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SEISMIC ANALYSIS OF RCC CHIMNEY AND ITS INTERACTION CHARTS

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Abstract — ***Most of the industrial RCC chimneys are tall structures with circular cross-sections. Industrial Chimneys are generally intended to support critical loads produced by seismic activity and Wind. So it is essential to evaluate the dynamic response of chimney to seismic activity & response to Earthquake is more critical as chimney is a slender structure. In the design of tall chimneys, estimation of exact earthquake is very difficult. Empirical as well as analytical approach proposed by different researchers for the estimation of earthquake response of a chimney doesn't give satisfactory results. Parametric study on chimney from height 150m & 200m.Our aim is to predict earthquake response of tall chimneys of different height and diameter with analytical approach taken as per IS 4998-1992 (PART I) and compare with corresponding experimental values. Interaction charts due to loads, soil and location will be prepared.***

Keywords- R.C.C chimney; seismic analysis; interaction charts; earthquake load; self-supported chimney

I. INTRODUCTION

Man has always been in search of an effective system to dispose off undesirable gaseous products of combustion which leads to the emergence of chimneys. Chimneys, as we all know today, are hollow, tall and slender vertical structures that carry smoke or steam away from a fire or engine at a high enough elevation to furnish adequate draft and to discharge the products of combustion without causing local air pollution. Romans used tubes inside the walls to draw smoke out of bakeries but real chimneys appeared only in northern Europe in the 12th century. Industrial chimneys became common in the late 18th century. DAHANU thermal power station, operated by reliance energy ltd. Near Mumbai has tallest Indian chimney. It is made by RCC. It's height is about 275.3 m or 903 ft. it is constructed in 1995.Construction of such tall chimneys need the better understanding of loads acting on them and of the of the structural behaviour, so that with the help of modern construction equipment and techniques such as slip form, reinforced concrete, the best material for chimney construction could be used efficiently. Steel ideally suited for height up to 45m, so need of RCC chimney arise.

Chimneys with height exceeding 150 m are considered as tall chimneys. However it is not only a matter of height but also the aspect ratio when it comes to classifying a chimney as tall. Today, Reinforced Concrete is the dominant material used for the construction of tall chimneys and for short chimneys precast concrete with or without pre stressing, Modern industrial chimneys consists of a concrete windshield with a number of steel stacks on the inside. RCC can take tension as well as compression, so the tall chimneys are now possible. Also we can reduce diameter and thickness of chimneys. Now tapered chimneys are also possible. Tapered chimney can save the construction material and hence save the cost.

II. OBJECTIVES

The main objectives of this papers is to get comparative study of seismic analysis of RCC chimney on varying height for 150m & 200m at an interval of 15m and 20m respectively. To predict the along seismic response of tall RCC chimneys of different height, zones and soil conditions subjected to dynamic loads. To calculate the earthquake loads, shear forces and bending moments at different locations in the chimney. To the show the interaction chart for the chimney of 150m and 200m in different zones.

III. ANALYSIS OF RCC CHIMNEY

CASE-I Considering 150m RCC chimney located in Bhuj, zone-V

A. Description of a Structure:-

1. Height of chimney = 150m, 2. Outer diameter at bottom = 12.5m, 3. Outer diameter at top = 5m, 4. Thickness of shell at bottom = 0.40m, 5. Thickness of shell at top = 0.25m, 6. Grade of concrete = M30, 7. Seismic Zone = V, 8. Basic wind speed = 50 m/sec, 9. Foundation type = RCC circular mat, 10. Type of soil = sandy soil, 11. Thickness of lining = 0.12m, 12. Inside temperature of chimney = 70 degree.

