2.5	**Probability factor (S_p)** Normal design → S_p= 1 → standard value of risk Q =0.02 $\therefore V_S = 45 \times 1.412 \times .78$ $= 49.562 m/s$	$S_p = 1$ Q =0.02 $V_S = 49.562$ m/s
	Stage 5:	
Cl:1.7.3	→Terrain categories effective height (H_e) The categories of terrain is B (country) (the building is in Khartoum). → Reference height ($H_r = 90$ m) (conservatively). → The effective height He may be conservatively taken as the reference height H_r ($H_e = H_r = 90$ m)	$H_r = 90$ m $H_e = 90$ m

	Stage 6:	
Cl:1.8	Choice of method :	
	→ Use standard method.	
	Stage 7:	
Cl:2.2.3	Standard effective wind speed (v_e):	
Eq:12	$v_e = v_s \times s_b$	
Cl:2.2.3.3	s_b	
	→ the terrain and building factor	
	→ site in country	
T:4	→ Closest distance to sea upwind	
	$\geq$ 100 km	
	➢ By using interpolation from table (4) and taken into account the variation of the height ranges We can get the value of the terrain and building factor (s_b)	
	Stage 8:	
Cl:2.1.2	Dynamic pressure (q_s):	
Eq:1	$q_s = 0.613 \times {v_e}^2$	
	Stage9:	
Cl:2.3	Standard pressure coefficients (C_p):	
Cl:2.4	External pressure coefficient for walls(C_{pe}):	
Cl:2.4.1.2	$D/_H \geq 4$ →use table 5	
	Span ratio of building $D/_H \geq 4$	
T:5	→ wind ward (front) → C_{pe}=0.6	C_{pe}
Cl:2.6	Internal pressure coefficient for	$= 0.6$

T:16	walls(C_{Pi}): Type of walls → two opposite walls equally permeable other face impermeable → wind normal to permeable face $C_{pi} = 0.2$	$C_{pi} = 0.2$
	Stage10:	
Cl:2.1.3	Wind load (p):	
Cl:2.1.3.1	External surface pressures (p_e):	
Eq:2	$p_{e=}q_s C_{pe} C_a$	
Cl:2.1.3.4	size effect factor ($C_a = C_{ae}$):	
Fig:5	Diagonal dimension(a): $a = \sqrt{{h_{la}}^2 + B^2}$	
Fig:4	C_{ae} → from curve(B) $p_e = q_s \times c_{pe} \times c_{ae}$	
Cl:2.1.3.2	Internal surface pressure (p_i)	
Eq:3	$p_i = q_s \times c_{pi} \times c_a$	
Cl:2.1.3.4	Size effect factor ($C_a = C_{ai}$):	
Cl:2.6	Effective diagonal dimension(a):	
Eq:13	$a = 10\sqrt[3]{B \times L \times h}$ $a = 10 \times \sqrt[3]{12 \times 12 \times 3} =$ 75.595m	a =75.595 m
Fig:4	∴ (C_{ai}) →curve(B) $p_i = q_s \times c_{pi} \times c_{ai}$	
Cl:2.1.3.3	**Net surface pressures:** For enclosed building:	
Eq:4	$p_{total} = p_e - p_i$	

Table (3.2): Calculations of wind loads:

story	height	D	v_b	v_s	s_b	v_e	q_s	a	c_{ai}	p_i	c_{pe}	h_{la}	a	c_{ae}	p_e	p_{total}	P(kN)
30	90	12	45	49.5612	2.046	101.4022	6303.117	75.595	0.795	1002.196	0.6	3	12.36932	0.939	3551.176	2548.98	91.7633
29	87	12	45	49.5612	2.0388	101.0454	6258.833	75.595	0.795	995.1544	0.6	6	13.41641	0.933	3503.695	2508.54	90.30745
28	84	12	45	49.5612	2.0316	1`00.6885	6214.705	75.595	0.795	988.1381	0.6	9	15	0.919	3426.788	2438.65	87.79141
27	81	12	45	49.5612	2.0244	100.3317	6170.733	75.595	0.795	981.1466	0.6	12	16.97056	0.915	3387.732	2406.586	86.63709
26	78	12	45	49.5612	2.0172	99.97485	6126.917	75.595	0.795	974.1799	0.6	15	19.20937	0.899	3304.859	2330.679	83.90446
25	75	12	45	49.5612	2.01	99.61801	6083.258	75.595	0.795	967.238	0.6	18	21.63331	0.891	3252.11	2284.872	82.25538
24	72	12	45	49.5612	2.0028	99.26117	6039.754	75.595	0.795	960.3209	0.6	21	24.18677	0.88	3188.99	2228.669	80.2321
23	69	12	45	49.5612	1.9956	98.90433	5996.407	75.595	0.795	953.4287	0.6	24	26.83282	0.878	3158.907	2205.478	79.39722
22	66	12	45	49.5612	1.9884	98.54749	5953.216	75.595	0.795	946.5613	0.6	27	29.54657	0.869	3104.007	2157.445	77.66803
21	63	12	45	49.5612	1.9812	98.19065	5910.18	75.595	0.795	939.7187	0.6	30	32.31099	0.86	3049.653	2109.934	75.95764
20	60	12	45	49.5612	1.974	97.83381	5867.301	75.595	0.795	932.9009	0.6	33	35.1141	0.852	2999.364	2066.464	74.39269
19	57	12	45	49.5612	1.9668	97.47697	5824.578	75.595	0.795	926.108	0.6	36	37.94733	0.85	2970.535	2044.427	73.59937
18	54	12	45	49.5612	1.9596	97.12013	5782.012	75.595	0.795	919.3399	0.6	39	40.80441	0.842	2921.072	2001.732	72.06237
17	51	12	45	49.5612	1.9524	96.76329	5739.601	75.595	0.795	912.5966	0.6	42	43.68066	0.838	2885.871	1973.275	71.03789
16	48	12	45	49.5612	1.94	96.14873	5666.926	75.595	0.795	901.0413	0.6	45	46.57252	0.834	2835.73	1934.689	69.64879
15	45	12	45	49.5612	1.925	95.40531	5579.632	75.595	0.795	887.1615	0.6	48	49.47727	0.83	2778.657	1891.495	68.09383

