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Effect of Wind Pressure on R.C Tall Buildings using Gust Factor Method

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***Abstract* - This paper presents a framework for evaluating the equivalent static wind load and a new description of the loading based on the gust loading envelope/peak dynamic loading is presented. The gust response factors and the equivalent static wind loads for various along wind response components at different shapes of building are discussed in detail.**
In the present study, analytical investigation of an different shapes of building situated in wind zone I and zoneIV of India, in accordance with IS 875(part 3)-1987, is taken as an example and the various analytical approaches (linear static and dynamic analysis) are performed on the building to identify the base shear, storey displacement, storey drift, overturning moment and storey shear. Also compared for different storey building models in both X and Y directions by using finite element software package ETAB's 9.7.4 version.

Keywords – Base shear, Drift,Dynamic effect, Equivalent static, Gust, Wind load.

1. INTRODUCTION

In current design practice, as wind is a randomly varying dynamic phenomenon, it has significant dynamic effect on buildings and structures especially on high-rise flexible structures. Most international Codes and Standards utilize the "gust loading factor" (GLF) approach for estimating dynamic effect on high-rise structures. The concept of GLF was first introduced by Davenport in 1967.
The wind generates pressure in windward wall and suction in leeward wall, lateral walls and part of the roof. Wind loading is a complex live load that varies both in time and space. The object of both analytical and physical modeling of wind loading is usually to derive an equivalent static load for design purposes. Such an equivalent load accounts for the variability in time and space of the true wind loads and for dynamic interactions which may occur between the structure and the wind. The detailed gust factor methods for tall slender buildings developed and established in codes and standards offer examples of such processes. Even without a significant resonant response of the structures, these methods illustrate that the size of the building leads to averaging of the smaller gust inputs and hence the net effective load is reduced. Now a day there is shortage of land for building, more buildings at a faster growth in both residential and industrial areas. The vertical construction is given importance because of which tall buildings are being built on a large scale. Wind is air in horizontal motion relative to the surface of earth.
Wind effects on structures can be classified as "static" and "dynamic".
Static- Static wind effect primarily causes elastic bending and twisting of structure.
Dynamic-For tall, long span and slender structures a 'dynamic analysis' of the structure is essential, Wind gusts cause fluctuating forces on the structure which induce large dynamic motions, including oscillations.
Story displacement: Storey displacement is defined as the Lateral deflection of predicted movement of a structure under lateral loads (wind loads).
Storey drift: It is defined as the displacement of one level with respect to the level below it.

2. DESIGN PROCEDURE

Design Wind Speed

Wind speed in the atmospheric boundary layer increases with height from at ground level to maximum at a height called the gradient height. The basic wind speed shall be modified to include risk level, terrain roughness, height of the structure and local topography to get the design wind velocity Vz and is given as:

$$V_Z = V_b . K_1 . K_2 . K_3$$

Where, V_Z= Design wind speed in m/s at any height 'z' m
V_b = Basic wind speed for various zones
K_1= Probability factor (risk coefficient)
K_2 = Terrain roughness and height factor
K_3= Topography factor

Risk coefficient (K_1): suggested life period to be assumed and the corresponding K1 factor for different class of structures as per IS: 875 (Part 3)

Terrain and height factor (K_2): Selection of terrain categories shall be made with due regard to the effect of obstruction, which constitute the ground surface.

Topography Factor (K_3): The effect of topography will be significant at a site when the upwind slope is greater than about 3°, and below that, the value of K_3 may be taken to be equal to 1.0. The value of K_3 is confined in the range of 1.0 to 1.36 for slopes greater than 3°.
Design Wind Pressure: The design wind pressure at any height above mean level shall be obtained by the Following relationship between wind pressure and wind velocity:

$$P_Z=0.6\, V_z^2$$

Where, P_Z= Design wind pressure in N/m^2 at height 'z' m
V_Z = design wind velocity in m/s at height 'z' m

Wind Load on Individual Members: (IS: 875 (Part 3)

$$F = (C_{pe} - C_{pi})\, AP_Z$$

Where, C_{pe} = external pressure coefficient,
C_{pi} = internal pressure- coefficient,
A = surface area of structural or cladding unit and
P_Z = design wind pressure.

Table: 1. Parameters considered for the study

No. of Storey	15
Bottom storey height	4m
Storey height	3m
Soil type	Medium
Wind zone, WDZ	I, IV
Shape of buildings	Square, I shape
Thickness of slab	0.125m
Beam size	0.3mx0.6m
Column size	0.5mx0.5m
Material Properties	
Grade of concrete	M25
Grade of steel	Fe 415
Dead load intensities	
FF on floors	1.75kN/m^2
FF on roof	2kN/m^2
Live load intensities	
LL on floors	3 kN/m^2
LL on roof	1.5 kN/m^2

Linear Analysis

Bottom storey height = 4m,
Each storey height = 3 m
The maximum dimension of the building is in between 20-50m. hence it is classified in to "Class B" Open terrain with well Scattered obstruction hence "category II" For all general buildings, k_1 = 1 Slope below 3^0, k_3 = 1 Where k_2 value depends on the height of building (from IS 875(part3) 1987 table 2).

