# MECHANICAL DESIGN AND ANALYSIS OF STEEL STACK BY VARYING ITS HEIGHT WITH CONSTANT DIAMETER

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**Abstract -** *Chimneys are tall and slender structures which are used to discharge waste/flue gases at higher elevation with sufficient exit velocity such that the gases and suspended solids(ash) are dispersed in to the atmosphere over a defined spread such that their concentration , on reaching the ground is within acceptable limits specified by pollution control regulatory authorities. This project summarizes the analysis and design concepts of chimneys as per Indian codes provisions incorporation was also made through finite element analysis. Chimney models are designed on the basis of constant diameter with change in height taken into consideration. These models are analyzed by finite element software STAAD Pro, ANSYS, emphasis also placed on effect of geometric limitations on the design aspects in designing chimney. The main objective of this study the design and constructional aspects of steel stack (with particular reference to steel plant) adhering to the guidelines given in internationally accepted standards/codes. Therefore, objective of this study was to take a practical case study and carry out design calculations by using the rules of codes viz., IS: 6533 part 1 and 2, IS: 875 part-3, IS: 1893 part1 and 4. Further to get full insight into the design of the steel stacks a complete 3-D finite element analysis was carried out by using ANSYS software. Results have been summarized and conclusions have been drawn.*

***Key Words*: Finite Element Software STAAD Pro, ANSYS, IS: 6533 part-1 and part-2, IS: 875 part-3, IS: 1893 part-1 and part-4.**

## 1. INTRODUCTION

Stacks as we know them today are tall slender structures which fulfill an important function. They had a humble beginning as household vents and over the years, as vent grew larger and taller they came to be known as chimneys/stacks. Steel stacks are ideally suited for process work where a short heat up period and low thermal capacity are required where as it encourages acid condensation and corrosion hence smutting and reduction in the life of stack. A chimney which was scientifically designed to take cognizance of gas temperature and velocity, corrosion aspects etc was called a stack. By usage the term stack has gained popularity and today it also signifies a chimney.

## 2. STATEMENT OF PROBLEM, OBJECTIVES AND CONSTRUCTION MATERIALS

Design analysis of 1.9m ID and varying heights of 30, 40, 50 and 60m height steel stacks to be used in "Salem" steel plant.

**Table -2.1:** Input data for steel stack design from Salem steel plant

| | |
|---|---|
| Location | Salem Industrial Area (Tamilnadu) |
| Stack size | 1900mm ID, 30m Height |
| Type | Self Supporting |
| Basic wind speed | 47m/s |
| Terrain category | 3 (Industrial suburb with avg. height above 10m) |
| Average Height of surrounding buildings | 10m |
| Suburb distance | 5 Km from city edge |
| Gas handled | Flue gas |
| Gas flow rate | 153000 m$^3$/hr @ 250 °C |
| Gas Temperature | 350 °C (max) |
| Ambient Temperature | 41.6 °C (max) |
| Material | Carbon steel(IS: 2062 Gr. B) |
| Corrosion allowance | 2mm |

### 2.1: OBJECTIVES

To study the design and constructional aspects of steel stack (with particular reference to steel plant) adhering to the guidelines given in internationally accepted standards/codes. Therefore, objective of this study was to take a practical case study and carry out design calculations by using the rules of codes viz., IS:6533 part 1 and 2, IS:875 part-3, IS:1893 part1 and 4. Further to get full insight into the design of the steel stacks a complete 3-D finite element analysis was carried out by using ANSYS software. Results have been summarized and conclusions have been drawn.

## 2.2: CONSTRUCTION MATERIALS

1. Stack shell – Carbon steel – IS: 2062 Gr. B (weldable grade)
2. Bolting material – 8.8 Gr. (IS: 1363/1364)
3. Platforms and ladders – St – 42 (structural steel IS: 2062)

## 3. ASSUMPTIONS MADE DURING DESIGN

Following are the assumptions made during the design of steel stack.

