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Vibration Analysis of Steel Chimney Subjected to Dynamic Wind Load

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Abstract— Stacks or chimneys are very important industrial structures for releasing out waste harmful gases to a higher elevation in atmosphere. Industrial Chimneys are having greater heights and slender structures with circular cross-sections. Steel stacks being slender and long sections they are more prone to dynamic wind oscillations and corresponding stresses. Present study deals with the design of chimney by varying its geometry, diameter and height and obtained dynamic response of self-supported steel chimney under dynamic wind. The project is based on the design concepts of chimneys according to Indian codes provisions and analyse through finite element method. 9 types of steel chimney models are made by varying its height, geometry and diameter. The main objective of this study is to perform vibration analysis of steel chimney for dynamic wind loads. Natural frequency and time period has been found out using analysis in Ansys. All the models are modelled in the Ansys Software.

Keywords—Chimney, dynamic response, natural frequency, slender, wind load.

I. INTRODUCTION

Chimneys are generally vertical structure as far as possible to make sure that the hazardous gases flow easily and quickly by taking air into the combustion. The height of a chimney determines its capability to pass gases to the outside environment via stack effect. Also, the dispersion of hazardous gases at greater heights can minimize their effect on the immediate surroundings. Steel chimneys are classified on the basis of their supports and shape. Based on support they are classified as cable stayed or guyed chimneys and self-supporting chimneys. Self-supporting chimneys are widely used in the industrial areas. Profile of a steel stack can be circular tapering or conical near base and cylindrical up to the top. IS 6533(part2):1989 deals with the circular chimneys that are having conical flare portion up to one third of the effective height of the stack from the bottom and then continued.

A. Geometric parameters of Steel Chimney

IS 6533(Part2):1989 defines the structural aspects for steel chimneys and gives recommendations for basic dimensioning of steel chimneys. The primary geometrical parameters of the steel chimney are associated with the corresponding environmental factors.

1. Clear Diameter of The Stack (D): It is the nominal diameter of the stack for unlined chimneys
2. Height of The Stack (H): It is the total height of the stack from base to top.
3. Top Diameter (D_t): It is the outer diameter of the stack at the top .according to codal provisions this diameter has to be minimum one twentieth of the height of the stack for unlined steel chimneys. This is one the basis of the undertaken work.
4. Base Diameter (D_b): It is the outer diameter at the base of the stack. Minimum dimensions of base diameter should be 1.6 times the dimension of the top diameter. Which means the ratio of base diameter and top diameter should be minimum 1.6

B. Necessity of the work

The undertaken work is important because dynamic analysis of steel chimneys has always been a critically important phenomenon. Steel chimneys are very important structural components in any industry and their analysis and design along with regular maintenance is a crucial factor in the modern industrial age. The main aim to undertake this work is to perform vibration analysis for different critical velocity using Ansys software.

II. PROBLEM STATEMENT

Details of the chimney are as follows,

1. Height of the chimney – 30m
2. Outer diameter of chimney at bottom – 3.2m
3. Outer diameter of chimney at top – 3.2m
4. Thickness of shell at bottom –0.02
5. Thickness of shell at top – 0.02
6. Height to base diameter ratio – 1.6
7. Base diameter to top diameter ratio – 1.6
8. Basic wind speed – 39m/s
9. Terrain category -2
10. Class of structure – c
11. Risk coefficient k1 – 1
12. Topography factor k3– 1

III. MODELLING AND ANALYSIS

Dynamic analysis is done according to IS 6533(Part2):1989 recommendations and responses are calculated for first mode of vibration in terms of:

- Fundamental Time Period
- Frequency
- Lateral Dynamic Wind Force
- Deflection

TABLE I NOMENCLATURE OF MODELED STEEL CHIMNEY

MODEL NO.1	Uniform 30m
MODEL NO.2	Uniform 45m
MODEL NO.3	Uniform 60m
MODEL NO.4	Tapered 30m
MODEL NO.5	Tapered 45m
MODEL NO.6	Tapered 60m
MODEL NO.7	Uniform + Tapered 30m
MODEL NO.8	Uniform + Tapered 45m
MODEL NO.9	Uniform + Tapered 60m