Table: 2. Linear Wind load calculations as per IS: 875(part 3)-1987 for zone I V_b=33m/s

FLOOR	h (m)	hi (m)	h/2 (m)	k2	Vz (m/s)	Pz	A	Story
1	4	4	2	0.98	32.34	0.62753	105	85.66
2	3	7	1.5	0.98	32.34	0.62753	90	73.42
3	3	10	1.5	0.98	32.34	0.62753	90	73.42
4	3	13	1.5	1.004	33.132	0.65864	90	77.06
5	3	16	1.5	1.026	33.858	0.68782	90	80.47
6	3	19	1.5	1.044	34.452	0.71216	90	83.32
7	3	22	1.5	1.06	34.98	0.73416	90	85.9
8	3	25	1.5	1.075	35.475	0.75508	90	88.35
9	3	28	1.5	1.09	35.97	0.7763	90	90.82
10	3	31	1.5	1.102	36.382	0.7942	90	92.92

11	3	34	1.5	1.11	36.63	0.80505	90	94.19
12	3	37	1.5	1.117	36.877	0.81597	90	95.47
13	3	40	1.5	1.125	37.125	0.82696	90	96.75
14	3	43	1.5	1.132	37.372	0.83802	90	98.05
15	3	46	1.5	1.14	37.62	0.84916	45	49.67

Table 3: Linear Wind load calculations as per IS: 875 (part 3)-1987 for Zone IV V_b=47m/s

FLOOR	h (m)	hi (m)	h/2 (m)	k2	Vz (m/s)	Pz (kN/m^2)	A m^2	Story Shear(kN)
1	4	4	2	0.98	46.06	1.272914	105	173.7528
2	3	7	1.5	0.98	46.06	1.272914	90	148.931
3	3	10	1.5	0.98	46.06	1.272914	90	148.931
4	3	13	1.5	1.004	47.188	1.336024	90	156.3149
5	3	16	1.5	1.026	48.222	1.395217	90	163.2404
6	3	19	1.5	1.044	49.068	1.444601	90	169.0183
7	3	22	1.5	1.06	49.82	1.489219	90	174.2387
8	3	25	1.5	1.075	50.525	1.531665	90	179.2048
9	3	28	1.5	1.09	51.23	1.574708	90	184.2408
10	3	31	1.5	1.1025	51.817	1.611032	90	188.4907
11	3	34	1.5	1.11	52.17	1.633025	90	191.064
12	3	37	1.5	1.1175	52.522	1.655168	90	193.6546
13	3	40	1.5	1.125	52.875	1.677459	90	196.2627
14	3	43	1.5	1.1325	53.227	1.6999	90	198.8883
15	3	46	1.5	1.14	53.58	1.72249	45	100.7657

GUST FACTOR

A gust factor, defined as the ratio between a peak wind gust and mean wind speed over a period of time can be used along with other statistics to examine the structure of the wind. Gust factors are heavily dependent on upstream terrain conditions (roughness)

Wind load calculation as per IS: 875(part-3)-1987 with gust factor

Time Period Calculation:
h=46m (height of structure)
Tx=0.09h/sqrt (d) …..(From page-48)
dx=30m (dx=plan dimension in X-direction) Tx=0.756 sec
dy=30m (dy=plan dimension in Y-direction)Ty=0.756 sec

Constants and Parameters:

(1) Force coefficient for Clad Building

Along X-axis: h/b =46/30 = 1.53>1, a/b=1. C_f=1.25(Fig-4, page-39) Along Y-axis: h/a =46/30 = 1.53>1, b/a=1. C_f=1.25(Fig-4,page-39)

(2) Peak Factor and Roughness Factor

G_f = peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuate load r = roughness factor which is depends on the size of the structure in relation to the Ground roughness. G_f=1.23(Fig-8,page-50) for Category-2 and building height-46m

(3) Background Factor (B) B = background factor indicating a measure of slowly varying component of fluctuating wind load

λ = (Cy b) / (Cz h) (From Fig 9,page-50)

Along X Axis:λ=0.543 Where, Cy = lateral correlation constant = 10 (page 52) Cz = longitudinal correlation constant = 12 (page 52) b = breadth of the structure normal to the wind stream. h = height of the structure.