1) The wind pressure varies with the height. It is zero at the ground and increase as the height increases. For the purpose of design it is assumed the wind pressure is uniform throughout the height of the structure.
2) For the purpose of calculations, it is assumed that the static wind load (projected area multiplied by wind pressure) is acting at the center of pressure.
3) In calculating the allowable stresses both tensile and bending, the Joint efficiency for butt welds is assumed to be 0.85.
4) The base of the stack is perfectly rigid and the effect of gussets and stool plate on the deflection and the stresses in the stack is not considered. This is applicable only for manual calculations.
5) There are no additional lateral movements from the duct transferred to the stack and Suitable arrangement has to be provided to absorb this movement from the duct.
6) Since the D/t ratio (mean diameter of stack to thickness of plate) is greater than 10, the structure is a thin cylinder and shell (plate) element can be used for finite element modeling.
7) Earthquake causes impulsive ground motions, which are complex and irregular in character, changing in period and amplitude each lasting for a small duration. Therefore, resonance of the type as visualized under steady state sinusoidal excitations will not occur, as it would need time to build up such amplitudes.
8) Earthquake is not likely to occur simultaneously with maximum wind or maximum flood or maximum sea waves.

## 4. METHODOLOGY

1) The stack is a cantilever system subjected to wind and earthquake loads. In order to determine the wind force acting on the stack, the stack is divided into number of zones. The zoning of the stack depends on the maximum plate width available for a particular thickness and capacity of the lifting equipment at the time of erecting of the stack. Normally the height of each zone is between 2.5m to 5m and typically 4m if the stack is to be welded at the site of location. In the current design calculations, the height of zone has been fixed at 5m after consultations with the client as well as fabricator (Refer layout drawing A-1 of Annex F).

2) The bending moment at the end of each zone is determined to find the required section modulus and hence the thickness.
3) The deflection at the top of the stack is calculated and checked against the allowable limits. In case the deflection at the top is more, and then the section modulus at the base of the stack is increased till the deflection is within limits. If, however, it is not possible to contain the deflection in spite of increasing the section modulus, the stack is guided at 2 or more locations.
4) The natural frequency is determined to check if the dynamic effect of the wind needs to be taken care during the design stage.
5) The check for resonance is carried out.

## 5. DESIGN MANUAL CALCULATIONS

### 5.1: DESIGN PARAMETRS

1. Deflection in mm
2. Compressive Stress in MPa
3. Natural Frequency in Hz

- Deflection is given by the equation:

$$X = \frac{wa^3}{3EI} + (L - a)\frac{wa^2}{2EI} \quad \text{.................................5.1}$$

Where,
X=Deflection in mm.
W=Total force acting on each zone.
L=Length of stack in mm.
a=Distance from base to the point of force acting.
E=Young's modulus= $2.1 \times 10^5$ MPa.
I=Moment of inertia in mm$^4$.

$$I = \frac{\pi}{64}\left(d_o{}^4 - d_i{}^4\right) \quad \text{.......................................5.2}$$

Deflection is calculated by using equation 5.1 for each zone and adding all X=187.49mm
In practice since the stack is tapered and thickness also varies along the height, taking the coefficient for the variation from Roark's formula for stress-strain,
X=187.49×0.4248
X=79.64mm

- Natural frequency is given by the equation:

$$f = \frac{1}{2\pi}\left[\sqrt{\frac{g\,\Sigma(mx)}{\Sigma(mx^2)}}\right] \quad \text{................................5.3}$$

Where,
$f$=frequency in Hz.
m= mass of the zone including the lining or covering in kg.
x=Deflection of same zone due the force equal to gravity acting on its mass centre with the base fixed and top free, in

meters.
g=Rate of gravitational acceleration=9.81m/s$^2$.

**Table-5.1:** Showing the weight of each zone

| zone | Thickness t in mm | OD in mm | ID in mm | Area in mm² | Volume (v) in mm³ | Mass ρ×v in Kg | Weight in N |
|---|---|---|---|---|---|---|---|
| 1 | 25 | 1950 | 1900 | 151189 | 755945732 | 5941 | 58288.4 |
| 2 | 20 | 1940 | 1900 | 120637 | 603185750 | 4741 | 46509.5 |
| 3 | 16 | 1032 | 1900 | 96308 | 481543321 | 3785 | 37130 |
| 4 | 12 | 1924 | 1900 | 72080 | 360403509 | 2832 | 27789 |
| 5 | 10 | 1920 | 1900 | 60004 | 300022098 | 2358 | 23134 |
| 6 | 8 | 1916 | 1900 | 47953 | 239766351 | 1884 | 18482 |
| | | | | | Total | 21453 | 211332 |