Table-1. Calculation of geometric parameter on chimney

Height	X	D	t	d = (D-2t)	Base area	Section Modulus	Exposed Area	Cumulative Area
150	10	5	0.25	4.5	3.73	4.21	80.625	-
135	9	5.75	0.265	5.22	4.56	5.98	91.875	0
120	8	6.5	0.28	5.94	5.47	8.14	103.125	172.5
105	7	7.25	0.295	6.66	6.44	10.75	114.375	275.625
90	6	8	0.31	7.38	7.49	13.84	125.625	390
75	5	8.75	0.325	8.1	8.60	17.44	136.875	515.625
60	4	9.5	0.34	8.82	9.78	21.60	148.125	652.5
45	3	10.25	0.355	9.54	11.03	26.34	159.375	800.625
30	2	11	0.37	10.26	12.35	31.71	170.625	960
15	1	11.75	0.385	10.98	13.74	37.75	181.875	1130.625
0	0	12.5	0.4	11.7	15.20	44.49	93.75	1312.5
-	-	-	-	-	-	-	-	1406.25

Table-2. Calculate total cumulative weight

Height	Weight (Insulation + Concrete)	Concrete Volume	Weight of Steel	Cumulative Total Weight
150	-	-	-	-
135	1581.69	62.20	146.16	1727.85
120	1911.99	75.25	176.83	3816.67
105	2268.25	89.33	209.93	6294.85
90	2650.47	104.46	245.48	9190.80
75	3058.66	120.62	283.47	12532.93
60	3492.81	137.83	323.89	16349.64
45	3952.93	156.07	366.76	20669.32
30	4439.01	175.35	412.07	25520.40
15	4951.05	195.67	459.82	30931.27
0	5489.06	217.03	510.01	36930.34

Table 3. Calculation for allowable stresses and moment

Height	Total Weight	Area	Z	W/A	M	M/Z	Max.=W/A+M/Z	Mini. =W/A-M/Z
(m)	(KN)	(m^2)	(m^3)	(KN/m^2)	(KN-m)	(KN/m^2)	(N/mm^2)	(N/mm^2)
150	-	3.73	4.21	-	-	-	-	-
135	1727.85	4.56	5.98	416.71	411.90	80.85	0.50	0.34
120	3816.67	5.47	8.14	760.85	1266.06	179.33	0.94	0.58
105	6294.85	6.44	10.75	1056.98	2581.67	273.26	1.33	0.78
90	9190.80	7.49	13.84	1319.77	4369.22	355.37	1.68	0.96
75	12532.93	8.60	17.44	1558.52	6623.63	423.53	1.98	1.13
60	16349.64	9.78	21.60	1779.37	9327.69	477.91	2.26	1.30
45	20669.32	11.03	26.34	1986.56	12458.98	519.82	2.51	1.47
30	25520.40	12.35	31.71	2183.11	15981.54	550.57	2.73	1.63
15	30931.27	13.74	37.75	2371.20	19845.33	571.36	2.94	1.80
0	36930.34	15.20	44.49	2552.49	23983.70	583.22	3.14	1.97

B. Earthquake Analysis:-

- The earthquake loads are obtained as per IS 1893 (Part-1) 2002. The fundamental time period for stack-like structures, is given by : $\mathbf{T=C_T\sqrt{\frac{Wt.h}{Es.A.g}}}$

Where, C_T=Coefficient depending upon the slenderness ratio of structure,

W_t=Total weight of structure including weight of lining & contents above the base
h= Height of structure above the base
Es= Modulus of elasticity of material of the shell
A= Area of cross-section at the base of the structural shell
g= Acceleration due to gravity

Radius of gyration= $\sqrt{\frac{\mathbf{MIbase}}{\mathbf{Abase}}}$

Slenderness ratio=$\mathbf{h/r_e}$

C_T=14.4 (from table-6 of IS-1893-4-2005)

T=0.640 Sec

- From IS 1893- 2002 (Part-1): Horizontal Seismic Force: $\mathbf{A_h} = \frac{\left[\frac{Z}{2}\right]\left[\frac{Sa}{g}\right]}{\frac{R}{I}}$

Where,

Z=Zone factor given,
I= Importance factor for RCC chimney
R= Response reduction factor, for RCC chimney
S_a/g=Spectral acceleration coefficient for sand soil sites
For sandy soil, S_a/g =2.08