Along Y Axis: λ=0.543 L (h) = 1333 A measure of turbulence length scale (Fig 8) for height of 72m Cz h / L(h) =0.414**Along X Axis** B =0.73 (From Fig 9) **Along Y Axis:** B =0.73 (From Fig 9)

(4) Size Reduction Factor (S)

Reduced Frequency Fo = (Czfo h) / Vz F_{ox} = 729.7/ Vz, fo = natural frequency of the structure in Hz = 1 / T = 1.322, Tx =0.756 Ty =0.756 Foy = 729.7/ Vz, h = height of the structure. Vz = hourly mean speed at height z

(5) Constant Ǿ: Ǿ is to accounted only for the buildings less than 75 m high in terrain category 4 and for the buildings less than 25 m high in terrain category 3, and is to be taken as zero in all other cases. Ǿ =0

(6) Gust energy factor (E) From Fig 11 and depends on [foL(h)] / Vz fo = natural frequency of the structure = 1 / T Ex =1762.23/ Vz, h = height of the structure. Ey =1762.23/ Vz, Vz = hourly mean speed at height z

(7) β - Damping coefficient Damping coefficient of the structure - Table 34 For R.C.C. β=0.016 page 52

(8) **Gust Factor - G** = (peak load) / (mean load), and is given by G = 1 + [G_f r [SQRT (B (1 + Ǿ)2 + (S E) / β)]] (from page-49)

(9) Along wind Load - Fx: Along wind load on the structure on a strip area A_e, at any height z Fx = C_f A_ePz G (from page-49) C_f = force coefficient for the building. A_e = effective frontal area considered for the structure at height z. Pz = design pressure at height z due to hourly mean wind obtained as 0.6 V_Z^2 (N/m2).

Table: 4.Details of wind load calculations as per IS: 875 (part-3) 1987 with gust factors in zone-1

FLOOR	h (m)	hi (m)	h/2 (m)	k2 Table 33 page49	Vz (m/s)	Pz (kN/m^2)	Fo	S Fig.10 page51	[fo L(h) / Vz]	E Fig.11 pag52	G	Story Shear (kN)
1	4	4	2.0	0.670	22.110	0.2933	33.0032	0.0187	79.7028	0.0281	2.0743	79.8542
2	3	7	1.5	0.670	22.110	0.2933	33.0032	0.0187	79.7028	0.0281	2.0743	68.4465
3	3	10	1.5	0.670	22.110	0.2933	33.0032	0.0187	79.7028	0.0281	2.0743	68.4465
4	3	13	1.5	0.700	23.100	0.3202	31.5887	0.0205	76.2870	0.0291	2.0774	74.8258
5	3	16	1.5	0.723	23.859	0.3416	30.5838	0.0218	73.8602	0.0298	2.0797	79.9131
6	3	19	1.5	0.746	24.618	0.3636	29.6409	0.0229	71.5830	0.0305	2.0819	85.1657
7	3	22	1.5	0.756	24.948	0.3734	29.2488	0.0234	70.6361	0.0308	2.0829	87.5051
8	3	25	1.5	0.770	25.410	0.3874	28.7170	0.0241	69.3518	0.0312	2.0842	90.8354
9	3	28	1.5	0.785	25.905	0.4026	28.1683	0.0248	68.0266	0.0316	2.0856	94.4716
10	3	31	1.5	0.789	26.037	0.4068	28.0255	0.0250	67.6818	0.0317	2.0860	95.4544
11	3	34	1.5	0.799	26.367	0.4171	27.6747	0.0254	66.8347	0.0319	2.0868	97.9256
12	3	37	1.5	0.810	26.730	0.4287	27.2989	0.0258	65.9270	0.0322	2.0876	100.6835
13	3	40	1.5	0.820	27.060	0.4393	26.9660	0.0263	65.1231	0.0325	2.0887	103.2364
14	3	43	1.5	0.831	27.423	0.4512	26.6091	0.0267	64.2610	0.0327	2.0895	106.065
15	3	46	1.5	0.842	27.786	0.4632	26.2614	0.0272	63.4215	0.0329	2.0904	54.4705

Table: 5. Details of wind load calculations as per IS: 875 (part-3) 1987 with gust factors in zone-4

FLOOR	h (m)	hi (m)	h/2 (m)	k2 Table 33 page49	Vz (m/s)	Pz (kN/sqm)	Fo	S Fig.10 page51	[fo L(h) / Vz]	E Fig.11 pag52	G	Story Shear (kN)
1	4	4	2	0.67	31.49	0.5950	23.1724	0.0362	55.9616	0.0362	2.1083	164.6
2	3	7	1.5	0.67	31.49	0.5950	23.1724	0.0362	55.9616	0.0362	2.1083	141.1
3	3	10	1.5	0.67	31.49	0.5950	23.1724	0.0362	55.9616	0.0362	2.1083	141.1
4	3	13	1.5	0.7	32.9	0.6494	22.1793	0.0378	53.5632	0.0375	2.1129	154.4
5	3	16	1.5	0.723	33.981	0.6928	21.4738	0.0389	51.8593	0.0385	2.1163	164.9
6	3	19	1.5	0.746	35.062	0.7376	20.8117	0.0399	50.2604	0.0393	2.1192	175.9
7	3	22	1.5	0.756	35.532	0.7575	20.5364	0.0404	49.5956	0.0397	2.1207	180.7
8	3	25	1.5	0.77	36.19	0.7858	20.1630	0.0409	48.6938	0.0402	2.1224	187.6
9	3	28	1.5	0.785	36.895	0.8167	19.7777	0.0415	47.7634	0.0407	2.1243	195.2
10	3	31	1.5	0.789	37.083	0.8251	19.6775	0.0417	47.5212	0.0409	2.1250	197.3
11	3	34	1.5	0.799	37.553	0.8461	19.4312	0.0421	46.9265	0.0412	2.1262	202.4

