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Effect of Openings in the Analysis of Shell for a 275m Tall Multiflue RCC Chimney

Choppalli Kalyani Ramarao
Student M.Tech(R) at SVNIT, Surat
Email: kalyani.choppalli@gmail.com

Patil Yogesh D.
Asst. Prof., Applied Mechanics Department, SVNIT. Surat
Email: chipatil@yahoo.com

***Abstract* – It has been observed that most of the existing studies have focused on the load considerations for design of tall chimneys. A step further, an attempt has been made through this paper, to analyze the stress developed in the chimney shell due the provision of functional openings. A comparison has been made between the stress levels for a 275m tall multiflue RCC Chimney for two conditions i.e. Chimney shell without openings and chimney shell with required functional openings. The design and analysis has been carried out using STAAD Pro and MS Excel Software.**

***Keywords* – Breach Openings In Chimney, Multiflue Chimneys, Parametric Analysis, Tall RCC Chimneys.**

I. Introduction

Industrial chimneys are of great importance as they serve a useful function of disposal of a large amount of waste gases in the atmosphere at high altitudes so that it dilutes before it settles down. The construction of tall, reinforced concrete chimneys has been on an increase in the last few decades owing primarily to the increasing demand of air pollution control. Chimneys in the range of 275m have been built and there is every reason to believe that this trend toward the taller chimneys will continue.

This paper on "Effects of openings in the analysis of shell for a tall multiflue RCC Chimney" gives the basic load considerations for static analysis of chimneys, the different types of functional openings required in the chimney and effects on the shell analysis for lined chimney. The analysis and design is done on the basis codal provisions of IS 4998(Part I), CICIND Model code for chimneys & ACI 307-1998 for static analysis and the relevant literature reviews.

Two cases have been analysed for this study. A chimney with the parameters specified in section IV of this paper has been analysed with all openings in place and the same chimney has been analysed without any openings. The comparison of stresses in concrete has been plotted.

II. Different Openings Provided in the Chimney Shell and its Purposes

Openings are provided in the chimney for the various reasons like

- Breach Openings at the bottom most part of the chimney for the entry of flue duct
- Openings at various levels for resting the internal platforms
- Openings at the top for ventilators
- Clean out doors.
- Access door.

Breach openings are provided in a concrete shell for the entry of flue gases, and concrete around such openings has to be protected against high temperature by fire brick lining or equivalent. The number of breach openings is equal to the number of flues viz. This paper analyses a twin flue chimney, hence two numbers of openings. The breeching connection can be either horizontal or inclined upwards, the latter being advantageous from flow considerations. However, a horizontal connection is preferred because of ease of construction and the turbulence created at the entry into the chimney helps grit and other particles to settle out of flue gases.

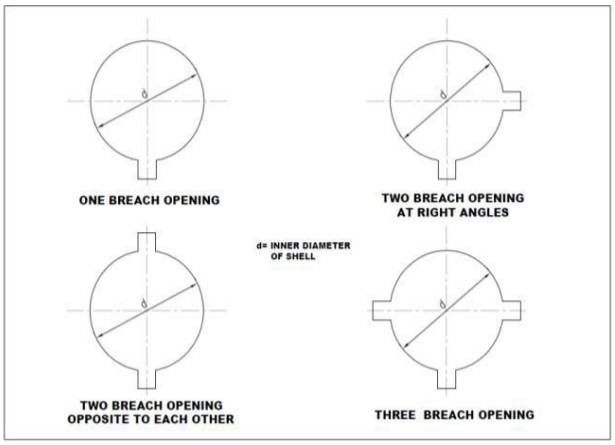

Fig.1. Breach Openings

The openings for resting of support and restraint platforms are closed after the complete construction activity is over. But it has been observed that sometimes these openings are left without closing. So, keeping in view the construction stages and uncovered openings, these are to be taken into design considerations.

Two pairs of clean out doors are provided in the shell and lining for access into a chimney and to clean the soot hopper. These doors should be suitably treated in order to be heat and acid resistant and should be of gas tight construction.

An access door is provided at the bottom of the chimney. When a metal liner is used, the opening meant for an access door is initially made large enough to serve as an access for liner cans which have to be transported to the chimney for erection.

Figure 2 shows the general arrangement diagram for the chimney analysed with all the openings.

