Effect of Lateral Loads and Soil Structure Interface on Structural Performance of RCC Chimney

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Abstract*—Chimneys are distinguished requirements for Power generation and other Manufacturing areas which are vital to be constructed vertically to discharge combustion gases and chemical waste gases to the environment. Due to the hasty growth of mechanization and escalating the requirement to control of Air pollution, the construction of tall Chimneys becomes a regular structure in contemporary circumstances. Tall chimney shells generally designed to resist vertical and lateral loads especially due to the effect of Wind and Earthquake. RCC Chimney shell will transfer these vertical and lateral loads to its foundation system. Soil Structure Interaction (SSI) is the response of soil which impacts the behavior of the structure or behavior of the structure which affects on response of soil. Soil Structure Interaction is essential for tall structures which especially resting on soft soil strata. This review work presents a widespread appraisal of the research presented in the area of RCC chimney and communicates most recent enlightenments and improvements happened in the analysis and design. This paper makes an attempt on focusing the modeling features of RCC chimneys which contains analysis, design aspects and several case studies, with the help of various software programs with the effects of lateral loads and soil structure interaction. The present review paper also corresponds to a complete anthology of the research accomplished on RCC chimney and will gives rationalized technical information for the researchers.

Keywords— Chimney, along and Across Wind load, Earthquake load, Soil structure interaction, Dynamic Analysis.

I. INTRODUCTION

India has been motivated to overcome the electrical power crisis due to rapid growth in the economic thunder in the country. At the same time Pollution norms have become stringent over the time, the chimney heights have risen up gradually from 110 m to 150 m to 225 m to 275 m and more even. In most of the thermal power plants, 275 m tall concrete chimneys have now become the standard norm. This fly ash is being extracted using Electro Static precipitators, which incidentally can be used in blended cements and also as one of the mineral admixture in concrete. Chimneys being tall slender structures and having its own kind of structural requirements associated with and therefore must be treated specifically from other kind of tower structures.

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In case the chimney is located in higher seismic zone with lower wind speeds, seismic force will become the governing case whereas in lower seismic zone, than the wind loads may become analogous.

During Earthquakes, ground displacements will takes place in response to the movement of the structure and soil response affects the behavior of the structure. Many of tall chimneys are flexible nature in structural point of view and with fixed base will induce a base acceleration depends on nature of the soil which the structure is being constructed. Such flexible structures which vibrate during earthquakes, the acceleration at the top portions of the chimney will be subjected with much higher accelerations than the ground acceleration which we generally gives as an input to perform the analysis. Soil structure interaction is prominent when tall chimneys are located on the soft soil compared with hard strata or stiff soil.

II. REVIEW ON EFFECT OF LATERAL LOADS

Analysis and Design of RCC chimneys shall be done for which they are subjected to Lateral loads i.e., wind and earthquake/seismic loads. The chimney analysis and design is to be done in due consideration with along-wind load and across-wind load. The recent tendency in wind analysis is final wind load to be the addition of of the two parts. One part is based on the mean or average wind speed and the other part is based on the wavering or fluctuating wind part comprising of gust effect. The mean or average wind load part is relates to the square of the wind speed at the particular location. The dynamic contribution used to evaluate with gust response factor methodology which is to be controlled by natural frequency, damping, numerical cross sectional properties of the chimney etc. Across wind loads due to vortex shedding in first and second modes of vibration shall be considered in the chimney analysis. The Design responses in the chimney due to earthquake or seismic effect will be assessed as per the specified codal provisions of IS 1893 (Part 4) based on simplified method (equivalent static lateral force method). Then the dynamic response (spectrum modal analysis) also required to be performed for evaluating the seismic responses built up in the chimney. The below presented literature is on the research work done for the analysis of Tall structures with most emphasis on Chimney structures with the effect of lateral loads.

Alok David John[1] et al, This paper concentrates on calculation of flexural responses due to across-wind effect, which is more preponderant for the case of hindrance at an angle of 45^o with the direction of wind. Bending moment calculated for this effect is about 200 percent when analogized with normal wind effect. To counter this effect, strakes are proposed for the top 33 percent portion of the chimney height, with which it is observed a considerable decrease in the resulting forces and moments.