12	3	37	1.5	0.81	38.07	0.8696	19.1673	0.0425	46.2892	0.0415	2.1275	208.1
13	3	40	1.5	0.82	38.54	0.8912	18.9336	0.0428	45.7247	0.0418	2.1285	213.4
14	3	43	1.5	0.831	39.057	0.9153	18.6830	0.0433	45.1194	0.0422	2.1301	219.3
15	3	46	1.5	0.842	39.574	0.9397	18.4389	0.0436	44.5300	0.0425	2.1312	112.6

Modeling In ETABS (9.7.4)

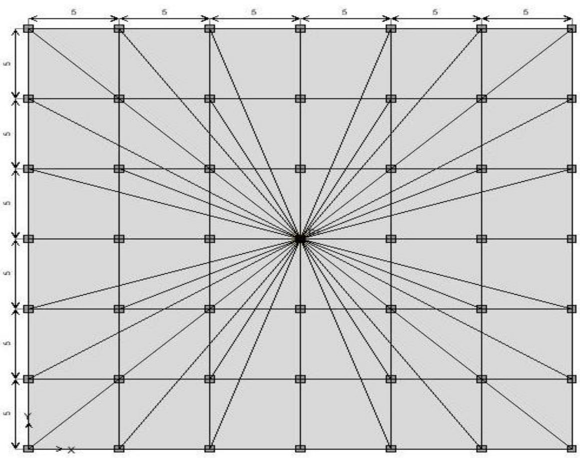

Fig 1: Extents of wind diaphragm for square-shape

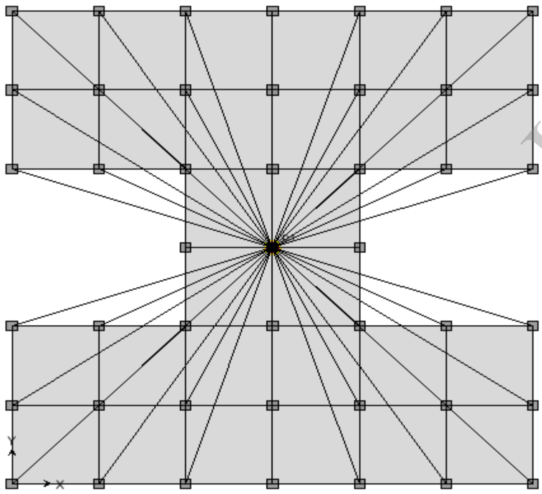

Fig 2: Extents of wind diaphragm for I-shape

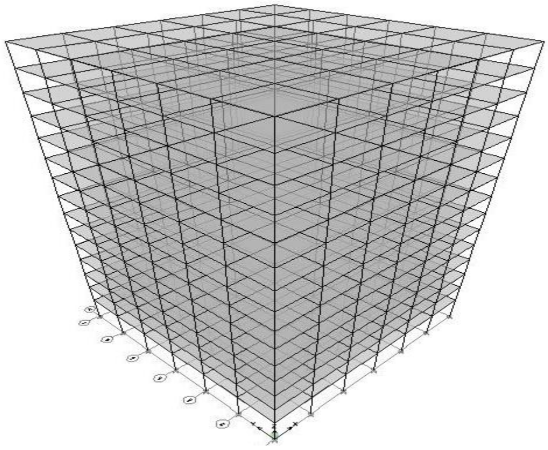

Fig 3:ETABS 3-D model for Square-shape

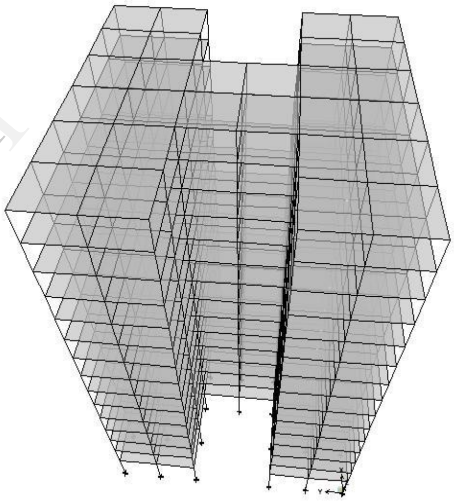

Fig 4: ETABS 3-D model for Square-shape

Table: 6. Point Displacement in mm for Square & I shape

sno of storeys	square shape								I shape							
	Without Gust factor				With Gust factor				Without Gust factor				With Gust factor			
	ZONE 1		ZONE IV		ZONE 1		ZONE IV		ZONE 1		ZONE IV		ZONE 1		ZONE IV	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
15	18.6	21.8	37.6	44.2	19.3	22.7	40	46.9	22.1	27.0	44.8	54.8	23	28.1	47.5	58.1
14	18.4	21.6	37.2	43.8	19.1	22.5	39.5	46.5	21.8	26.6	44.3	54	22.7	27.8	47	57.3