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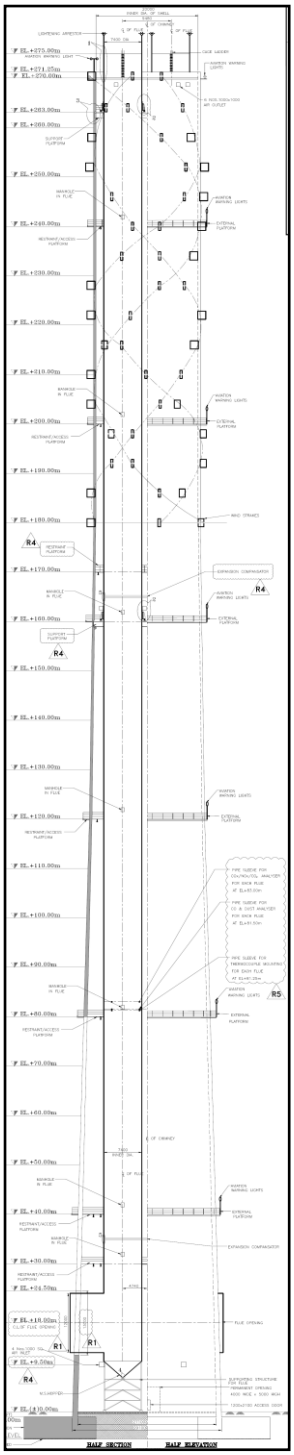

Fig. 2: General Arrangement for the chimney with all openings.

III. Design of Chimney

The design of a chimney has the following stages:

Physical dimensioning
- Load calculations
- Analysis for wind
- Analysis for earthquake
- Shell design
- Liner design
- Accessories design

Load Considered for Design of Chimney:

The following loads are considered for the analysis and design of the chimney:
- Dead loads
- Live loads
- Wind loads
- Seismic loads,
- Temperature effects.

- *Dead Loads*

Dead loads shall include the weight of chimney shell, liners, liner supports, other accessories and load of ash and soot as applicable.

- *Live Loads*

Live loads shall be taken in accordance with IS 875 (Part 2):1987. The imposed loads on internal platform and hood of multi-flue chimneys shall include appropriate loads during construction.

- *Wind Loads*

The effect of wind on these tall structures can be divided into two components, known respectively as
- Along-Wind Effect
- Across-Wind Effect

Along Wind Effects

Along-wind loads are caused by the 'drag' component of the wind force on the chimney when the wind acts on the face of a structure. For the purpose of estimation of these loads the chimney is modeled as a cantilever, fixed to the ground. The wind is then modeled to act on the exposed face of the chimney causing predominant moments in the chimney. Additional complications arise from the fact that the wind does not generally blow at a fixed rate. Wind generally blows as gusts. This requires that the corresponding loads, and hence the response be taken as dynamic. True evaluation of the along-wind loads involves modeling the concerned chimney as a bluff body having incident turbulent wind flow. However, the mathematical rigor involved in such an analysis is not acceptable to practicing engineers. Hence most codes use an 'equivalent static' procedure known as the gust factor method. This method is immensely popular and is currently specified in a number of building codes including the IS (IS: 4998) code. This process broadly involves the determining of the wind pressure that acts on the chimney due to the bearing on the face of the chimney, a static wind load. This is then amplified using the 'gust factor' to take care of the dynamic effects.

Along-wind effect is due to the direct buffeting action, when the wind acts on the face of a structure. For the purpose of estimation of these loads the chimney is modeled as a cantilever, fixed to the ground. The wind is then modeled to act on the exposed face of the chimney causing predominant moments in the chimney.

Across Wind Effects

Across-wind loads are caused by the corresponding 'lift' component of wind. In spite of considerable research the problem of accurately predicting the across-wind response has to be fully resolved. Hence the CICIND code does not take into account across-winds. For this study the codes

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used therefore were the IS 4998(Part 1): 1992 and the ACI 307-95.

Static Wind Effects

Drag Force

Wind exerts a static force known as drag on a bluff body obstructing an air stream. The distribution of wind pressure around the circumference of such a body depends on its shape and direction of wind incidence.

The drag force on a single stationary bluff body can be written down as

Fd = (1/2) xCdxAxρaxU2

Where,

Fd = drag force in N

Cd = drag coefficient

A = area of section normal to wind direction in sq. m.

Circumferential Bending

The radial distribution of wind pressure on a horizontal section of a chimney depends on Re. It is assumed that the along wind resultant of such pressures is balanced by the resultant of shear forces induced in the structure and these shear forces, in turn are assumed to vary sinusoidally along the circumference of the chimney shell. With these assumptions, bending moments in the shell can be obtained using established analytical methods.