**Table-5.2:** Showing x and mx² to calculate frequency

| Zone | Mass in kg | Deflection in mm (x) | x² | mx | mx² |
|---|---|---|---|---|---|
| 1 | 5941 | 3.84 | 14.7 | 22816.2 | 87614 |
| 2 | 4741 | 11.50 | 132.3 | 54521.8 | 62000121 |
| 3 | 3784 | 19.16 | 367.1 | 72519.2 | 1389468 |
| 4 | 2832 | 26.83 | 719.8 | 76003.2 | 2039166 |
| 5 | 2358 | 34.50 | 1190.2 | 81356.8 | 28066811 |
| 6 | 1884 | 42.16 | 1777.4 | 79453.4 | 3349740 |
| | | Total | | 386670 | 10299803 |

$$f = \frac{1}{2\pi}\left[\sqrt{\frac{9.81 \times 386670.45}{10299803.34}}\right]$$

*f*=3.09Hz

- Compressive stress is given by equation:

The stress at the base of the stack is determined by;

$$\sigma = \frac{M}{Z}$$ ...................................................................5.4

Where,
σ= compressive stress in MPa.
M= Bending moment in N-mm
Z= Section modulus in mm³.

Compressive stress=50.35MPa

# 6. VALIDATIONS OF MANUAL RESULTS BY FEA USING ANSYS

## 6.1: ANALYSIS PROCEDURE

The manual calculations are compared with the analysis results to validate the assumptions made and later the complete model with all the main features like, stool plate, base plate, gussets, platform, breach opening and manhole opening are made to simulate the actual construction. The platform supporting structure is made out of beam element (Beam – 188). The stack is fixed at anchored bolt points. Now in this case the base of stack is fixed rigidly with all DOF fixed. The figure 7.2 shows the meshed model and boundary conditions. The steps involved in analysis are as follows

1) Create layout drawings using AutoCAD.
2) Create actual model in Catia/ Ansys.
3) Mesh the modal, specify the material properties, and apply loads and boundary conditions.
4) Extract the required results, Deflection, stresses, Natural frequency etc

## 6.2: LOADING

Following loading where considered
Total wind load = 228989N
Total weight = 11332.9N
Imposed load on platforms = 2.943x10$^{-3}$N/mm$^2$

## 6.3: BONDARY CONDITIONS

The base of stack was fixed with all degrees of freedom and resultant force as calculated earlier was applied at the center of each zone. For further analysis shell is welded to base plate of given thickness, anchor bolts of calculated size are used to fix at the base. The same effect was transmitted to FEM model, by fixing at the determined bolt locations with all degree of freedom fixed.
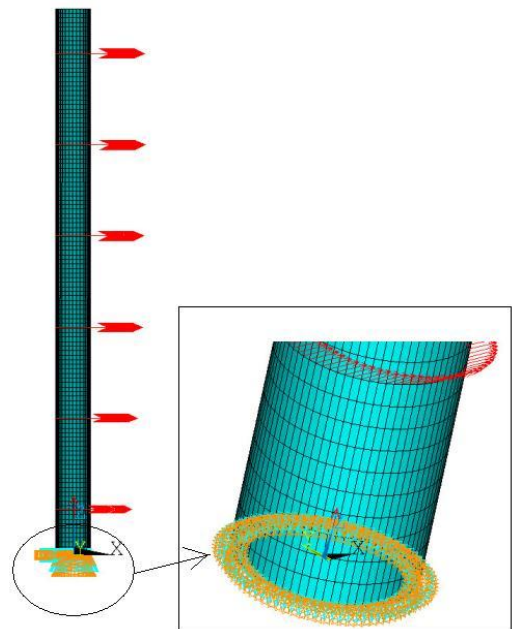


**FIG: 6.1** Shows the boundary conditions for the analysis of the stack with base fixed rigidly with all DOF fixed.

## 6.4: ANALYSIS RESULTS

The results from ANSYS are shown below and comparison with the manual calculations is summarized in table below.
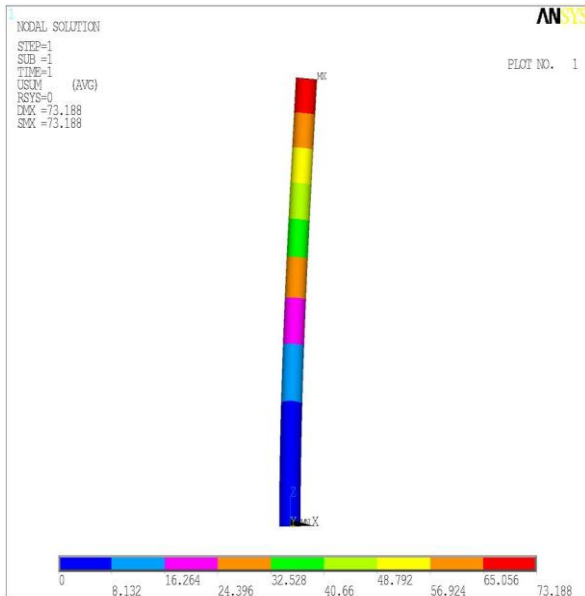
1.  Deflection in mm at the top of stack



