Interrelation of Dynamic Response and Geometry of Short Steel Chimneys

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Abstract- ***Steel stacks are smoke releasing slender structures constructed in various industries. They are subjected to static and dynamic loadings. Dynamic analysis is carried out by considering both seismic loading and dynamic wind loadings. Apparently dynamic wind effects are critical for steel stacks and they govern the stability conditions. Steel stacks being slender and long sections they are more prone to dynamic wind oscillations and corresponding stresses. Present study deals with interrelation of geometrical configuration and obtained dynamic response of short self-supported steel stacks under dynamic wind loadings and seismic loadings. 42 steel stack configurations for 7 different heights of stacks are selected and analyzed for dynamic wind loadings and seismic loadings as per Indian standards (IS:6533 part2)and IS 1893(part 4). a relation between dynamic response and governing geometry of the stack is found out. Use of excel sheets and STAAD-proV8i software is done for analysis.***

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Key words: steel stacks,steel chimneys ,dynamic analysis ,wind oscillations of chimneys

INTRODUCTION

Stacks or chimneys are very important industrial structures for releasing out waste harmful gases to a higher elevation in atmosphere. Stack structures are tall, slender and tapering with circular cross-sections. Steel stacks are ideally suited for works involving short heating period and less thermal capacity. Fig. 1.1 shows chimneys located in an industrial campus.

1.1 forces acting on steel stacks

Steel chimneys or stacks are basically under the influence of following loads

1. Static load
2. Dynamic wind load
3. Seismic loads

Static loads include self-weight and weight of lining and other components of stacks. (Ref.IS 6533(part1):1989)It also includes static wind loads and corresponding static wind pressures. (Ref. IS 875(part3):1987).Dynamic wind effects include along wind and across wind effects .this includes the drag forces and the vortex excitation along with aerodynamic forces acting on stack causing stacks to oscillate(ref.IS 6533(part2):1989).

1.2 Geometry of steel stacks

Geometry of a stack or a chimney plays an important role in the process of analysis as it affects the stiffness parameters. (Ref. IS 6533:1989 part2). Basic geometry of steel stack is governed by top diameter (D_t), base diameter (D_b) and effective height of stack (H_e). Following IS codes are used for the analysis of steel stack.

1. IS 6533 (Part-1): 1989 “Indian standard design and construction of steel stacks-code of practice - Mechanical aspects.”

2. IS 6533 (Part-2): 1989 “Indian Standard Code of practice for design and construction of steel chimneys "structural aspects.

3. IS 875 (Part-3):1987: For calculation of wind loads

4. IS 1893 (Part-4):2005: This code covers the seismic considerations to be followed for the design .Seismic zones and formulae based on design considerations will be included from this code.

LITERATURE REVIEW

Ciesielski, *et. al.* (1996) observed cross vibration on a steel chimney arising out of aerodynamic phenomenon. This paper shows that specially designed turbulizers, mechanical dampers can reduce this cross vibrations considerably

Kawecki and Zuranski (2007) measured the damping properties of the steel chimney due to cross-wind vibrations and also compared different approaches to the calculation of relative amplitude of vibration at small scruton number. They also gave importance to climatic considerations.

Chmielewski, *et. al.* (2005) studied about natural frequencies and natural modes of 250 m RC chimney with the flexibility of soil. This paper shows use of finite element method for analysis along with the experimental work to investigate the free vibration

Wilson (2003) conducted experimental program to show the earthquake response of tall reinforced concrete chimney. A non-linear dynamic analysis procedure is developed to evaluate the inelastic response of tall concrete chimney subjected to earthquake excitation. Based on experiments, the results encourage reliance on the development of ductility in reinforced concrete chimneys to prevent the formation of brittle failure modes.

Menon and Rao (1997) reviews the procedures to evaluate the across wind response of RC chimneys. Reliability approach is used to ascertain disparities in the design. It is recommended that it is necessary to design for the across wind loading for certain conditions.

FORMULATION OF RESEARCH PROBLEM

Description of selected steel stacks/chimneys

1. Type of stack = circular self-supporting industrial steel stacks
2. Heights of stacks: 30 m ,35m,40m,45m ,50m ,55m,60 m (short stacks)
3. Top diameter for each stack is taken as minimum h/30 as per provision in IS 6533 :1989
4. Variation in base diameter for each stack for fixed value of top diameter will be in following incremental ratios (ratio D_b/D_t) : 1.6,1.7,1.8,1.9,2.0,2.1
5. Type: unlined single flume.
6. Temperature inside chimney : 200^0c average
7. Flare height: one third of total height.
8. Thickness of stack shell= 16 mm (constant for all stacks)
9. Base : rigid
10. location :Mumbai
11. wind speed : 44m/s
12. material :Mild steel
13. variation in geometry : top to base diameter ratio in each configuration
14. soil :medium (bearing capacity 200kN/m^2)
15. seismic zone :III
16. damping :5%