Dynamic Wind Effects

Gust Loading

The literal meaning of gust is a short blast of wind. Complications arise from the fact that the wind does not generally blow at a fixed rate. Wind generally blows as gusts. This requires that the corresponding loads, and hence the response be taken as dynamic. True evaluation of the along-wind loads involves modeling the concerned chimney as a bluff body having incident turbulent wind flow. However, the mathematical rigor involved in such an analysis is not acceptable to practicing engineers. Hence, most codes use an 'equivalent static' procedure known as the gust factor method. This method is immensely popular and is currently specified in a number of building codes including the IS (IS: 4998) code. This process broadly involves the determining of the wind pressure that acts on the chimney due to the bearing on the face of the chimney, a static wind load. This is then amplified using the 'gust factor' to take care of the dynamic effects.

All along-wind loads that act on the chimney are not due to the static wing bearing on the surface of the chimney alone. There is a significant change in the applied load due to the inherent fluctuations in the strength of wind that acts on the chimney. It is not possible or feasible to take the maximum load that can ever occur due to wind loads and design the chimney for the same. At the same time it is very difficult to quantify the dynamic effect of the load that is incident on the chimney. Such a process would be very tedious and time consuming. So, most of the codes make use of the gust factor to account for this dynamic loading. To simplify the incident load due to the mean wind is calculated and the result is amplified by means of a gust factor to take care of the dynamic nature of the loading.

The gust factor is defined as the ratio of the expected maximum moment to the mean moment at the base of the chimney.

Aerodynamic Admittance

A structures response to wind load, at any frequency, depends on the spatial characteristics of wind turbulence. This aspect is taken into account by a term called "aerodynamic admittance coefficient". The calculated response of a structure to wind load has to be multiplied by this aerodynamic admittance coefficient to allow for response modification due to spatial wind turbulence characteristics.

Vortex Formation & Excitation

A vortex is a spinning, often turbulent, flow of fluid. Any spiral motion with closed streamlines is vortex flow. The motion of the fluid swirling rapidly around a center is called a vortex.

The phenomenon of alternately shedding the vortices formed in the wake region is called vortex shedding. This is the phenomenon that gives rise to the across-wind forces.

Wake Buffeting

Buffeting is defined as the unsteady loading of a structure by velocity fluctuations in the incoming flow and not self-induced. Buffeting vibration is the vibration produced by turbulence.

Wake buffeting is the aerodynamic effect on a downstream chimney due to vortices shed from an upstream structure. Buffeting effects in any particular case should be evaluated on a scale model tested in wind tunnel. Information on wind pressures exerted due to buffeting is limited in spite of the fact that many chimney are built in groups and in the proximity of other tall structures.

Buffeting effects in any particular case should be evaluated on a scale model tested in a wind tunnel. Based on previous model tests, the following broad observations may be made. A leeward chimney experiences much larger amplitudes than a windward one.

Buffeting effects on a chimney due to another similar chimney depend on spacing between them. The interference effect reaches a maximum when the center to center spacing between similar chimneys is about five times the diameter measured at one third the height from the top.

In a chimney, oscillations of large amplitude can be caused if the predominant frequency of vortex shedding from an upstream obstruction coincides with its natural frequency. Thus, frequency mistuning is an important tool to reduce buffeting effect.

- *Seismic Load / Effects*

Chimneys are particularly vulnerable to earthquakes because they are tall, slender structures. Such structures have to be carefully designed to safely withstand the forces likely to be imposed on them by ground motion.

An earthquake resistant design essentially consists of evaluating the structural response to an assumed likely ground motion and then calculation the corresponding shear forces and bending moments which the structure

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needs to safely resist. The characteristics of a likely ground motion depend on source mechanism, properties of the sub surface media transmitting seismic waves, reverberations in local layered geology and many such factors.

For analysis, a chimney is treated as a cantilever beam with predominant flexural deformation sand is analysed by one of the following methods.

- Response spectrum method
- Modal analysis technique
- Time history response analysis

• *Temperature Effects*

The concrete shell of a chimney has to withstand the effects of a thermal gradient prevailing across its thickness. As a result of such temperature gradient, vertical and circumferential stresses are developed whose values can be determined after establishing the magnitude of the thermal gradient under steady state conditions.

As per the CICIND Model code for chimneys, the effects of temperature differences between the inner and outer faces of the concrete shell should be calculated for the steady state heat flow. The characteristic value of the flue gas temperature should be determined from the given operational conditions and controls.