KRC Reddy[2], he presented along wind analysis of chimneys by random vibration approach and specifications given in Indian, American and Australian codes of practice. RC chimneys have been modeled as MDOF system subjected to static load and dynamic load due to mean component and fluctuating components wind loads. The fluctuating component of wind velocity at a point is assumed as sequential random process. Four numbers of chimneys are considered for research using the above specifications for studying their responses. It is concluded that these methods are simple in nature, are not provided to evaluate the chimney displacements and producing different results. Also discussed the assumptions which used in the codes of practice have been discussed.

Lokeshwaran. N[3] et al, Authors considered in the research that chimneys with circular and elliptical cross sections with different heights and two different profiles in elevation. One is narrowed from bottom to top and the other narrowed from bottom to 0.67H and straight henceforth are analyzed for the effects of earthquake and vortex shedding reasoned by wind forces. Analyses also have been carried out for different diameter thickness ratios. Out of total number of models have been analyzed, half numbers for earthquake forces and another half numbers for effect of vortex shedding. Analytical results in terms of stresses induced on the structure, earthquake base shear, joint acceleration, joint displacements and vortex shedding base shear are evaluated. The results indicated that output parameters for circular and elliptical cross-sections show significant variations.

K. S. Babu Narayan[4] et al, A computer Algorithm has been developed for developing interaction envelops for helping in reduction of computational time for the design of tall chimneys. This is recommended by authors to be used in structural optimization works in which the total cost can be reduced or by increasing strength and efficiency of the structure, cost benefit ratio could be increased.

C. K. Ramarao[5] et al, In this research, 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.

T. Subramani[6] et al, Authors described a simplistic method for evaluating the natural time period, horizontal displacement, shear and bending responses developed with the help of a group of mathematical expressions, for targeting the evaluation error becomes below 10%. These results are used for already constructed RCC and steel chimneys. At the analysis stage, it corroborates that the basis of consistent masses offers superior responses than the basis of lumped masses. Characteristic indicators have been presented to describe the model with which to carry out a statistical analysis of the chimney. This paper also concludes that the earthquake effect is main reason for damages to the structure which could be reduced further when the analysis and design shall be based on the stress criterion.

Prof. Udaysingh Patil[7] et al, Different cross sections of steel chimneys are analyzed for static as well as dynamic response of wind by Indian standard code (IS 875 Part III and IS 6533), Australian / New Zealand code (AS/NZS: 1170: 2002 for wind action) and Euro code (DD ENV 1991-2 -4: 1995 for wind action) for along as well as across wind response. A comparative study has been made on static moment at the base of steel chimney by conventional method with the static moment obtained by IS 6533 Part 2. Similarly the dynamic moment at the base of the steel chimney are compared considering IS 6533 part2, AS/NZS: 1170.2: 2002 and DD ENV 1991 -2 - 4: 1995. Analysis has been carried out using STAAD PRO software considering three codes and it is observed that moment obtained at the base of steel chimney by IS 6533 part 2 using terrain height multiplier factors from table no 33 instead of table no 2 the total design moment are drastically reduced and hence its beneficial. Tedious procedure for determining the coefficient of dynamic response is given in this EURO standard which can be countered using spreadsheets. Large variation in maximum wind speed is observed in Indian code and Australian Code because of difference in terrain height multiplier factor. The moment obtained by using Australian code is least amongst all three codes because the coefficient of dynamic forces C_{dyn} is least when compared to the other two codes. Indian standard code gives maximum moment at the base of chimney as it gives total design moment i.e., sum of static and dynamic moments. Moments obtained by Euro code when compared with other two codes increases for height less than 60 m because the coefficient of dynamic force increases for chimneys less than 60 m in height.