IS Codal provisions for geometry are the basis of variations in the geometry. Minimum top diameter of unlined chimney should be one twentieth of the effective height of chimney /stacks and minimum outside diameter at the base should be equal to 1.6 times the top diameter of the stack. (As per IS 6533(part2):1989 (reaffirmed in 2003) cl.7.2.4 (b) and (c).)Manual calculations are done for validating the results of STAAD-pro v8i software results. Dynamic wind responses are calculated using MS-excel sheets and seismic responses are calculated by STAAD-pro v8i.

Table 1 geometry of selected steel stacks

Total height of stack (Metres) (H)	Effective height (2/3× H) (Metres)	Top diameter (constant) (H/30)	Varying top to bottom diameters From minimum 1.6 and then incr up to 2.1 Dt/ D_b rati			
			1.6	1.7	1.8	1.9
H	**H_e**	**D_t (m)**	**D_b** (m)	**D_b** (m)	**D_b** (m)	**D_b** (m)
30	20	**1**	1.6	1.7	1.8	1.9
35	23.33	**1.16**	1.856	1.972	2.088	2.204
40	26.66	**1.33**	2.128	2.261	2.394	2.527
45	29.97	**1.5**	2.4	2.55	2.7	2.85
50	33.33	**1.66**	2.656	2.822	2.988	3.154
55	36.3	**1.83**	2.928	3.111	3.294	3.477
60	40	**2.00**	3.2	3.4	3.6	3.8

METHODOLGY

1.IS:6533 (Part-1 & 2): 1989, IS 875 (Part-3 & 4): 1987, and IS 1893 (Part-4):2005 are used as for analysis and design, which gives detailed procedure to determine static, dynamic and seismic loads coming on the structure.

2. Detailed procedure for analysis and design of mechanical and structural aspect is implemented in calculations.

3. A sample calculation of a single steel stack for static and dynamic analysis and design along with seismic analysis will be manually carried out for all parameters.

4. Use of computer aided software as STAAD-pro v8i and MS-EXCEL sheets are done for analysis of all steel stacks.

Dynamic wind sample calculations (as per IS 6533 (part2):1989)

Dynamic wind response includes dynamic force, dynamic moment and corresponding deflections

Calculations are done by using excel sheets .total 18 excel sheets are prepared for iterative calculations. Sample calculation results for 30m chimney are shown in short below.

Table 2 Sample Calculation for 30 M Chimney with 1m Top Diameter and 1.6m Base Diameter

Cumm. Ht	P_{static}	Time Period	Ƹi	€i from table 5 IS 6533 p.2	Mk	V
	(N)	**(Sec)**		**Unlined**		
5	5938.3	0.685	0.025	2.502	0.6	0.7
10	4709.7	0.685	0.025	2.502	0.6	0.7
15	4672.9	0.685	0.025	2.502	0.575	0.7

20	5079.0	0.685	0.025	2.502	0.55	0.7
25	5341.5	0.685	0.025	2.502	0.5325	0.7
30	5610.5	0.685	0.025	2.502	0.515	0.7

Segmental Ht.	**Yik & Yij**	**M_k & M_j**	**Hij**	**P_{dyn}**	**P_k (Kn)**
	staad	**kg**		**Newton**	
5	0.0223	2884	0.045	2.28	5.94
10	0.1037	2280.6	0.2089	8.37	4.72
15	0.265	1979	0.5339	18.565	4.69
20	0.4859	1979	0.9789	34.037	5.11
25	0.7377	1979	1.486	51.673	5.39
30	1.0	1979	2.0145	70.049	5.68

3.3 Seismic Response sample Calculations (for 30 m chimney)(IS 1893 (part4):1989)

Seismic Zone = Zone III, Zone Factor (Z) = 0.16

Importance Factor (I) = 1.5

Response Reduction Factor (R) = 2.0

Fundamental Time Period (T) = $C_T\sqrt{\frac{Wt.h}{Es.A.g}}$ = 0.665s

Fundamental Time Period for Flared Structure (Te) = T/2 = 0.3325s

Radius of Gyration (r_e) = $\frac{1}{\sqrt{2}}\left(\frac{Db}{2}\right)$ = 0.565m

Base Diameter (Db) = 1.6m

Slenderness ratio (k) = h/ r_e = 53.09

Coefficient (C_T) = 1.8*k = 95.57

Weight of Stack = 254kN (As per STAAD.Pro)