Calculation for Model No.1 – Uniform 30 m Steel Chimney (Terrain Category – 1I)

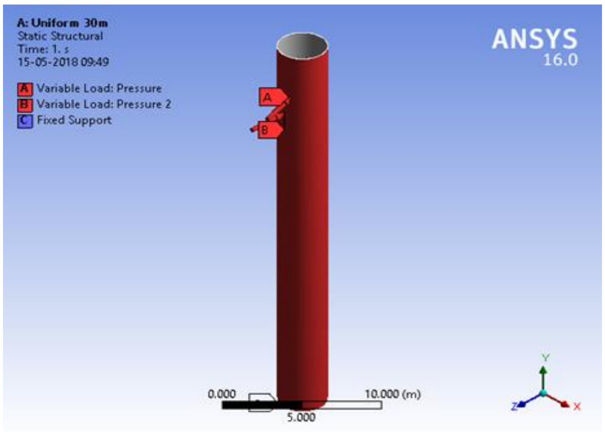

FIG. 1 UNIFORM 30M CHIMNEY

A. Discretization of Model -1 Stack

Steel stack is divided into suitable number of zones. (6 Zones of each 5m). All the calculations of dynamic wind loadings are depending upon individual calculations for each zone/segment and integrating the results of each zone as per the recommended method in Clause 8.2 and 8.3 of IS 6533(Part2):1989

B. Self-Weight Calculations for Segment 1 (0 to 5 m) of Model-1

Height considered (h) = 5.0m

Mean Outer Diameter (D) = 3.2 m

Mean Inner Diameter (d) = 3.16 m

Cross Sectional Area (A) = = 0.19976 sq.m.

Weight of this part (W) = (78.5kN/cu.m) x 0.19976 x 5 = 78.40 kN

Similarly, Weights of all the segments are computed using excel spreadsheet and summarized as follows:

TABLE II SUMMARY OF WEIGHTS OF ALL SEGMENTS FOR MODEL-1

Height (m)		**Bottom diameter**	**Top Diameter(m)**	**Thickness (mm)**	**Weight Of Part(kN)**
0	5	3.2	3.2	20	78.40
5	10	3.2	3.2	20	78.40
10	15	3.2	3.2	20	78.40
15	20	3.2	3.2	20	78.40
20	25	3.2	3.2	20	78.40
25	30	3.2	3.2	20	78.40

Wind Load Calculation for Segment 1 (0 to 5m) of Model-1

Vz = 1×0.98×1×39 = 38.22 m/s

Pz = 0.7×0.6×38.222 / 1000 = 0.8764 kN/m2

TABLE III DESIGN STATIC WIND PRESSURE AT VARIOUS LEVELS FOR MODEL-1

Height		**K_2**	**Design wind speed(V_z)**	**Bottom Outer Diameter (D_b)**	**Top Outer Diameter (D_t)**	**Design Static Pressure (kN)**
0	5	0.98	38.22	3.2	3.2	15.41
5	10	0.98	38.22	3.2	3.2	15.41
10	15	1.02	39.78	3.2	3.2	16.70
15	20	1.05	40.95	3.2	3.2	17.70
20	25	1.07	41.925	3.2	3.2	18.55
25	30	1.1	42.9	3.2	3.2	19.42

C. Calculations of Mode, Frequency and Time period for Model-1

Mode Shape and Time Period are calculated in Ansys. Self-Weight of each segment is analysed by placing it normally at the mass Centre as one of the combinations for frequency calculations and modal Analysis. [IS 6533 (Part2): 1989)Clause 8.3.1] First mode is assumed for analysis as per codal recommendation.

Calculation of fundamental time period and frequency are done using Ansys and excel spreadsheets for first mode results are as follows:

Time Period T = 0.2889 sec

Frequency f = 3.4613 cycles/sec

D. Calculations of Dynamic Wind responses for Model-1

Static Wind Pressure = 15419.05 N

V_b = 39 m/s

Time Period (From Ansys) (Ti) = 0.2889 sec.