The characteristic value of the ambient temperature should be taken as the regional average minimum temperature for the two coolest months of the year.

Temperatures may be for simplicity be calculated as for plane walls in case of chimneys.

Loading Combinations to Be Considered For Design

Dead loads
Dead loads + wind loads
Dead loads + earthquake loads
Dead loads + temperature effects
Dead loads + wind loads + temperature effect
Circumferential effect due to wind
Circumferential effect due to temperature
Circumferential effect due to wind + temperature

IV. Our Approach

• *Parameters of the Chimney Considered For Basic Design*

Total height of the chimney above grade level.: 275 m.

No. of flues	: Two
No. of Boilers	: Two
Volume of Gas per Boiler.	: 1280 m3/sec
Mass flow of Gas	: 4000 T/h
Density of gases	: 0.85 kg/m3
Temperature of flue gases.	: 130º C
Top Internal shell diameter	: 20 m
Top External shell diameter	: 20.8m
Bottom internal shell diameter	: 27.054 m
Bottom external shell diameter	: 29.045 m
Location	: Malwa (Madhya Pradesh)
Steel grade	: Fe 500
Flue diameter	: 7.4m

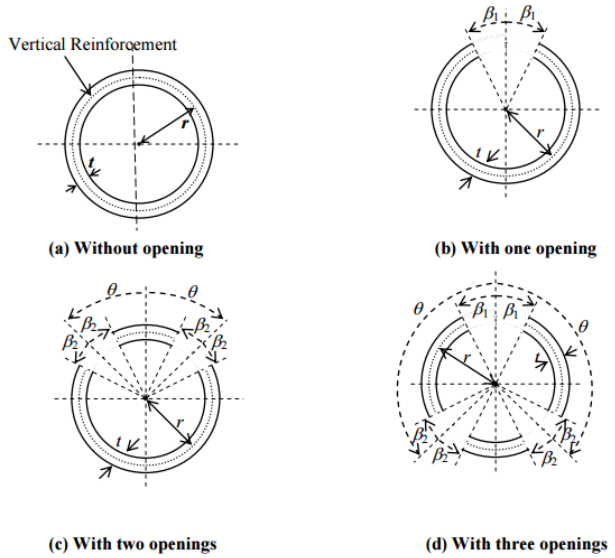

Fig.3. Different cases of shell openings

The chimney has been analysed and designed as a freestanding cantilever of variable annular section and is subjected to axial loads, moments and temperature. It has been divided into 48 nodes (node 1 being the topmost) for calculation purposes.

Vertical stresses are calculated both at full annular sections (where there are no openings in shell, β = 0) and at notched annular sections (where there are openings in shell, β not equal to 0)

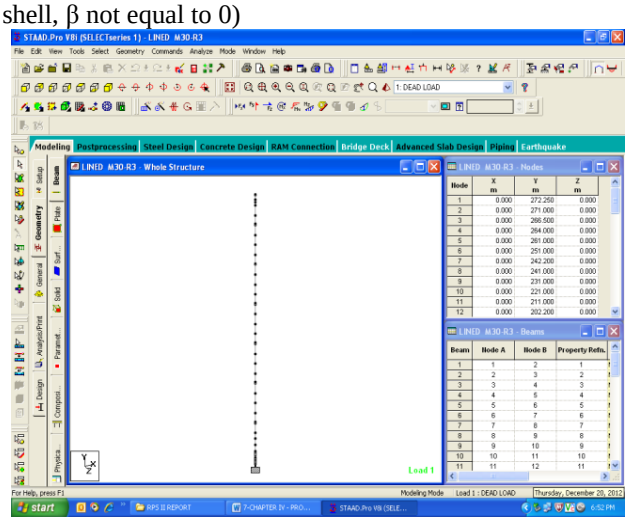

Fig.4. Model of the chimney shell in STAAD PRO

• *Procedure Followed For Design*

1) Compute the Bending Moment M due to wind or earthquake force acting above the section under consideration in accordance with IS875 and IS 4998(Part 1) 1992
2) Compute the dead load W of the portions of chimney above the section under consideration.
3) Determine eccentricity e = M/W.
4) Determine e/r where r is the radius of shell at the section under consideration.
5) Assume percentage of steel at the section under consideration.