Table (3.2): Calculations of wind loads {continuous}:

14	42	12	45	49.5612	1.91	94.66189	5493.016	75.595	0.795	873.3895	0.6	51	52.39275	0.825	2719.043	1845.653	66.44352
13	39	12	45	49.5612	1.895	93.91847	5407.077	75.595	0.795	859.7252	0.6	54	55.31727	0.82	2660.282	1800.557	64.82004
12	36	12	45	49.5612	1.88	93.17506	5321.815	75.595	0.795	846.1686	0.6	57	58.24946	0.817	2608.754	1762.585	63.45307
11	33	12	45	49.5612	1.865	92.43164	5237.232	75.595	0.795	832.7198	0.6	60	61.18823	0.81	2545.295	1712.575	61.65269
10	30	12	45	49.5612	1.85	91.68822	5153.325	75.595	0.795	819.3787	0.6	63	64.13267	0.8107	2506.68	1687.302	60.74286
9	27	12	45	49.5612	1.826	90.49875	5020.485	75.595	0.795	798.2571	0.6	66	67.08204	0.803	2418.87	1620.612	58.34205
8	24	12	45	49.5612	1.802	89.30928	4889.379	75.595	0.795	777.4112	0.6	69	70.03571	0.8	2346.902	1569.491	56.50166
7	21	12	45	49.5612	1.778	88.11981	4760.007	75.595	0.795	756.8412	0.6	72	72.99315	0.798	2279.091	1522.25	54.80101
6	18	12	45	49.5612	1.746	86.53386	4590.21	75.595	0.795	729.8434	0.6	75	75.95393	0.795	2189.53	1459.687	52.54873
5	15	12	45	49.5612	1.71	84.74965	4402.875	75.595	0.795	700.0571	0.6	78	78.91768	0.792	2092.246	1392.189	50.1188
4	12	12	45	49.5612	1.656	82.07335	4129.189	75.595	0.795	656.5411	0.6	81	81.88406	0.79	1957.236	1300.695	46.825
3	9	12	45	49.5612	1.586	78.60406	3787.481	75.595	0.795	602.2095	0.6	84	84.85281	0.788	1790.721	1188.512	42.78642
2	6	12	45	49.5612	1.484	73.54882	3315.98	75.595	0.795	527.2408	0.6	87	87.82369	0.785	1561.827	1034.586	37.24509
1	3	12	45	49.5612	1.3233	65.58434	2636.7	75.595	0.795	419.2353	0.6	90	90.79648	0.741	1172.277	753.0415	27.1095

3.5. Procedure

- Linear analysis will be adopted.
- We will assume there is no reversal wind load.

3.5.1. Comparison (1): Drift index and displacement of storeys comparison

1. Drawing the frame using a deck and the other sections(composite beams, beams, columns and the first bracing type) with auto sections and then connecting etch storey floor joints with a diaphragm and assigning deck with the dead ,imposed and wind loading.
2. Run analysis and design for the frame sections.
3. Choosing the sections which are satisfy to resist the forces by making auto select section null, and then redrawing the failed once until all members pass the stress/capacity check and analysis/design check with noting reconnecting the diaphragms in each time of this steps.
4. Moving the previous bracing type and drawing the next bracing type and reconnecting the diaphragms.
5. Repeat the same steps from (2 to 4) above using the other bracing type and rigid frame until we reach to the last bracing type.
6. The last frame obtained by using the last bracing type is the constant frame for drift index displacement of storeys comparison.

And subsequently we can say we are fixed all variables (sections and loading conditions) and change one variable (displacements) and this is the basic concept of comparisons.

7. From the constant frame we can get the displacement of rigid frame directly and we can get also the displacement of the braced frames by drawing the different bracing shapes in it (with

constant section of bracing which is the greater bracing section obtained from the previous design of frames) and reconnecting the stories floor joints with a diaphragm and then run analysis.

3.5.2. Comparison (2): Weight comparison

The sections which used in comparing of the weight of models members are chosen automatically by Etabs programs (by drawing them by auto select section).

In this comparison we draw any full-model alone, and then analysis and design the model until all members pass the stress/capacity check and analysis/design check and thereby we can get all complete models ready for comparing.