13	18.0	21.2	36.5	43	18.8	22.1	38.8	45.6	21.4	26.1	43.4	52.9	22.3	27.1	46.1	56.1
12	17.5	20.6	35.5	41.9	18.2	21.5	37.6	44.3	20.8	25.3	42.2	51.3	21.7	26.3	44.8	54.4
11	16.9	19.9	34.2	40.3	17.5	20.7	36.2	42.7	20	24.3	40.6	49.3	20.8	25.2	43	52.2
10	16.0	19	32.5	38.5	16.6	19.7	34.4	40.6	19.1	23.1	38.7	46.8	19.8	24	40.9	49.5
9	15.1	17.8	30.6	36.2	15.6	18.5	32.3	38.2	17.9	21.7	36.3	43.9	18.6	22.4	38.3	46.4

8	13.9	16.6	28.3	33.6	14.4	17.1	29.8	35.4	16.6	20.0	33.6	40.6	17.1	20.7	35.4	42.8
7	12.7	15.1	25.7	30.6	13.1	15.6	27.1	32.2	15.1	18.2	30.6	36.9	15.6	18.8	32.2	38.9
6	11.3	13.5	22.9	27.4	11.6	13.9	24	28.7	13.4	16.2	27.2	32.9	13.8	16.7	28.5	34.5
5	9.7	11.7	19.8	23.8	10	12.1	20.7	24.9	11.6	14.0	23.4	28.4	11.9	14.4	24.6	29.8
4	8.1	9.8	16.4	19.9	8.3	10.1	17.1	20.8	9.6	11.7	19.4	23.6	9.8	12	20.3	24.7
3	6.3	7.7	12.8	15.7	6.4	7.9	13.3	16.4	7.5	9.1	15.1	18.5	7.6	9.4	15.8	19.3
2	4.4	5.5	8.9	11.3	4.5	5.7	9.2	11.7	5.2	6.5	10.5	13.1	5.3	6.6	11	13.7
1	2.4	3.2	4.8	6.5	2.4	3.2	5	6.7	2.8	3.6	5.7	7.4	2.9	3.7	5.9	7.7

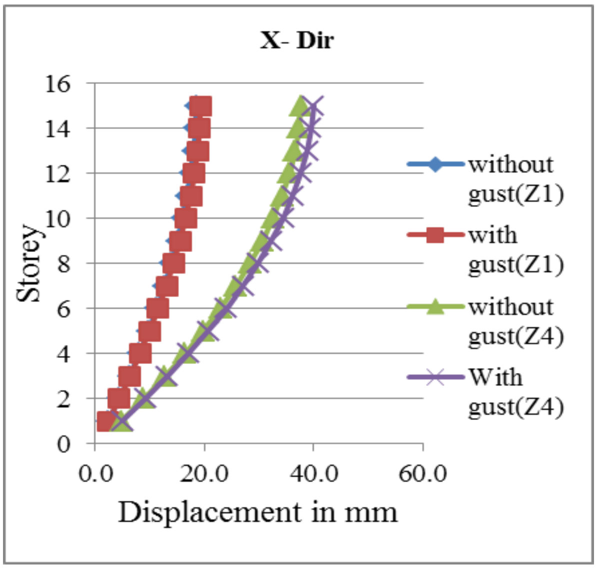

Fig 5: Square shape displacement when wind load in X-direction for zone-I and zone-IV