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6) Select the value m for concrete grade to be used.
7) Determine α (one half of the central angle subtended by the neutral axis as a chord on the circle of radius r in degrees)
8) Determine stress for different values of α and β (half of the angle subtended by the opening as a chord at center in degrees) as given in IS 4998 Part 1-1975.
9) Calculate temperature stresses in steel and concrete.
10) Calculate stress in steel and concrete due to wind induced moment.
11) Check combined stresses.
12) If stresses are exceeding the permissible limits given in IS 4998, either increase shell thickness or reinforcement or both & repeat the steps.

Table 1: Nodal locations and size of openings considered for analysis.

Node No	EL	No of opening	Equivalent width of opening
1	271	0	0
2	270	0	0
3	266	2	6.6
4	263	0	0
5	260	0	0
6	250	0	0
7	241	2	1.32
8	240	0	0
9	230	0	0
10	220	0	0
11	210	0	0
12	201	2	1.32
13	200	0	0
14	190	0	0
15	180	0	0
16	170	0	0
17	161	2	1.32
18	160	0	0
19	150	0	0
20	140	0	0
21	130	0	0
22	121	2	1.32
23	120	0	0
24	110	0	0
25	100	0	0
26	90	0	0
27	81.2	2	1.32
28	80	0	0
29	70	0	0
30	60	0	0
31	50	0	0
32	41.2	2	1.32
33	40	0	0
34	30	0	0
35	24.5	2	7.7
36	18	2	7.7
37	11.5	2	7.7
38	10	0	0
39	9.5	2	4.4
40	9	0	0
41	7.5	0	0
42	5	2	4.4
43	3.75	0	0
44	2.5	2	4.4
45	2.25	2	5.72
46	1.2	2	5.72
47	0	2	5.72
48	0	0	0

V. RESULTS

Following are the results of analysis which has been done in accordance with section IV of this paper.

Table 2: Shear force and bending moment values for analysis

LEVEL (M)	SHELL O/S DIA. (M)	THK (M)	NO. OF OPENINGS	BETA (DEG.)	DIRECT LOAD (K N)	MOMENT (KN-M)
272.25	20.80	.400	0.	.00	.00	193.17
271.00	20.80	.400	0.	.00	801.11	526.58
266.50	20.80	.400	2.	18.78	5663.09	4415.54
264.00	20.80	.400	0.	.00	7265.30	7965.73
261.00	20.80	.400	0.	.00	15364.96	16233.08
251.00	20.80	.400	0.	.00	21773.80	43890.05
242.20	20.80	.400	2.	3.69	27413.59	75339.23
241.00	20.80	.400	0.	.00	28182.65	83512.22
231.00	20.80	.400	0.	.00	35926.50	128223.00
221.00	20.80	.400	0.	.00	42335.35	179710.00
211.00	20.80	.400	0.	.00	48744.20	237347.50
202.20	20.80	.400	2.	3.69	54383.99	293322.20
201.00	20.80	.400	0.	.00	55153.05	306113.20
191.00	20.80	.400	0.	.00	62896.89	375336.50
181.00	20.80	.400	0.	.00	69305.74	448921.80
171.00	21.08	.417	0.	.00	75892.97	526373.40
162.20	21.33	.431	2.	3.60	83321.80	598787.60
161.00	21.37	.433	0.	.00	84173.47	613627.90
151.00	21.65	.450	0.	.00	98889.04	702333.10
141.00	21.93	.467	0.	.00	106570.60	793826.60
131.00	22.22	.483	0.	.00	114628.80	887776.70
122.20	22.47	.498	2.	3.43	122037.70	972776.80
121.00	22.50	.500	0.	.00	123071.70	988333.30
111.00	23.05	.541	0.	.00	133964.30	1086771.00
101.00	23.59	.583	0.	.00	144009.50	1186875.00
91.00	24.14	.624	0.	.00	155035.20	1288442.00
82.20	24.62	.660	2.	3.14	165568.20	1379194.00
81.00	24.68	.665	0.	.00	167066.00	1393906.00
71.00	25.23	.707	0.	.00	182142.70	1497982.00
61.00	25.77	.748	0.	.00	196297.10	1602889.00
51.00	26.32	.789	0.	.00	211553.50	1708422.00
42.20	26.80	.826	2.	2.90	225926.10	1801804.00
41.00	26.86	.831	0.	.00	227956.40	1815335.00
31.00	27.41	.872	0.	.00	247753.90	1921708.00
25.50	27.71	.895	2.	16.60	259788.80	1980530.00
19.00	28.06	.922	2.	16.40	272300.50	2049977.00
12.50	28.42	.948	2.	16.19	285333.80	2119448.00
11.00	28.50	.955	0.	.00	288417.40	2135552.00
10.50	28.53	.957	2.	9.13	289452.10	2140967.00
10.00	28.55	.959	0.	.00	290489.70	2146376.00
8.50	28.64	.965	0.	.00	293621.40	2162459.00
6.00	28.77	.975	2.	9.06	298903.80	2189221.00
4.75	28.84	.980	0.	.00	301574.30	2202611.00
3.50	28.91	.986	2.	9.02	304266.10	2215997.00
3.25	28.92	.987	2.	11.76	304807.00	2218680.00
2.20	28.98	.991	2.	11.73	307087.50	2229924.00
1.15	29.04	.995	2.	11.71	309381.80	2241169.00
.00	29.10	1.000	0.	.00	311911.00	2253486.00