$\xi i = \frac{Ti\,.Vb}{1200}$ = 0.00938

Coefficient for Unlined Chimney (Table-5) = 1.75

M_k (from codal Table-6) = 0.7

V (from codal Table-7) = 0.7

ɼik & ɼij = 0.135 (Relative ordinates of mode shape)

M_k & M_j = Weight of First part in Kg = 78.40×1000/9.81 = 7992.74 kg

Deduced acceleration(m/s^2) : $\text{nij} = \frac{\text{yij} \sum_{k=1}^{r} \gamma\text{ik} \times \text{Pstk} \times \text{mk}}{\sum_{k=1}^{r} \gamma^2\text{ik} \times \text{Mk}} = \frac{0.135 \times 46928.89}{22829.59}$ = 0.277

P_{dyn} = M_j ×ξi × nij × v = 7992.74 × 0.0098×0.277×0.7 = 14.56 N

In the similar manner all the segments of the steel stack are analysed and all dynamic parameters are calculated .they are later integrated to find the resultant dynamic response.

TABLE IV DYNAMIC WIND ANALYSIS RESULTS OF EACH SEGMENT FOR MODEL-1

Segmental Height of Model-1	P_{static} (N)	Time Period (Sec.)	ξi calculated	ξi Unlined	M_k	V
5	15419.05	0.2889	0.00938	1.75	0.6	0.7
10	15419.05	0.2889	0.00938	1.75	0.6	0.7
15	16703.44	0.2889	0.00938	1.75	0.575	0.7
20	17700.44	0.2889	0.00938	1.75	0.55	0.7
25	18553.36	0.2889	0.00938	1.75	0.5325	0.7
30	19426.34	0.2889	0.00938	1.75	0.515	0.7

TABLE. V. RESULTS FOR CALCULATIONS OF TOTAL LATERAL DYNAMIC WIND FORCE

Segmental Height of Model-1	ɼik & ɼij Relative Ordinates For Mode 1	M_k & M_j (Kg)	ŋij Deduced Acceleration m/s^2	P_{dyn} (N)
5	0.135	7992.74	0.277	14.56
10	0.416	7992.74	0.855	44.87
15	0.571	7992.74	1.173	61.59
20	0.731	7992.74	1.502	78.85
25	0.897	7992.74	1.843	96.76
30	1	7992.74	2.055	107.87

IV. RESULT & DISCUSSION

A. Comparison of Natural frequency

TABLE.VI COMPARISON OF NATURAL FREQUENCY FOR UNIFORM CHIMNEY

NATURAL FREQUENCY			
Mode	**U30**	**U45**	**U60**
0	0	0	0
1	3.46	2.31	1.34
2	3.46	2.31	1.34
3	5.25	2.36	1.73
4	5.27	2.37	1.73
5	8.56	5.08	3.57
6	8.58	5.08	3.57

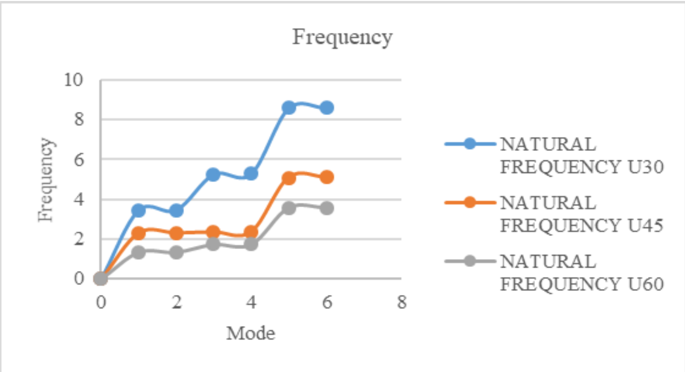

FIG. 2 COMPARISON OF NATURAL FREQUENCY OF UNIFORM CHIMNEY

From the FIG. 2, it is observed that maximum frequency considerably reduce as height of section increased.