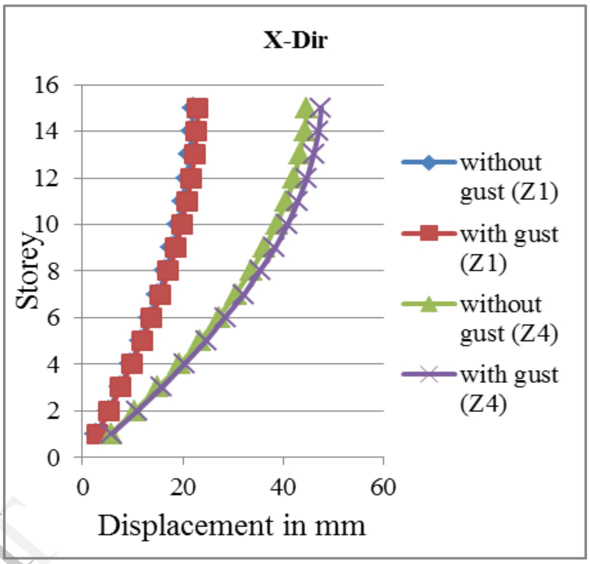

Fig 8: I shape displacement when wind load in X-direction for zone-I and zone-IV

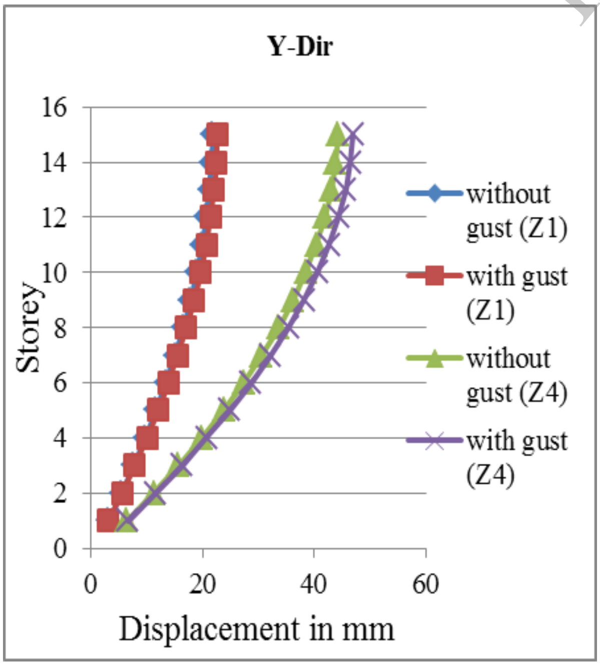

Fig 6: Square shape displacement when wind load in Y direction for zone-I and zone-IV

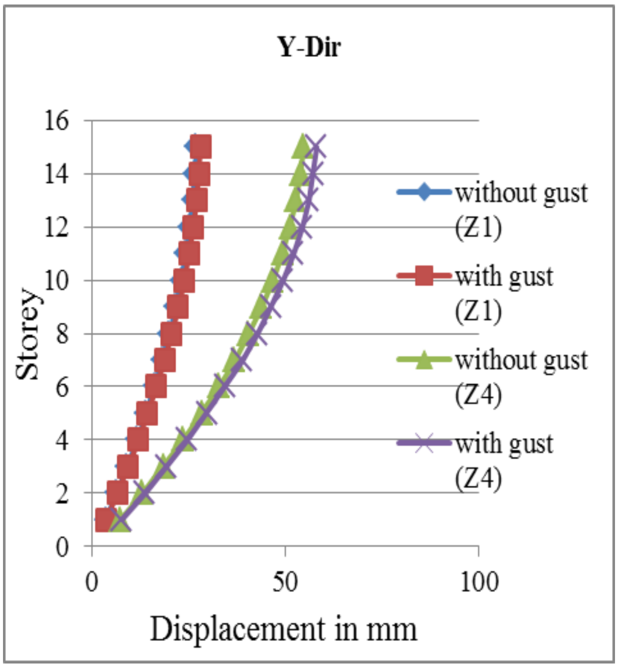

Fig 9: I shape displacement when wind load in Y direction for zone-I and zone-IV

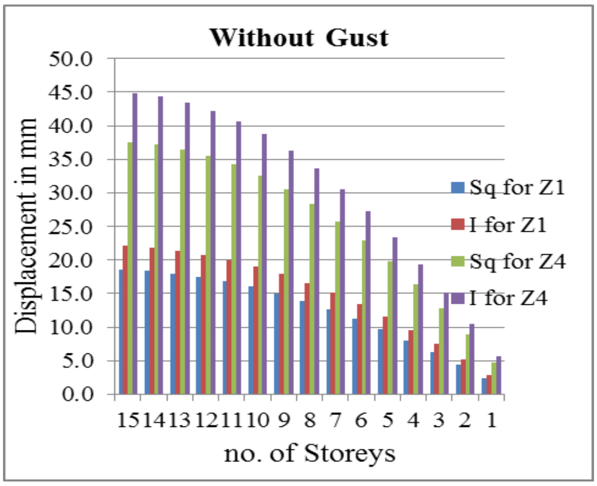

Fig 7: displacement when wind load in X-direction
For zone-I & zone-IV without gust

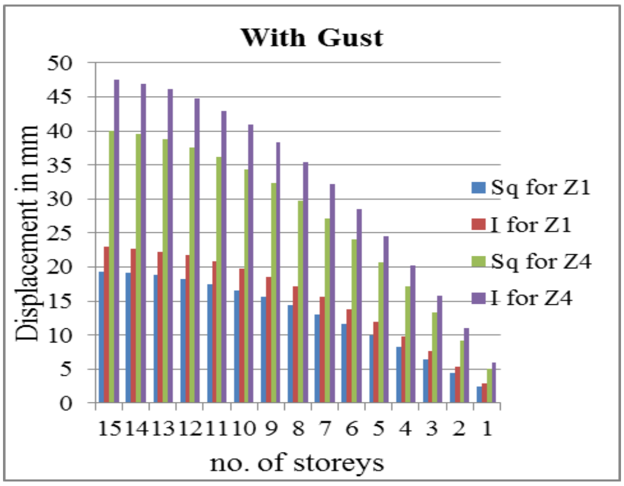

Fig 10: displacement when wind load in X-direction
For zone-I & zone-IV With gust