Elastic Modulus of Steel = 200000 MPa

Cross sectional Area at the base of shell (A) = $\pi.Db.Ts$ = 0.08 sq.m

Acceleration due to gravity (g) = 9.81 m/s^2

Design horizontal acceleration spectrum value (Ah) = $\frac{\left(\frac{Z}{2}\right).\left(\frac{Sa}{g}\right)}{\left(\frac{R}{I}\right)}$

= 0.15

Spectral acceleration coefficient (Sa/g) = 2.5 (As per Clause 6.4.5 of IS 1893(Part-1): 2002 for Medium soil)

Design Static Seismic Base Shear (Vb) = Cv. Ah. W. Dv = **57.15kN**

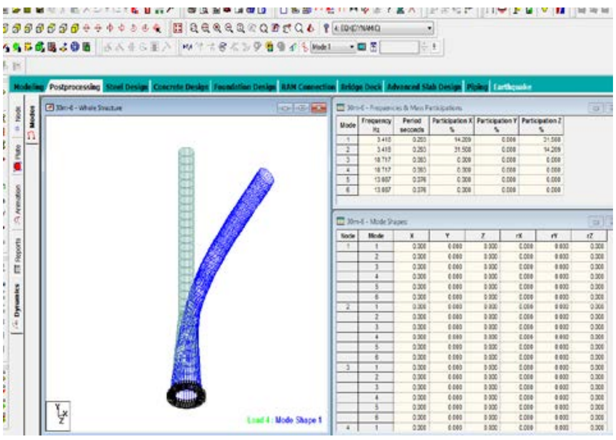


Fig.2 mode shape of steel stack (typical shape)

models of 30 m ,45m and 60 m with 6 variations of top to base diameters are modeled in STAAD-proV8i .for fundamental time period, frequency ,mode shapes ,von mises stresses ,principal stresses bending stresses, base shear and moments using response spectrum method.

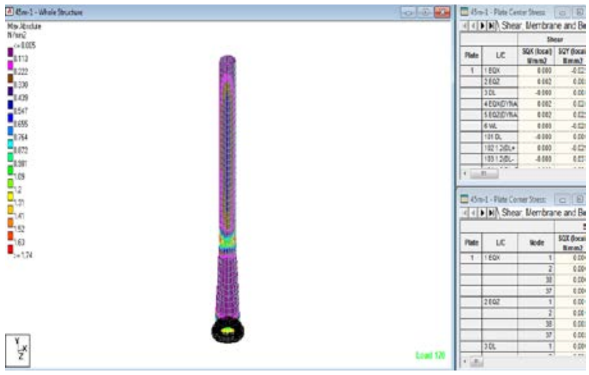


Fig 3 absolute stresses on steel stack 45m

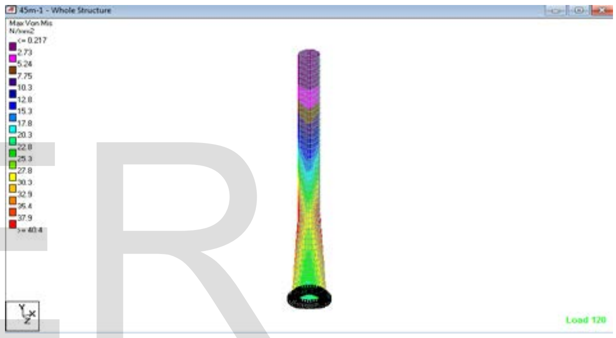


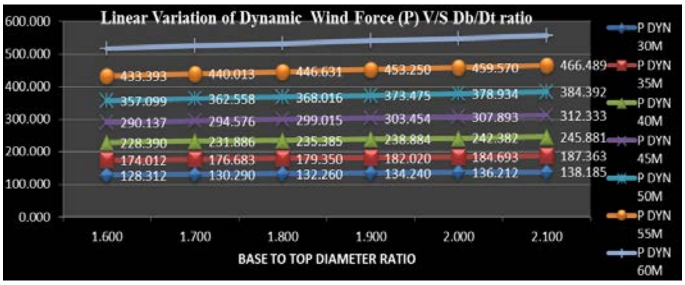
Fig .4 maximum von mises stresses on steel stack 45 m

RESULTS

Table 3: Typical Seismic Response Of Stacks

Height (m)	**Top Dia(m)**	**Bottom Dia(m)**	**Time period (T) (sec.)**	**Frequency(f)**	**SRSS shear(kN)**	**Absolute shear (kN)**
30	**1.000**	1.600	0.3325	3.007	61.65	81.06
		1.700	0.322	3.103	72.83	79.96
		1.800	0.3125	3.192	78.83	78.92
		1.000	0.3054	3.274	77.76	77.93
		2.000	0.2985	3.349	60.58	77.01
		2.100	0.2925	3.418	57.57	76.14
35	**1.160**	1.856	0.376	2.654	103.03	113.83
		1.972	0.3664	2.729	82.33	112.51
		2.088	0.3572	2.799	89.79	111.24
		2.204	0.349	2.865	108.91	110.03
		2.320	0.3417	2.926	78.29	108.88
		2.436	0.3293	3.037	76.02	106.73