TABLE.VII COMPARISON OF NATURAL FREQUENCY FOR TAPERED CHIMNEY

NATURAL FREQUENCY			
Mode	T30	T45	T60
0	0	0	0
1	3.68	2.36	1.84
2	3.68	2.36	1.84
3	9.47	3.15	2.64
4	9.48	3.15	2.64
5	12.30	5.20	3.86
6	12.31	5.22	3.86

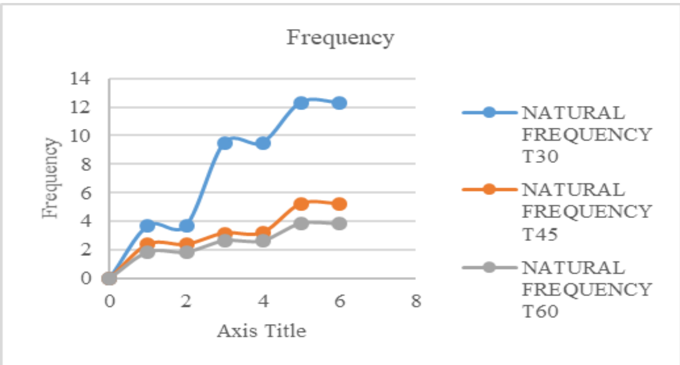

FIG. 3 COMPARISON OF NATURAL FREQUENCY OF TAPERED CHIMNEY

From the FIG. 3, it is observed that maximum frequency considerably reduce as height of section increased.

TABLE.VIII COMPARISON OF NATURAL FREQUENCY FOR UNIFORM + TAPERED CHIMNEY

NATURAL FREQUENCY			
Mode	UT30	UT45	UT60
0	0	0	0
1	2.94	1.97	1.20
2	2.94	1.97	1.20
3	13.36	5.91	3.61
4	13.36	5.91	3.61
5	13.93	6.67	4.08
6	13.93	6.67	4.08

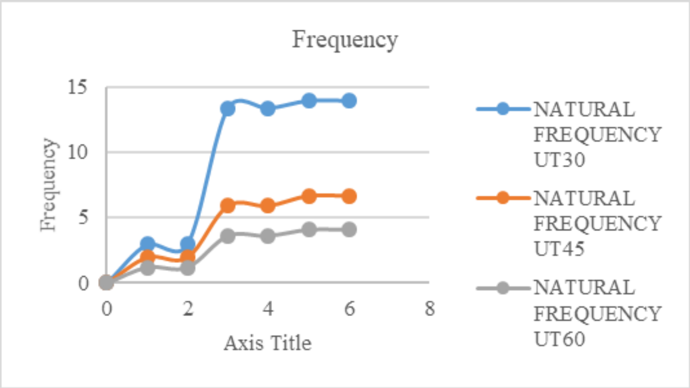

FIG. 4 COMPARISON OF NATURAL FREQUENCY OF UNIFORM + TAPERED CHIMNEY

In the above graph, it is observed that maximum frequency considerably reduced as height of section increased.

TABLE.IX COMPARISON OF NATURAL FREQUENCY OF 30M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

NATURAL FREQUENCY			
Mode	U30	T30	UT30
0	0	0	0
1	3.46	3.68	2.94
2	3.46	3.68	2.94
3	5.29	9.47	13.36
4	5.29	9.48	13.36
5	8.58	12.30	13.93
6	8.59	12.31	13.93

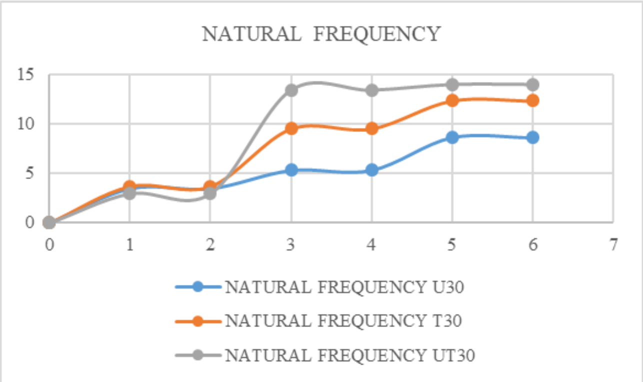

FIG. 5 COMPARISON OF NATURAL FREQUENCY OF 30M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

From the FIG. 5, it is observed that maximum frequency considerably reduced in Uniform + Tapered section but increased in tapered section than uniform section.

