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Dynamic & Vibration Analysis of stack: A Case Study

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ABSTRACT

A case study of stack from an Industry having Diesel Power Plant (2 × 10 MW) has been considered. The company has manufactured two chimneys that serve to discharge exhaust gases from diesel generating sets to the atmosphere. The objective is to perform dynamic and vibration analysis of this stack. A self-supporting steel stack of 56 m height and 1.5 m diameter at top has been designed as per site ambient conditions and design calculations have been compared with actual site values.Dynamic analysis of stack involves computation of stiffness, equivalent end mass, natural frequency and critical wind speed. Vibration analysis includes the calculation of lowest natural frequency of the chimney and frequency of 2nd mode & 3rd mode of oscillation too are calculated.

***Keywords:** Critical wind speed, Equivalent end mass, lowest natural frequency, Stiffness.*

1. INTRODUCTION

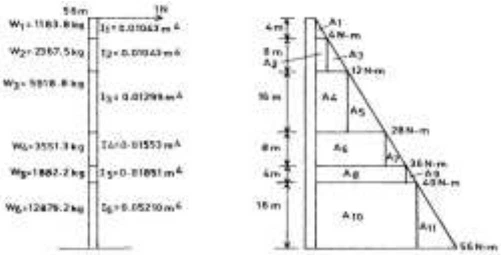
As part of the case study, stack (chimney) from an Industry having **Diesel Power Plant (2 × 10 MW)** has been considered. The company has manufactured two stacks. Both stacks serve to discharge exhaust gases from diesel generating sets to the environment. Data is represented in Table 1. A self-supporting steel stack of 56 m height and 1.5 m diameter at top has been designed by using Data from Table 1. Consideration of the first mode of natural oscillation is sufficient for calculating the wind loads on chimney. It is recommended to consider higher modes of oscillation only if the height of chimney is more than 50 m. Second natural frequency of a cantilever stack is about six times of first mode of oscillation [1], [2].

II. DYNAMIC ANALYSIS OF STACK

Stiffness of the top of stack is found by applying a horizontal force F, of 1 N at the top and calculating the resulting deflection, δ which it causes using the moment area theorem. The bending moments for unit horizontal force at top of chimney are shown in Fig. 1. The bending moments are rearranged in Fig. 1 (b) for the moment area calculation. Areas and position of centroid are shown in Table 2.

Table I: Data of The Case Study Stack [19]

Type of plant	Diesel Power plant
Power output	2×10 MW
Type of fuel	RFO (Residual Furnace Oil)
Quantity of RFO consumed per unit of power generation	188 gm/KWH
Concentration of Sulphur in fuel	3%
Quantity of flue gases at 100% load	80700 kg/hr
Specific volume of flue gas at STP	0.823
Required flue gas exit velocity, v_s	15 m/s
Height of Power Plant Building, h	20 m
Ambient temperature	25 ^{0}C



(a) (b)

Fig. 1. (a) Dimensions, I values and Masses of the stack sections (b) Bending Moments for 1 N Force applied to the Top [3], [4]

Table Ii: Area and Position Of Centroid [19]

Area No.	Area, m^2	Position of Centroid w.r.t. to stack top, m
A1	8	2.67
A2	32	8.00
A3	32	9.33
A4	192	20.00
A5	128	22.67
A6	224	32.00
A7	32	33.33
A8	144	38.00
A9	8	38.67
A10	640	48.00
A11	128	50.67

2.1 Stiffness of the Top of Chimney

STEP A: Stiffness of the Top

δis the moment of M/EI diagram about the top of chimney due to unit horizontal force at the top and EI is flexural rigidity of the chimney [5].

$$Change\ of\ slope\ between\ points = \frac{1}{EI}\begin{bmatrix} Area\ of\ Bending\ Moment \\ Diagram\ between\ points \end{bmatrix}$$

For the whole M/EI diagram:

$$\delta \times E = \left[\frac{8 \times 2.67}{0.01043} + \frac{32 \times 8 + 32 \times 9.33}{0.01043} + \frac{192 \times 20 + 128 \times 22.67}{0.01299} + \frac{224 \times 32 + 32 \times 33.33}{0.01553} + \frac{144 \times 38 + 8 \times 38.67}{0.01851} + \frac{640 \times 48 + 128 \times 50.67}{0.05210}\right] = 21.31 \times 10^{5} N/m$$

$E_{steel} = 2.10 \times 10^{11}$ N/m^2

δ = (21.31×10^5)/ (2.10 × 10^{11}) = 1.01 × 10^{-5} m

Stiffness at the chimney top = K = 1/δ = 0.99 × 10^5 N/m

STEP B:Equivalent End Mass

The equivalent end mass of a section having a mass M_i and located at distance z_i from the base, is given by:

$$M_E = \sum_{i=1}^{n} \left(\frac{z_i}{H}\right)^3 M_i$$

For a chimney, constructed of lifts of different thicknesses, the equivalent end mass is the sum of equivalent end masses of all sections. Masses of stack sections have been increased by 5% to account for stiffeners, platforms and ladders etc. [6], [7].