REPRESENTATION OF RESULTS



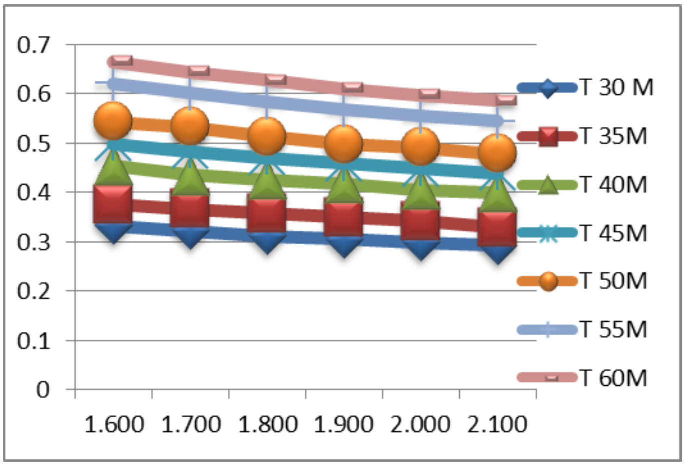


Fig.4 Linear Response of Time Period V/S H/Db Ratio

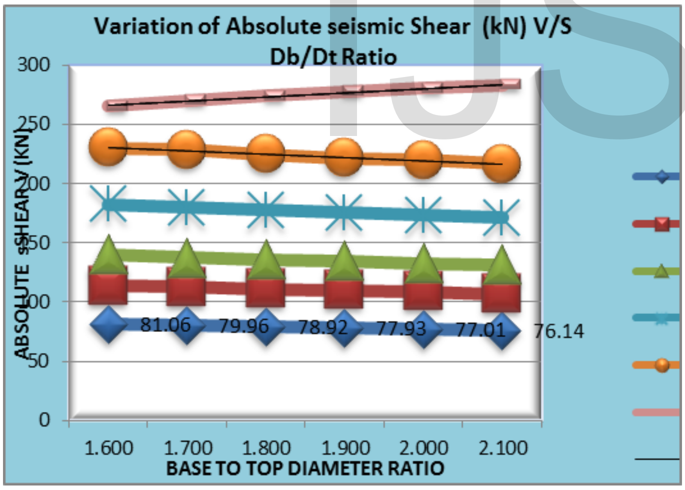


Fig.5 Linear Response of modal frequency and frequency V/S Db/Dt Ratio

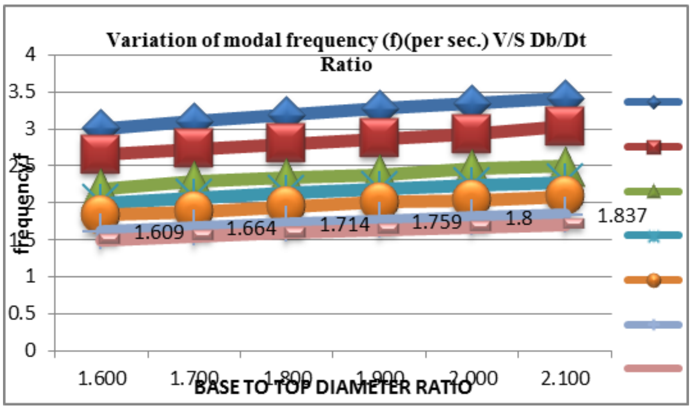


Fig.6 Linear Variation of Modal Frequency With Base To Top Diameter Ratio

CONCLUSIONS

1. From graphical representation it can be proved that for a self-supported steel stack unlined in construction with constant shell thickness the change in geometry is directly proportional to the static and dynamic response of the stack.
2. Dynamic wind response as base moment, base shear, and fundamental modal frequency is linearly increasing as the base diameter increases.
3. Seismic responses such as absolute shear, fundamental time period and corresponding frequency are linear functions of bottom to top diameter ratio and height to base diameter ratio.
4. Between 1.6 ratios of base to top diameter to 2.1 ratios for the same the linear variation in each quantity is nearly 12% increased for frequency.
5. Absolute seismic shear decreases linearly by 5% from minimum to maximum ratio.
6. As the ratio increases the stacks are more prominent for bearing the shear .

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