Table: 7. Drift for Square & I shape

no of Storey	square shape								I shape							
	Without Gust factor				With Gust factor				Without Gust factor				With Gust factor			
	ZONE 1		ZONE IV		ZONE 1		ZONE IV		ZONE 1		ZONE IV		ZONE 1		ZONE IV	
	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy	Ux	Uy
15	0.067	0.072	0.136	0.145	0.072	0.077	0.149	0.159	0.081	0.121	0.165	0.246	0.088	0.13	0.181	0.268
14	0.114	0.127	0.23	0.258	0.122	0.137	0.253	0.284	0.137	0.187	0.277	0.379	0.147	0.201	0.304	0.415
13	0.167	0.189	0.338	0.383	0.179	0.203	0.37	0.42	0.199	0.26	0.405	0.528	0.214	0.279	0.443	0.576
12	0.220	0.251	0.446	0.508	0.235	0.268	0.485	0.554	0.262	0.333	0.532	0.676	0.281	0.356	0.58	0.735
11	0.272	0.311	0.552	0.631	0.289	0.331	0.598	0.684	0.325	0.405	0.659	0.821	0.345	0.43	0.714	0.889
10	0.323	0.371	0.656	0.752	0.342	0.392	0.708	0.811	0.386	0.475	0.782	0.963	0.408	0.503	0.844	1.039
9	0.373	0.428	0.757	0.869	0.394	0.452	0.815	0.935	0.445	0.543	0.902	1.101	0.47	0.573	0.971	1.184
8	0.422	0.484	0.856	0.983	0.444	0.51	0.917	1.054	0.502	0.608	1.019	1.233	0.528	0.64	1.092	1.322
7	0.468	0.538	0.95	1.092	0.491	0.565	1.015	1.167	0.557	0.67	1.131	1.359	0.585	0.703	1.208	1.453
6	0.513	0.59	1.04	1.197	0.536	0.617	1.109	1.276	0.61	0.729	1.238	1.48	0.638	0.763	1.319	1.577
5	0.555	0.639	1.127	1.297	0.579	0.666	1.195	1.376	0.66	0.785	1.34	1.593	0.688	0.818	1.421	1.69
4	0.596	0.686	1.208	1.392	0.617	0.711	1.275	1.469	0.708	0.837	1.436	1.699	0.733	0.868	1.515	1.793
3	0.633	0.732	1.285	1.484	0.652	0.753	1.347	1.556	0.752	0.887	1.526	1.799	0.775	0.913	1.6	1.887
2	0.671	0.789	1.36	1.6	0.686	0.807	1.418	1.667	0.796	0.947	1.615	1.92	0.815	0.969	1.683	2.001
1	0.594	0.796	1.204	1.615	0.605	0.762	1.249	1.674	0.702	0.91	1.424	1.845	0.715	0.927	1.477	1.914