Anusha S[8] et al, The reliability analysis has been carried out by using Monte Carlo simulation for stresses in concrete and steel due to wind load and also for combined effect of wind load, self weight and temperature. The number of cases which correspond to the generated stress being larger than the permissible stress is counted. The probability of failure P_f is computed by considering resistance and action to be normal deviates. The details on randomness of design variables are presented. Reliability analysis of an RC chimney subjected to wind load and temperature stresses is presented. Probability of stress up-crossing is computed using the MC simulation method. The method demonstrates that there is always a probability, however small, that the induced stress may exceed the permissible stress, even though deterministically the condition is satisfied. By establishing the probability distribution to describe the failure rate, it is possible to keep the failure rate as low as possible.

A. Rashmi[9] et al, This paper deals with the analysis of RC chimney using linear static method for 180m height RC chimney using SAP 2000 software. The effect of various parameters like grade of concrete, openings, different seismic zones, various thickness, soil conditions and for various other geometric parameters of the chimney on the seismic performance of the structure. A parametric research is accomplished to know the response of various parameters on the base shear and fundamental time period. Also comparison of base shear and fundamental time period from SAP 2000 with that obtain from IS codal provision.

S.Sowjanya Lakshmi[10]et al, All the criteria involved in the analysis and studied the response of RC Chimneys. All the loads that are to be considered during the analysis phase of the chimney were taken into account. Out of all the loads considered the most important were found to be the wind loads. The earthquake loads or seismic loads were not found to be critical for design. The methods suggested by the IS code were studied. Calculations were however done using the response spectrum method. The moment profile was calculated and plotted. The loads due to seismic action were found to be far less than that from the wind velocities, and hence it would not be a major consideration in design.

N. Victor Babu[11] et al, This paper presented a computer aided investigation on the seismic and wind effects on chimneys of different heights in the Indian scenario. Self supported steel stacks of overall height 90m and 110m subjected to wind and seismic loads are considered in this study. The chimneys are analyzed using STAAD.Pro software for seismic Zones II, III, IV and V and wind loads of basic wind speeds 39m/sec, 44msec, 49m/sec, and 50m/sec. Maximum shear force and bending moments developed in the steel stacks along with lateral displacements and mode shapes are determined and compared to study the structural response of steel stacks.

S.S Patil[12] et al, In this paper, equations were developed considering a standard case of tall RCC chimney with one end fixed and other end free. Loads considered were a combination wind load and dead load of the structure. Wind load has been calculated as per IS 4998 (Part 1): 1992. Across wind loads were neglected as it is a part of dynamic analysis. Finally the values obtained by carrying out the analysis by first order and second order are compared and also with the positive variation in height has been analyzed. Beam column theory has been used for the analysis. Concluded that, using beam-column theory slender chimney can be analyzed for secondary moment with lateral deformation. Also concluded that second order effect increases with increase in height.

Remyasree A R[13] et al, This study focused the effect of wind load, earthquake load as well as temperature effects on reinforced concrete (RC) chimneys. Wind analysis was carried out by along wind effects by using the Simplified method and seismic analysis by time history analysis for different heights varying from 275m to 400m with three different radius-thickness ratios and for different longitudinal sections such as tapered and partially tapered by using the software SAP2000v14. Analyses were conducted to study the variation of displacement and shell stress for the wind analysis, peak displacement for the seismic analysis and temperature effects. The results indicated that as the radius-thickness ratio increases the displacement values were decreasing. The RC chimney with more height and the partially tapered section will be critical compared to fully tapered chimney for the wind, seismic and temperature effects and fully tapered chimney structure exhibiting minimum displacement.

Dr. B K Raghu Prasad[14] et al, This paper attempted to evaluate the effect of pendulum dampers having diversified natural frequencies. The damper which is having the more equivalent logarithmic decrement is established to decrease the response considerably. Response has been also compared with that of chimney lumped with mass at its tip. This paper also discussed the dynamic analysis of 150m height fixed base RCC chimney for the wing effect. The displacement, velocity and acceleration have been decreased to the chimney with the pendulum damper. The displacement, velocity and acceleration also decreased considerably for different modes, when tip mass is added.