**FIG: 6.2** Deflection at the top of the stack for analysis with base fixed rigidly.

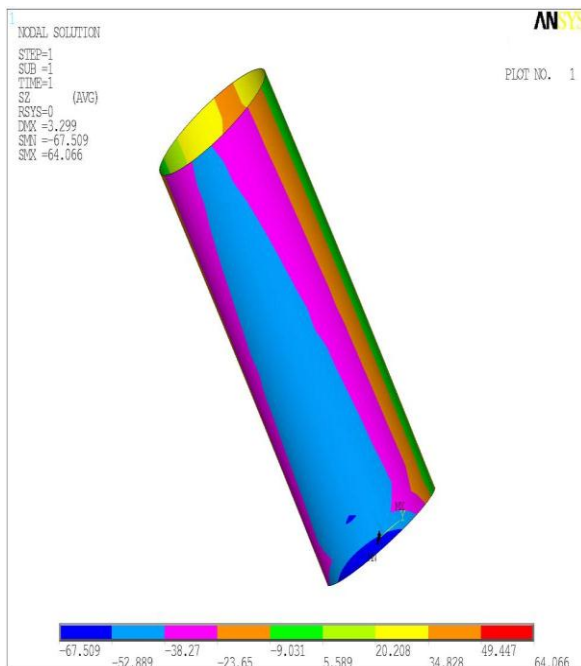2.  Compressive stress in MPa at the base of stack



**FIG: 6.3** Compressive stress at the base of the stack for analysis with base fixed rigidly.
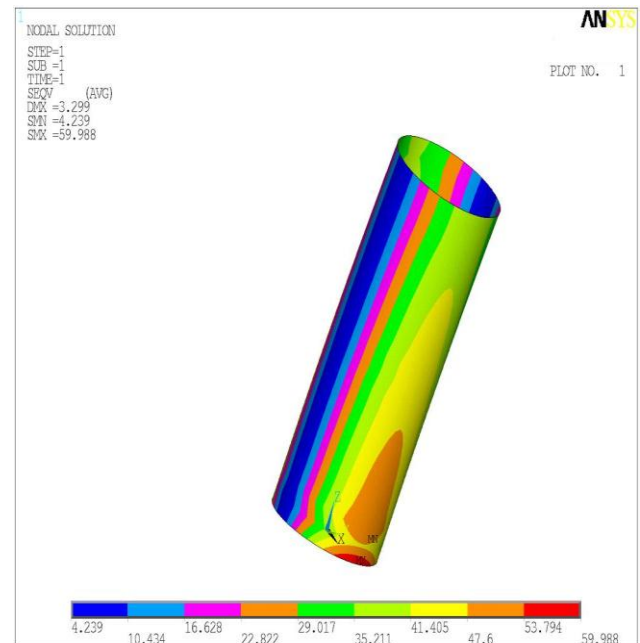
3.  Von misses stress in MPa at the base of the stack



**FIG: 6.4** Von misses stress at the base of the stack for analysis with base fixed rigidly.

## 6.5: RESULIT SUMMERY

**Table-6.1:** Tabulation of results to compare manual results with FEA results.

| Parameters | Manual calculation | Analyzing using ANSYS | Percentage of variation w.r.t to ANSYS |
|---|---|---|---|
| **Deflection in mm** | 79.69 | 73.18 | 8.16% |
| **Compressive stress in MPa** | 52.63 | 50.35 | 4.33% |
| **Natural frequency in Hz** | 3.06 | 3.18 | -4% |

**Note:** The manual calculations assume that the base of stack is rigid i.e. the elastic rigidity of bolts and foundation is neglected. The same has been simulated in Ansys by fixing all DOF at the base of the stack.

## CONCLUSION:

From the above table it is clear that the manual calculations are within the range of ±10% hence we can conclude that the mathematical model and assumptions made during the design process are correct.

## REFRENCES:

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