The corresponding values of $(z_i/H)^3$ are:

$$\left(\frac{z_1}{H}\right)_1^3 = \left(\frac{52 + \frac{4}{2}}{56}\right)^3 = 896.6 \times 10^{-3}$$

$$\left(\frac{z_2}{H}\right)_2^3 = \left(\frac{44 + \frac{8}{2}}{56}\right)^3 = 629.7 \times 10^{-3}$$

$$\left(\frac{z_3}{H}\right)_3^3 = \left(\frac{28 + \frac{16}{2}}{56}\right)^3 = 265.6 \times 10^{-3}$$

$$\left(\frac{z_4}{H}\right)_4^3 = \left(\frac{20 + \frac{8}{2}}{56}\right)^3 = 78.7 \times 10^{-3}$$

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$$\left(\frac{Z_5}{H}\right)_5^3 = \left(\frac{16+\frac{4}{2}}{56}\right)^3 = 33.2 \times 10^{-3}$$

$$\left(\frac{Z_6}{H}\right)_6^3 = \left(\frac{\frac{16}{2}}{56}\right)^3 = 2.9 \times 10^{-3}$$

Total equivalent end mass = [(1.05×1183.8×0.897) + (1.05×2367.5×0.630) + (1.05×5918.8×0.266) + (1.05×3551.3×0.079) + (1.05×1882.2×0.033) + (1.05×12879.2×0.003)] = 4729.6 kg

STEP C: Lowest Natural Frequency

The lowest natural frequency of stack is calculated by substituting the values of stiffness and equivalent mass [8], [9]:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{M_E}} = \frac{1}{2\pi}\sqrt{\frac{0.99 \times 10^5}{4729.6}} = 0.73\ Hz$$

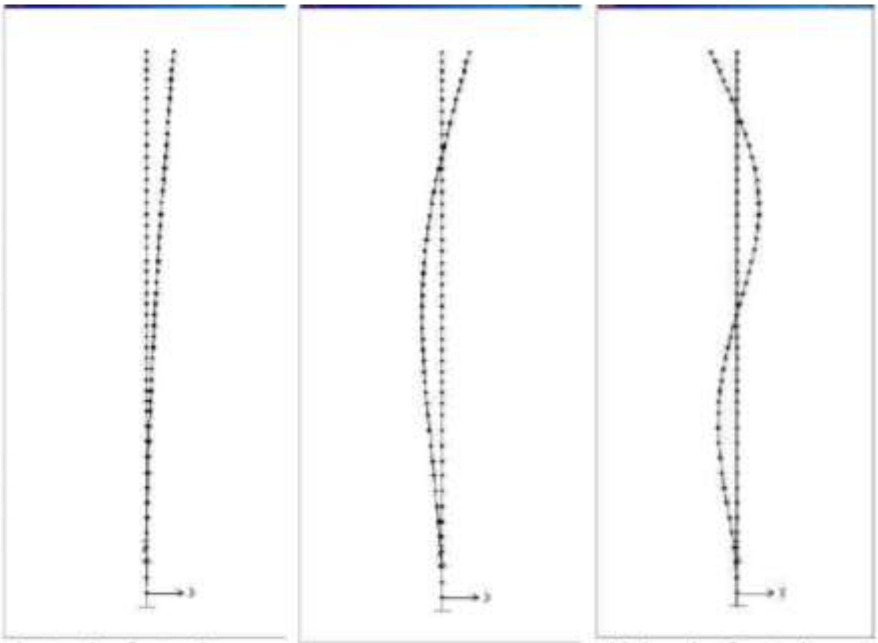
STEP D: Critical Wind speed

The critical wind speed, U_c causing vortex shedding is calculated as [10], [11]:

$$U_c = \frac{f_n D}{St}$$

$$U_c = \frac{0.73 \times 1.5}{0.2} = 5.5\ m/s = 19.71\ km/hr$$

3. VIBRATION ANALYSIS OF STACK [12]-[14]



First mode of natural frequency   Second mode of natural frequency   Third mode of natural frequency

Fig. 2. Three Modes of Vibration of Natural Frequency [19]

This means that the chimney will vibrate in the across wind direction in its lowest natural frequency whenever the wind speed reaches 5.5 m/s (6.8 m/s to 4.1 m/s), it will also vibrate in the wind direction whenever the wind speed is 2.7 m/s. This is the first mode of oscillation. The second natural frequency of a cantilever is about six times the lowest, so the frequency corresponding to second mode of oscillation is 6×0.73 = 4.38 Hz and the wind speed is 32.8 m/s;

The critical wind seed of 2nd mode of

$$U_{c2} = \frac{4.38 \times 1.5}{0.2} = 32.8\ m/s = 118.3\ km/hr$$

which is less than the site basic wind speed of 47 m/s. This means that the chimney may vibrate in the across wind direction in its 2nd mode of oscillation; whenever the wind speed reaches 32.8 m/s (41.1 m/s to 24.6 m/s). The chimney should vibrate only in the fundamental mode, so this stack has design limitations[15], [16].

4.CONCLUSIONS

The chimney should vibrate only in the fundamental mode of oscillation. The case study (present) stack is vibrating in 2nd mode of oscillation too; so this stack has design limitations. Its design may be improved by installing helical strakes at the top one third portion of stack or by installing vibration dampers[17], [18].

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