Optimization of Tall RCC Chimneys: A Review

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Abstract— RCC chimney is tall, slender and self-standing structure. To attain its construction cost efficiency, achieving efficacy in design is a necessity. However its design is lengthy, laborious, and complex governed by many parameters and varying forces. Therefore designers assume values of various variables and then check them for safe stresses. Such structures though are stable but are generally overdesigned, so computerized optimization of design is required. This paper does the literature review of papers correlated to optimization of tall chimney design and carry out a wide-ranging assessment of various model parameters which influence its dimensions. This study also offers an updated material for researchers in this field.

Keywords: chimney, computerized, optimization, cost efficiency, model parameters

I. INTRODUCTION

Reinforced cement concrete chimneys are tall, slender and self-standing structures which are primarily used to discharge toxic gases at considerable heights into atmosphere. Reinforced concrete is the most favoured construction material for such structures and therefore need to be used efficiently. Since these structures are huge and slender; therefore they require better understanding of loads acting on them and their structural behavior. Design of a chimney involves many parameters and varying forces making the calculations lengthy, laborious and complex. The primary varying forces are wind force, seismic force, self-weight and temperature stresses. The wind force is affected by along wind force, across wind force or the combination of the two. Their estimation can be done by Random response method (Gust factor method) or Simplified method (Peak factor method) for along direction and Simplified method or Random response method for across direction wind loads. The effect of seismic force is calculated using static response spectrum method or time history method of analysis. The complex evaluation of the dynamic forces caused due to wind and earthquake compounds with the variation of various model parameters such as thickness of shell, taper of the stack, diameter of stack, shape of stack. Therefore to design such massive structures designers prefer to choose certain values of these model parameters based on prior experience and then they check them for the safe stresses. Such structures though are stable but are generally overdesigned. Therefore computerized optimization of the assumed values is required to obviate hit and trial procedure. It carries out a wide-ranging assessment of various modal parameters which influence its dimensions. This review paper does literature review of various papers correlated to the computerized optimization of chimneys and carry out a wide-ranging assessment of various model parameters which influence its dimensions.

II. LITERATURE REVIEW

A. Kapoor and Hariharan, 1973, in work,

"Optimal Design of Reinforced Concrete Chimneys" minimizes the cost of RCC chimney using mathematical programming technique. It finds value of design vector D which minimize cost of superstructure C = f(D). The Sequential Unconstrained Minimization Technique (SUMT) performed by the Variable Metric Method, a decomposition procedure, has been used to reduce the number of behavior constraints. Golden section search technique is used to perform linear minimization. The study concluded the following:-

1) Seismic force dominates upper half but wind loads predominate lower half of chimney.
2) Existing cost of chimneys couldn't be compared with optimised cost because of difference in design criteria.
3) The optimised cost range of chimney can be obtained.
4) Batter at the bottom and constant diameter from the top is more economical section.

B. Wakchaure et al., 2013, primarily focused in their paper,

"Cost Optimization of Reinforced Concrete Chimney" to develop cost optimization software in MATLAB to design a low cost RCC chimney. The optimtool module is used to find out the structure having minimum cost using interior point method. Conventional and optimal design comparison showed percentage savings in overall cost. Nonlinearities in constraints were handled by sequential quadratic programming (SQP). RCC Chimney having height 66 m, constant outer diameter of 4m and thickness varying from top to bottom in three steps was optimized. Thickness of shell at top segment (24m), middle segment (24m) and bottom segment (18m) kept as 200mm, 300mm and 400mm respectively. Optimal values obtained are for three cases which include segments of different heights: Case (I) 3 segments of 24m, 24m, and 18m; Case (II) 6 segments of 12m, 12m, 12m, 12m, 9m, and 9m; Case (III) 11 segments of 6m each. The study concluded the following:-

1) On increasing the numbers of segment, values became optimized.
2) In this software initial guess is important for getting more precise optimum values.

C. Narayan et al., 2015 in their paper,

"Interaction Envelopes for Limit State Design of Chimneys" focused on development of an interactive user friendly computer package employing rectangular stress block for creating interaction envelopes which can be used as design aids for tall stacks. The study concluded the following:-

1) Availability of interaction envelopes immensely help the designer in expeditiously solving the design problem however it will not give a true optimized structure values.

2) Adoption of rectangular stress block leads to slight conservatism.
3) Distribution of reinforcement in more than one layer can be done.

D. Rajkumar and Patil, 2013, in their paper,

"Analysis Of Self Supporting Chimney" analysed parametric model of RCC chimney of height from 150m to 250m at an interval of 5m, for hard soil in zone II, soft soil in zone V, wind speed varying from 33 m/s to 55 m/s with an internal temperature of 100^{o} C using Microsoft Visual Basic 6.0 and compared maximum values obtained due to wind and seismic loads. The study concluded the following:-

1) Wind loads are always governing the design of RCC Chimney.
2) Stresses induced due to seismic loads at critical Zone V, soft soil is almost equal to stresses induced by wind at minimum basic speed i.e., 33m/s.
3) The seismic response even at critical zone is not a design criterion.
4) Minimum M25 grade concrete to be used since lower grade fail in permissible stresses.
5) Near the top of chimney temperature is a design criterion.

E. Menon and Rao, 1997, in their paper,

"Uncertainties in Codal Recommendations for Across-Wind" identified conditions wherein across-wind response, instead of along-wind response govern the design. Two separate chimneys with little or no taper and highly taper have been analysed by simplified modal analysis and equivalent static model analysis. The condition of highly tapered is governed by IS 4998: $(D_t/D_{b)} < 1- [(H/D_b)/25]$. The study concluded the following:-

1) Across-wind loading is unlikely to predominate if the tower is highly tapered.
2) Slender but cylindrical chimneys have possibilities of the second mode (across-wind) condition becoming critical.