TABLE.X COMPARISON OF NATURAL FREQUENCY OF 45M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

NATURAL FREQUENCY			
Mode	U45	T45	UT45
0	0	0	0
1	2.31	2.36	1.97
2	2.31	2.36	1.97
3	2.51	3.15	5.91
4	2.52	3.15	5.91
5	5.15	5.20	6.67
6	5.15	5.22	6.67

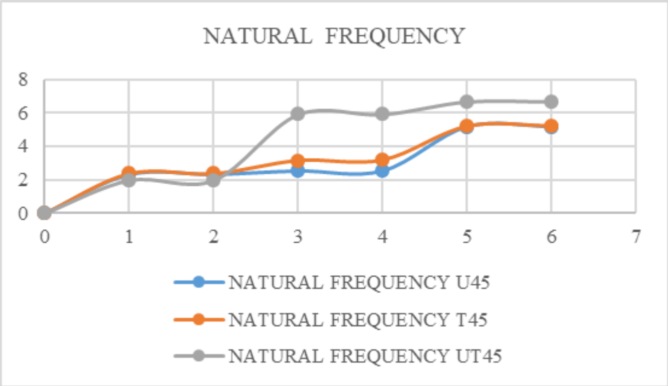

FIG. 6 COMPARISON OF NATURAL FREQUENCY OF 45M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

From the FIG. 6, it is observed that maximum frequency considerably reduced in Uniform + Tapered section but increased in tapered section than uniform section.

TABLE.11 COMPARISON OF NATURAL FREQUENCY OF 60M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

NATURAL FREQUENCY			
Mode	U60	T60	UT60
0	0	0	0
1	1.41	1.84	1.20
2	1.41	1.84	1.20
3	1.73	2.64	3.61
4	1.73	2.64	3.61
5	3.65	3.86	3.86
6	3.65	6.18	3.86

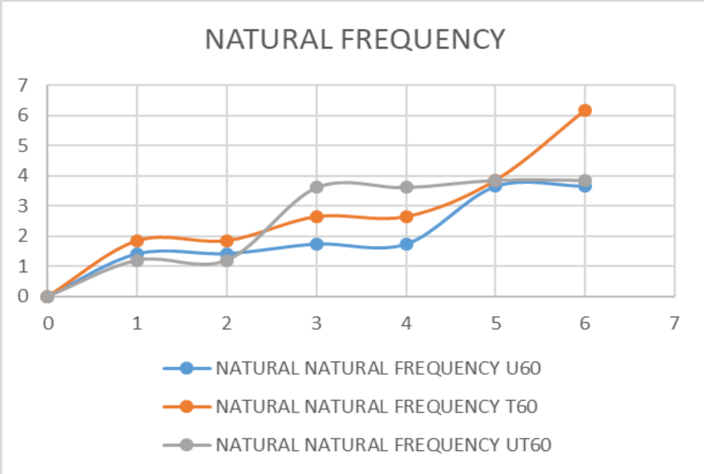

FIG. 7 COMPARISON OF NATURAL FREQUENCY OF 60M HIGH STEEL CHIMNEY FOR DIFFERENT SHAPES

From the FIG. 7, it is observed that maximum frequency considerably reduced in Uniform + Tapered section but increased in tapered section than uniform section.

V. CONCLUSION

In this study, wind response of steel chimney is studied on nine different types of chimneys by changing geometry, height and keeping H/D ration constant. We found out that the maximum frequency considerably reduced in Uniform + Tapered section but increased in tapered section than uniform section.

VI. ACKNOWLEDGEMENT

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REFERENCES

[1] K. Sachidanandam, R.Vijaya sarathy, ”Analytical Behaviour of Steel Chimney Subjected to Dynamic Loading” IJSART Vol. 5, (2016)

[2] Kalagouda R Patil, Dr. B S Manjunath, “Mechanical Design And Analysis of Steel Stack by Varying Its Height With Constant Diameter”

[3] Analysis of self-supported steel chimney as per Indian standard by Kirtikanta sahoo

[4] IS 6533 Part 1: 1989, “Design and Construction of Steel Chimney”, Bureau of Indian Standards, New Delhi.

[5] IS 6533 Part 2: 1989, “Design and Construction of Steel Chimney”, Bureau of Indian Standards, New Delhi.

[6] IS: 875(part 1) –1987), handbook on code of practice for design loads (other than earthquake) for buildings and structures (bureau of Indian standards, new Delhi, 1989)