A_h =0.19

- Design Shear Force & Moment: by Equilateral Static Lateral Force method,

$\mathbf{V=C_v.\ A_h.\ W_t.\ D_v}$
$\mathbf{M=A_h.\ W_t.\ h.\ D_m}$

Where,

Cv = Coefficient of shear force depending on slenderness ratio, k =1.02
h = Height of center of gravity of structure above base

Table 4. Calculation of Shear Force & Moment

Height (m)	H (m)	X (Distance From Top) (m)	Dv	Dm	Weight (KN)	V=Cv*Dv*Ah*Wt (KN)	M=H*Dm*Wt*Ah (N/mm^2)
150	150	0	0	0	36930.34	0	0
135	150	15	0.423	0.127	36930.34	1094.64	36453.88
120	150	30	0.643	0.180	36930.34	1621.87	51805.67
105	150	45	0.835	0.224	36930.34	2069.96	64510.00
90	150	60	1.019	0.268	36930.34	2428.13	77297.75
75	150	105	1.661	0.479	36930.34	3825.74	137899.62
60	150	90	1.419	0.388	36930.34	3137.26	111650.36
45	150	105	1.661	0.479	36930.34	3674.01	137899.62
30	150	120	1.953	0.604	36930.34	4105.52	173851.06
15	150	135	2.309	0.773	36930.34	4522.92	222706.17
0	150	150	2.750	1.000	36930.34	5386.66	288056.62