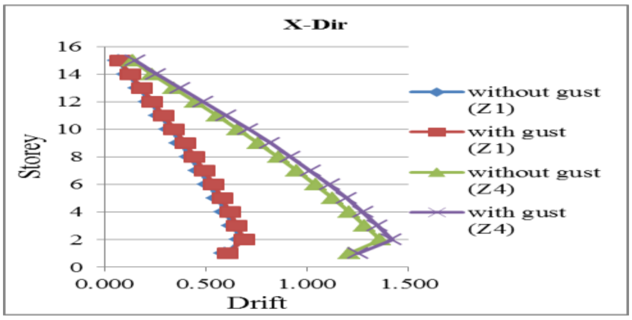

Fig 11: Square shape drift when wind load in X-direction for zone-I and zone-IV

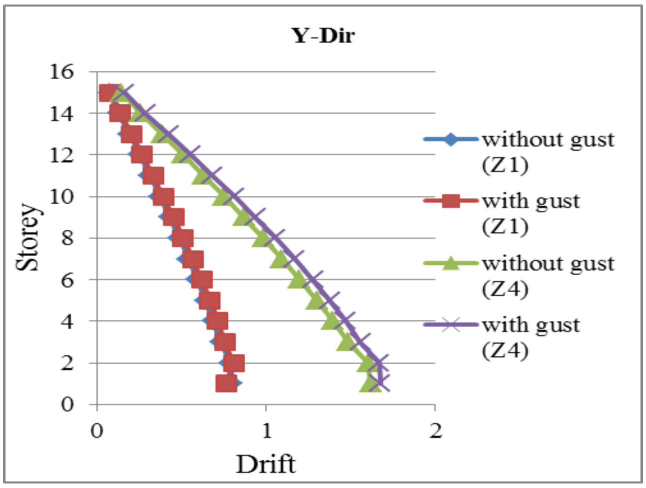

Fig 12: Square shape drift when wind load in Y direction for zone-I and zone-IV

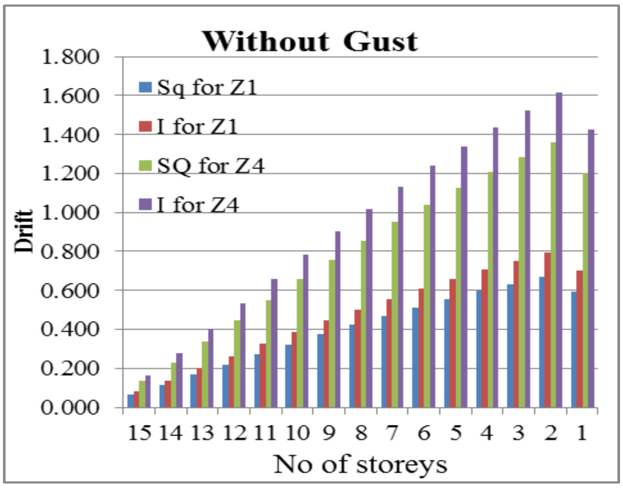

Fig 15: drift when wind load in X-direction for zone-I & Zone-IV without gust

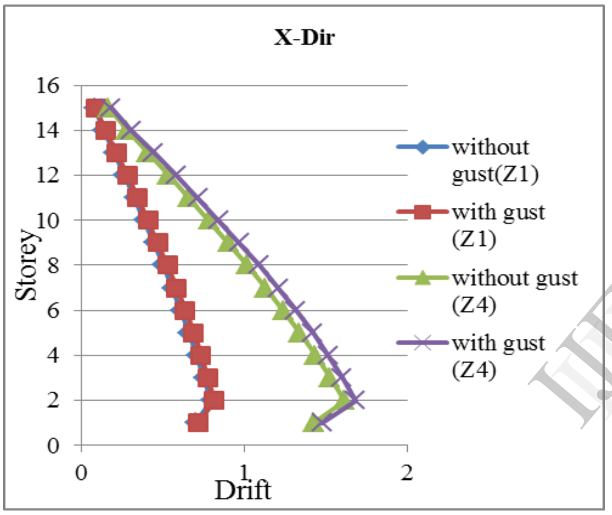

Fig 13: I shape drift when wind load in X-direction for zone-I and zone-IV

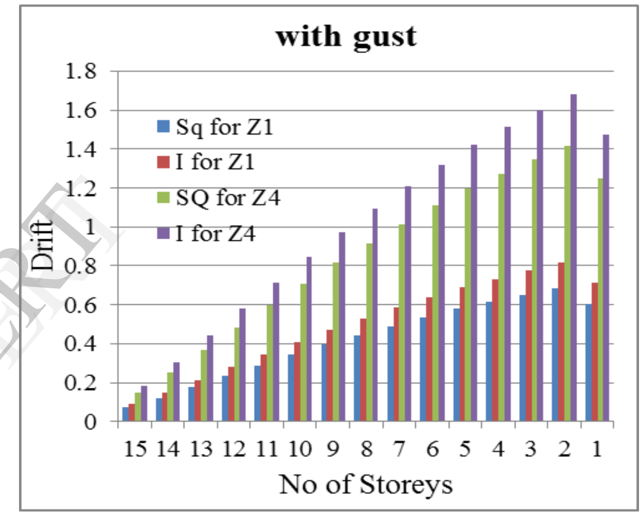

Fig 16: drift when wind load in X-direction for zone-I & Zone-IV with gust

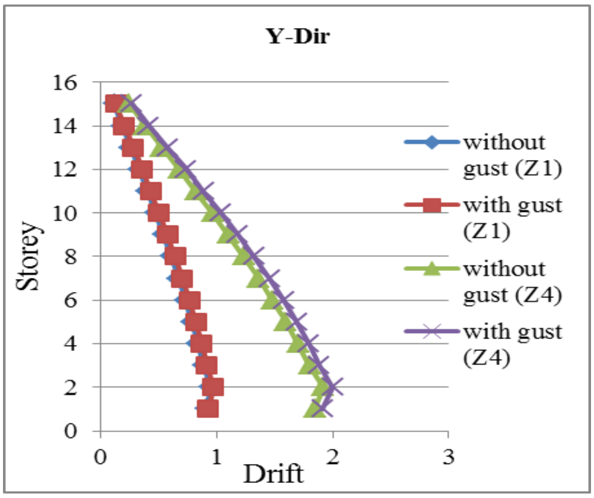

Fig 14: I shape drift when wind load in Y direction for Zone-I and zone-IV

CONCLUSIONS

- The story displacement is maximum at the top story and becomes zero at bottom story. As the story increases then the displacement also increases for zone-1 and zone-4 with and without gust factor.
- If the wind zone is increases then the story displacement also increases for different shape buildings.
- The story displacements in regular structures with and without gust factor in zone-1 and zone-4 is lesser when compare to the displacements in irregular structures.
- The story drift is gradually increases from first story to second story and it is maximum at

second story in both X and Y-directions and it becomes decreases to top story for different shapes in zone-1 and zone-4 with and without gust factor.

- When the wind zone is increases then the story drift also increases for different shapes. And the story drift in irregular shape structures with and without gust factor in zone-1 and zone-4 is maximum when compared to regular shape structures.

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