F. Remyasree and Vijayan, 2016, in their study,

"Non-Linear Seismic Analysis of Reinforced Concrete Chimney" focused the effect of wind load, earthquake load as well as temperature effects on 30 models of RCC chimneys with 5 different heights varying from 275m to 400m with three different radius-thickness ratios and for different longitudinal sections such as tapered and partially tapered. Along wind analysis was carried out using the simplified method and seismic analysis by time history analysis on the software SAP 2000 v14., Wind analysis were done to study variation of displacement and shell stress and seismic analysis were conducted to study peak displacement besides temperature effects analysis also. The results indicated the following:-

1) Radius-thickness ratio increases the shell stress but decrease displacement values.
2) When compared to partially tapered section, fully tapered chimney exhibits lesser displacement value for the wind, seismic and temperature effects.

G. Baiju and Geethu, 2016, in their paper,

"Analysis of Tall RC Chimney as per Indian Codes" did a parametric study to understand the variation of lateral deflection at the top on uniformly tapered of 1 in 50 taper, single flue, brick lined, circular RCC chimneys having height-to-base diameter ratio as 12 and height ranging from 275 m to 315 m at an interval of 10 m. Dead load, wind load and temperature stresses have been considered for analysis by limiting deflection at top to H/500. The study concluded that the wind effects are major constituent as compared to temperature effects.

H. Nagar et al., 2015, in their study,

"Non Liner Dynamic Analysis of RCC Chimney" determined the nonlinear behavior of chimney using software SAP-2000 by carrying out time history analysis for seismic loads and gust factor analysis for along wind loads on twelve models of different heights varying from 150 to 300m but of different longitudinal sections such as uniform, tapered and uniform-tapered. Resulting peak displacement, acceleration from wind analysis and joint displacements, base shear from seismic analysis are compared. The study concluded that uniform tapered RCC chimney exhibited minimum displacement for both seismic and wind load effects hence is best suitable section.

I. Shaikh and Khan, 2014, in their work,

"Governing Loads for Design of A tall RCC Chimney" compared results of wind analysis with seismic analysis at various sections along its height for deciding the design values. Wind analysis for along wind is done by peak factor method as well as by gust factor method and for across wind by simplified method as well as by random response method. Seismic analysis is performed using static response spectrum method. The study concluded the following:-

1) Effect of wind forces is quite significant as compared to earthquake forces.
2) The geometry of chimney has to be so chosen that the deflection at the top is within permissible limits.

J. Reddy et al., 2012, in their paper,

"Study of Wind Load Effects on Tall RC Chimneys" presents the study of along and across wind effects on a 275m tall twin flue RCC lined chimneys for Ist & VIth wind zones of India. The study concluded the following:-

1) Across wind loads for zone I and along wind loads for zone VI are governing loads.
2) Shear force, bending moment and deflection for across wind are same in both zones because the across wind calculation is directly proportional to the weight of the chimney, frequency and its mode shapes, but not on the wind speed.

K. Prasad et al., 2018, in their paper,

"Earthquake and Wind Analysis of a 100m Industrial RCC Chimney" compared wind analysis results with seismic analysis results. The study concluded that wind loads are the governing loads because effect of wind force is quite significant as compared to seismic forces.

L. Pradeep and Prasad, 2014, in their paper,

"Governing Loads for Design Of A 60m Industrial RCC Chimney" compared wind and seismic analysis results for 60m RCC chimney by generating chimney model in STAAD

Pro. Eight node solid element model and line element model were considered. The study concluded the following:-

1) Deflection value for the 8 node solid element model and the linear model are same.
2) Effect of wind force is quite significant as compared to the earthquake forces.

M. M. Reddy et al., 2011, in their paper,

"Wind and Earthquake Analysis of Tall RC Chimneys" analyzed and compared design wind loads and earthquake loads on two chimneys to decide the most critical loads for the design of chimney shell. The study concluded that the combined design wind loads are always governing the design of chimney shell.

N. N. Kumar et al., 2017, in their paper,

"A Parametric Study On Lateral Load Resistance Of Steel Chimneys" presents a computer aided investigation on chimneys of overall heights 90m and 110m subjected to wind and seismic loads using STAAD Pro software for seismic Zones II, III, IV and V and wind loads of basic wind speeds 39m/sec, 44m/sec, 49m/sec, and 50m/sec. Maximum shear force, bending moments, lateral displacements and mode shapes are determined and compared to study the structural response of steel stacks. The study concluded that there is more impact of wind load on the chimney when compared to seismic load.

III. Conclusions

This paper discussed several papers which focused to optimize the design of RCC chimney and its analysis governed by various forces and varying model parameters. From the review article following conclusions can be drawn for a tall RCC chimney:-

1) Wind forces are quite significant as compared to earthquake forces.
2) The seismic response even at critical zone is not a design criterion.
3) Temperature is also a design criterion especially near the top of chimney.
4) Across-wind loading is unlikely to predominate if the tower is highly tapered.
5) Fully uniform tapered chimney exhibits lesser displacement value for wind, temperature and seismic effects as compared to partially tapered section, hence is best suitable section.
6) Though radius-thickness ratio increased shell stress but displacement values decreased.
7) Distribution of reinforcement in more than one layer is possible.
8) M25 or higher grade of concrete to be used for chimney construction.
9) Deflection value for 8 node solid element model and linear model are same.

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