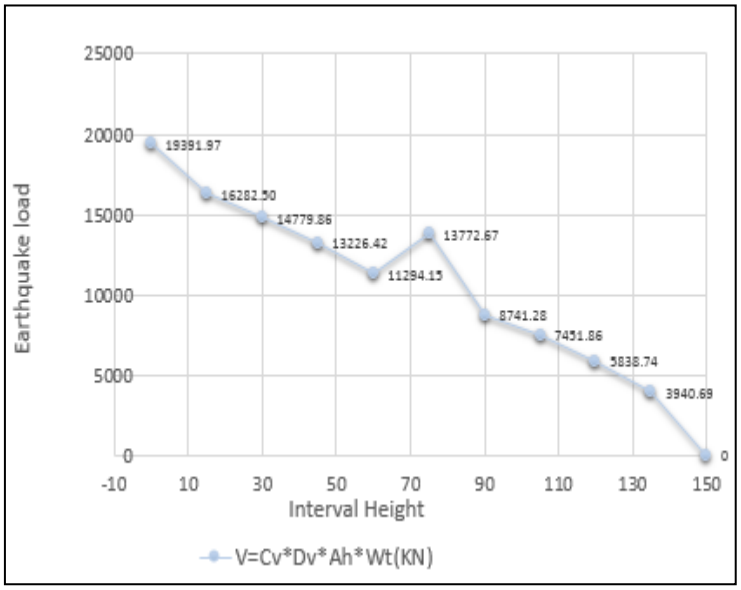

Figure 1. Behaviour of RCC chimney corresponding to earthquake load in zone v

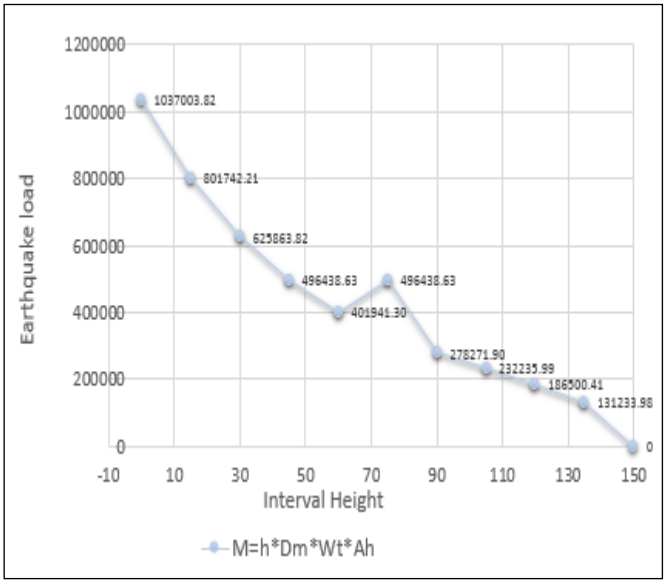

Figure 2. Behaviour of RCC chimney corresponding to moment in zone v

Figure 1 and 2 shows the graph of the Earthquake load v/s Interval height and moment v/s Interval height respectively, which shows the behaviour of RCC chimney corresponding to earthquake load and moment for the RCC chimney located at Bhuj in zone v. Similarly, the interaction chart for the behaviour of RCC chimney corresponding to earthquake load and moment for the RCC chimney located in different zones is shown in **figure 3 and 4**, respectively.

Table 5. Calculation of Earthquake load in different zones in KN

Location of RCC chimney	Bhuj	Ludhiana	Mumbai	Aurangabad	Vishakhapatnam
Height	Zone 5	Zone 4	Zone 3	Zone 2-A	Zone 2-V
150	0	0	0	0	0
135	3940.686955	3157.601727	2105.067818	1094.635265	1315.667386
120	5838.741659	4678.478893	3118.985929	1621.872683	1949.366205
105	7451.856325	5971.038722	3980.692481	2069.96009	2487.932801
90	8741.280492	7004.231163	4669.487442	2428.13347	2918.429651
75	13772.66514	11035.78938	7357.192919	3825.740318	4598.245574
60	11294.1492	9049.799038	6033.199358	3137.263666	3770.749599
45	13226.42488	10598.09686	7065.397905	3674.006911	4415.873691
30	14779.86362	11842.83944	7895.226292	4105.517672	4934.516433
15	16282.49794	13046.87335	8697.915564	4522.916093	5436.197227
0	19391.97145	15538.43866	10358.95911	5386.658736	6474.349442

Table 6. Calculation of Moment in different zones in KN-m

Location of RCC chimney	Bhuj	Ludhiana	Mumbai	Aurangabad	Vishakhapatnam
Height	Zone 5	Zone 4	Zone 3	Zone 2-A	Zone 2-V
150	0	0	0	0	0
135	131233.9809	105155.4334	70103.62226	36453.88358	43814.76391

120	186500.4066	149439.4283	99626.28556	51805.66849	62266.42848
105	232235.9925	186086.5325	124057.6883	64509.99792	77536.0552
90	278271.9	222974.2788	148649.5192	77297.74999	92905.94951
75	496438.6281	397787.3623	265191.5749	137899.6189	165744.7343
60	401941.2993	322068.3488	214712.2326	111650.3609	134195.1453
45	496438.6281	397787.3623	265191.5749	137899.6189	165744.7343
30	625863.8248	501493.4494	334328.9662	173851.0624	208955.6039
15	801742.206	642421.6395	428281.093	222706.1683	267675.6831
0	1037003.821	830932.5487	553955.0325	288056.6169	346221.8953

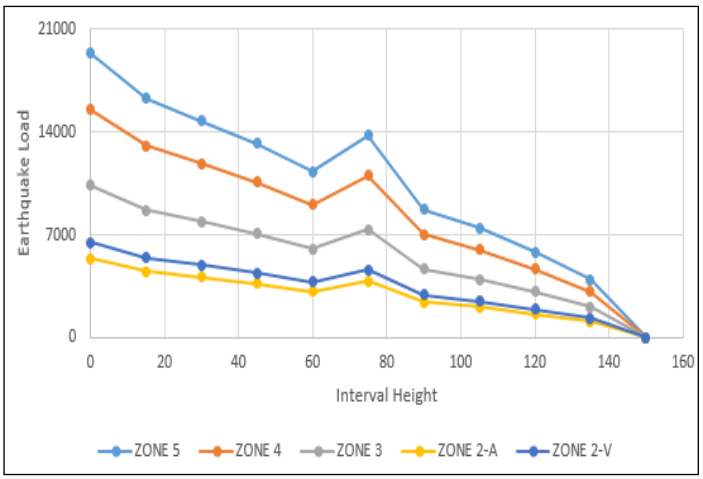

Figure 3. Interaction chart of Earthquake Load for the RCC chimney located in different zones