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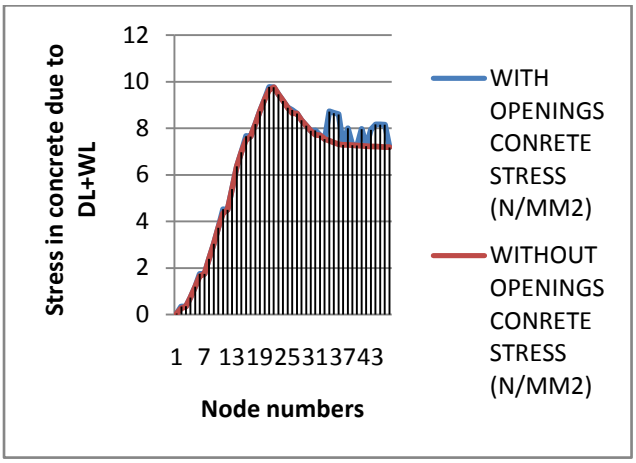

Fig.5. Comparison of Stress pattern for analysis of chimney with and without openings for load case Dead load + Wind load

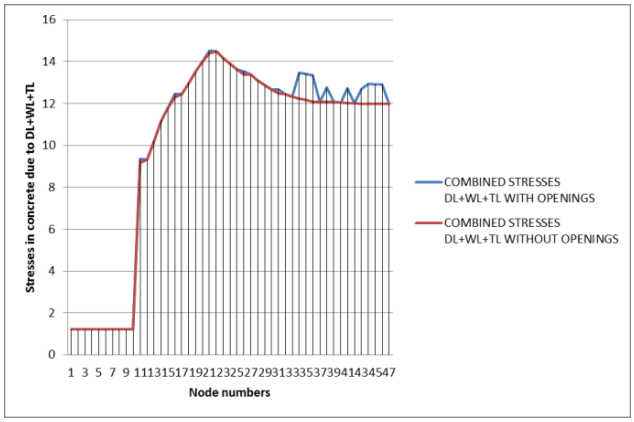

Fig.6. Comparison of Stress pattern for analysis of chimney with and without openings for load case Dead load + Wind load + Temperature loads.

VI. Conclusion

The openings provided at top half portion of the chimney shell are considerably small and have less impact on the concrete stresses of chimney shell whereas, the openings provided in the bottom half portion of the shell result in considerable stress variations. In this particular case, the stresses in shell with openings have been found 10-16 % higher than the stresses in shell without openings.

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AUTHOR'S PROFILE

Choppalli Kalyani Ramarao

obtained her bachelor's degree in civil engineering in 2006 from Jawaharlal Nehru Technological University (JNTU), Hyderabad, India and is currently pursuing her masters in Structural Engineering from Sardar Vallabhbhai Patel Institute of Technology (SVNIT), Surat, India.

Her areas of interest include Power Projects, Metro rail Projects, Steel Structures & Enabling works. She has worked with Gammon India Limited, Afcons Infrastructure Limited and Al Futtaim Carillion.

Dr. Yogesh D. Patil

obtained his bachelor's degree in Civil Engineering from Pune University, India in 1994 and M.E in Structural Engineering from South Gujarat University, India in 1999. He completed his Ph.D in Structures in 2010 from Sardar Vallabhbhai Patel Institute of Technology (SVNIT), Surat, India.

He is presently working as an Assistant Professor in Applied Mechanics Department, SVNIT, Surat. His major areas of interest include Earthquake Engineering, Reinforced Concrete Structures, Fiber Reinforced Concrete, Steel Structures & RC Beam Column Joints. In the past, he has also worked with companies like Larsen & Toubro.

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