III. REVIEW ON SOIL STRUCTURE INTERFACE EFFECT ON STRUCTURAL PERFORMANCE

A common hypothesis in large amount of research on controlling of the seismic or earthquake reaction of structures or buildings is that the soil structure interface effect are little and also negligible. The design is generally being performed with fixed base condition and responses from dynamic analysis.

Soil-structure interaction studies the on dynamic wind or earthquake response of tall RCC chimneys have not received much awareness till date, though some attempts have been made for the seismic analysis of tall chimneys with the influence of soil flexibility.

Flexibility effect of soil continuum results in enhancing of natural time period in lateral direction due to the overall diminution in structure stiffness in lateral direction. Such escalation in the natural time period may significantly changes the seismic response behavior of the structures or buildings which are resting on rigid foundation. Therefore during analysis, it is being required to think about the soil flexibility beneath the foundation.

The below presented literature based on the research work done on analysis, design and study of Tall structures and most emphasis on Chimney structures for the soil structure interface effect.

Indrajit Chowdhury[15], Author discussed about the estimation of Earthquake loads as per IS 1893 part 4. He also proposed few improvements to fill the gap between codal provisions and industry practices and made the design more meaningful and realistic by introducing a term Dynamic Soil Structure interaction. A design methodology and procedure has been presented in the paper. He evaluated that the method proposed by him compares with the code with the help of real life chimney of height 272 m.

B. R. Jayalekshmi[16] et al, The radial and tangential forces and moments in the chimney shell, horizontal displacements along the height of the chimney and moment at the base of the chimney were assessed with SSI analysis and differentiated with the results found from the fixed base chimney.

The moment at the chimney base significantly decreases due to the SSI effect. It is observed that the changes in various analytical results in the chimney due to the SSI effect influenced considerably by the various parameters of chimney and its sub structure. Horizontal displacement, tangential and radial moments augment with increase in the soil flexibility whereas the chimney base moment increases with decrease in soil flexibility. It is also observed that the various responses in chimney are increased effectively with the reduction in the pile cap thickness. The variations of tangential and radial moments are observed superior in increase in the chimney slenderness. A significant change of tangential moments are observed in the higher elevated chimneys whereas the substantial changes in the radial moment is observed all chimneys under consideration.

Fathima S[17] et al, In this present research the earthquake response of the RCC chimneys of different heights with considering soil flexibility are being analyzed. Equivalent static method as per earlier version of IS 1893 has been used for the 3D FEM and free vibration analysis of combined chimney super structure, sub structure and soil system. The results are achieved for various soil conditions i.e., loose soil to hard condition. Lateral deflection at chimney top and tangential and radial responses of chimney shells are evaluated with SSI effect and collated that with traditional analysis.

Indrajit Chowdhury[18] et al, This paper proposed a closed-form analytic mathematical model from the first principles of dynamics to determine the aerodynamic SSI of a tall chimney. The procedure extends the design procedures which can commonly adopted in industry. The aerodynamic response of a tall chimney is studied for various soil stiffness values and the amplification are compared with the fixed base response as conventionally obtained by practicing engineers. The method does not require elaborate computational effort and thus could be attractive to engineers in the industry. Aerodynamic forces are amplified due to SSI and the current practice of designing chimneys using a fixed base approach and considering it to be safe is neither correct nor conservative. For the adopted chimney-soil- foundation system, amplification can be as high as 16%.

A. Parvathy Karthika[19] et al, From the literature review, performance of the multi-storied buildings of ten (G+10) and twenty storey (G+20) with ground floor, located under fixed support and over raft foundation of varying depth 0.8 m, 1 m, and 1.2 m. Area springs are included in the local 'z' axis to make the foundation flexible there by creating the soil structure interface effect. The building response is analyzed in terms of natural time period, horizontal deflection, storey drift and seismic base shear. This study shows that, the SSI will have an influence on dynamic behavior of the building needs to be considered in the design of earthquake resistant buildings.