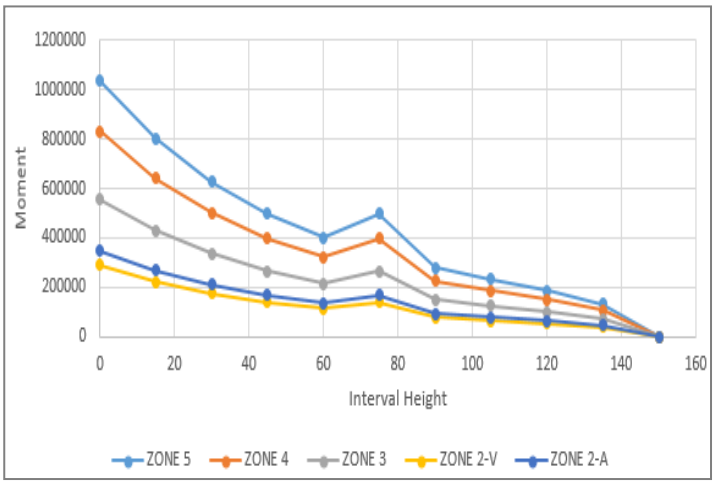

Figure 4. Interaction chart of Moment for the RCC chimney located in different zones

CASE-II Considering 200m RCC chimney located in Bhuj, zone-V

A. Description of a Structure:-

1. Height of chimney = 200m, 2. Outer diameter at bottom = 16m, 3. Outer diameter at top = 6m, 4. Thickness of shell at bottom = 0.45m, 5. Thickness of shell at top = 0.3m, 6. Grade of concrete = M30, 7. Seismic Zone = V, 8. Basic wind speed = 50 m/sec, 9. Foundation type = RCC circular mat, 10. Type of soil = sandy soil, 11. Thickness of lining = 0.12m, 12. Inside temperature of chimney = 70 degree.

The interaction chart for the behaviour of RCC chimney corresponding to earthquake load and moment for the RCC chimney located in different zones is shown in **figure 5 and 6**, respectively. The shear force calculation and the moment calculation for the 200m chimney is shown in **table 7 and 8**, respectively.

Table 7. Calculation of Earthquake load in different zones in KN

Location of RCC chimney	**Bhuj**	**Ludhiana**	**Mumbai**	**Aurangabad**	**Vishakhapatnam**
Height	**Zone 5**	**Zone 4**	**Zone 3**	**Zone 2-A**	**Zone 2-V**
200	0	0	0	0	0
180	7824.102919	5215.319214	3476.879476	2173.049673	2417.069038
160	11582.2531	7721.502068	5147.668045	3217.292528	3598.702648
140	14750.71128	9833.807517	6555.871678	4097.419799	4550.81227
120	17331.51769	11554.34513	7702.896753	4814.310471	5404.887519
100	19851.86395	13234.57597	8823.050646	5514.406654	8583.804371

80	22362.805	14908.53667	9939.024444	6211.890278	7026.075193
60	26188.7775	17459.185	11639.45667	7274.660416	8228.141323
40	29276.03955	19517.3597	13011.57313	8132.233209	9195.175727
20	32065.3869	21376.9246	14251.28307	8907.051917	10503.59896
0	38188.92345	25459.2823	16972.85487	10608.03429	12509.4744

Table 8. Calculation of Moment in different zones in KN-m

Location of RCC chimney	**Bhuj**	**Ludhiana**	**Mumbai**	**Aurangabad**	**Vishakhapatnam**
Height	**Zone 5**	**Zone 4**	**Zone 3**	**Zone 2-A**	**Zone 2-V**
200	0	0	0	0	0
180	344588.2721	229725.5147	153150.3431	95718.96446	112876.1373
160	489704.3617	326469.5745	217646.383	136028.9894	160411.5441
140	609794.8019	406529.868	271019.912	169387.445	199749.3455
120	730673.8128	487115.8752	324743.9168	202964.948	239345.4576
100	872266.9038	581511.2692	387674.1795	242296.3622	426993.6368
80	1055399.348	703599.5652	469066.3768	293166.4855	345715.1951
60	1303526.174	869017.4497	579344.9664	362090.604	426993.6368
40	1643365.023	1095576.682	730384.4545	456490.284	538314.0142
20	2105178.549	1403452.366	935634.9106	584771.8191	689589.4094
0	2722917.893	1815278.596	1210185.73	756366.0815	891941.1338

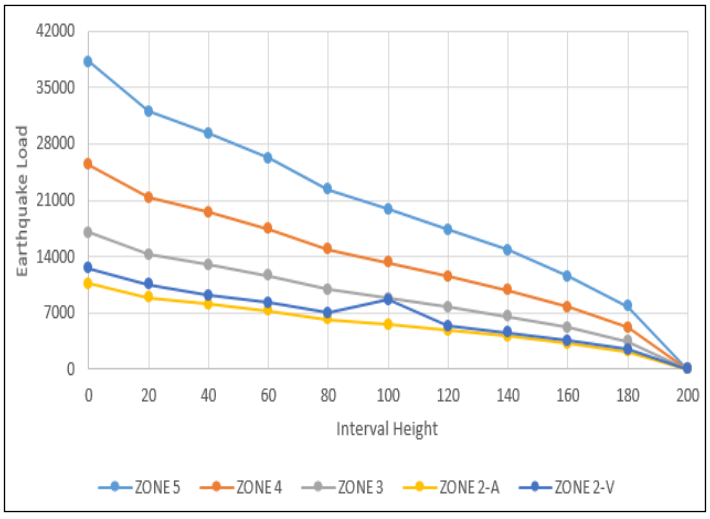

Figure 5. Interaction chart of Earthquake Load for the RCC chimney located in different zones

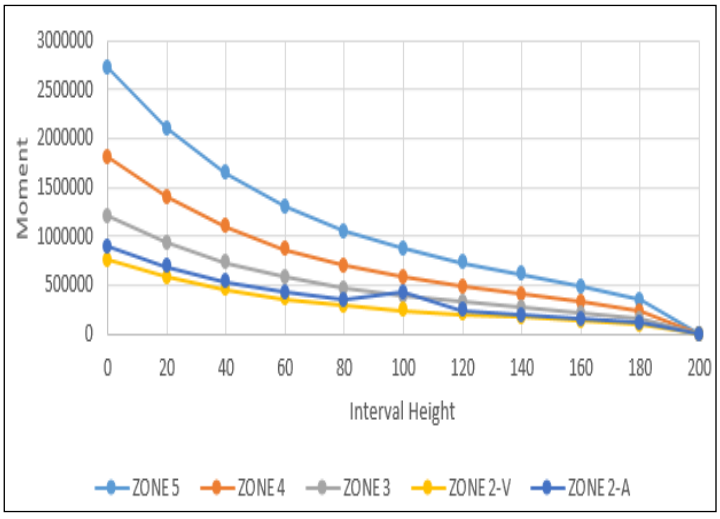

Figure 6. Interaction chart of Moment for the RCC chimney located in different zones

IV. CONCLUSION

If the aspect ratio of chimney is greater than 28 than the design of chimney is to be checked for higher modes of oscillation. The minimum grade of concrete to be used for chimney should be greater than M25 since lower grades fail in permissible stresses. Temperature is also a design criteria especially near the top of chimney where the stresses induced by moment due to wind & self-weight is minimum the temperature stresses predominates.

V. FUTURE SCOPE

The wind analysis of RCC chimney can also be done, considering different zones. The comparison of wind load and earthquake load can be done to find the critical load and this critical load shall be considered for design. The interaction charts for the wind load can be prepared. Design of RCC chimney considering this analysis can be done. All these process can be done on RCC chimney with different height and different zones considering its location.

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