Negar Sadegh Pour[20] et al, The present paper proposed an analytical model for both seismic and fluctuating wind response of tall chimneys and studied for various soil stiffness and are compared with the fixed base conventional method as per UBC 97(for seismic load) and CICIND (for wind loading). The salient feature of this analytical research is unlike adding the soil stiffness to the diagonal terms of the stiffness matrix it used a modified mathematical model (considering multi-degree of freedom) for soil coupling as was developed originally by Veletsos and Meek for single degree of freedom. This paper also extended this theory to accommodate the material and radiation damping of the soil within the modal analysis framework for dynamic soil structure interaction (DSSI) response for the chimney. This paper concluded that the proposed method is being semi analytic and does not required to elaborate modeling effort thus could make it computationally attractive for engineers undertaking design of such chimneys in the industry.

Kuladeepu M N[21] et al, In the research, the dynamic performance of structural space frames resting on raft foundation against earthquake forces combining with soil structure interface effect is contemplated SAP2000 software. For the combined analysis, sub structure and soil strata are contemplated as components of a solitary element. A realistic soil model has been substituted for the soil strata beneath the foundation. In this case, soil is assumed to be homogeneous, isotropic, elastic half space for which dynamic shear modulus and Poisson's ratio are the required parameters. Effect of variables which number of floors, soil strata and height to lateral dimension ratio for critical Indian seismic zone is also evaluated. Structural reactions or effects are studied for space frame with and without contemplating the Soil Stiffness. Horizontal natural time period and earthquake base shear, lateral deflections and story drifts for both cases are differentiated to study the particular effect on structural space frames.

G. Saad, F[22] et al, This research outcome presented the earthquake response of RC building frames with several basement stories. Suggestions presented on the numeral or proportion of basement stories to be considered for the analysis of RC shear wall building frames. As a conventional case, buildings are idealized with a fixed base at foundation level, and then the number of underground levels is consistently enhanced to study the difference in performance of the building frames. Base shear, bending moment and inter-story shears have been assessed to know the soil structure interface effect on the design procedure.

I. Chowdhury[23] et al, The present research paper presented various analytical expressions on modal analysis contemplating the dynamic soil structure interaction. The final outcome is also presented with STAAD Pro software to know on the disparities. The study also demonstrated the significance of including the dynamic soil structure interface effect for the analysis of tall stacks subjected to earthquake forces.

Aneet Khombe,[24] et al, The present paper deals with dynamic analysis of chimney which comprises linear and non linear analysis, soil structure interaction studies and seismic and wind analysis. The effect of foundation flexibility on the reinforcement concrete chimneys to wind excitation can be significant and should be addressed in design stage. None of the present codes mentioned any method for estimation of influence of soil structure interaction. Authors advised to consider the soil structure interaction consequences for the assessment of wind load in different codes.

It is established that earthquake response of chimneys is affected considerably by supporting soil beneath the foundation and nature of earthquake excitations manifesting the substructure. The chimney behavior could be considerably affects during earthquake in case of disregarding any one of the above parameters, and also leads to destructive consequences.

IV. NEED FOR THE FURTHER RESEARCH

With the literature presented in this paper it is understood that the chimney structures needs to be designed for latest codes established in resent past by Bureau of Indian Standards on Wind loads and Earthquake loads (IS 4998-2015[25] and IS 1893 [Part 4] – 2015[26]). It is being observed from the literature that very few or none are presented the use of latest revised codes. It is also experiential from the literature furnished above that very few research has been going on the consequences of soil structure interface on structural behavior and its foundation system. The effect of foundation flexibility on the reinforced concrete chimneys due to wind excitation can be considerable and should be addressed in the design stage. None of the present codes proposed any method for estimation of effect of soil structure interaction. It is advisable to take soil structure interface effects into account for calculation of wind load in various codes across the design world. A parametric study is required with the contemplation the variables like seismic zones, wind zones, height of chimney, geometric aspect ratios of chimney, soil flexibility, foundation system adopted; study to be done for their effect on over all structural behavior of RCC chimney and its foundation subjected to lateral loads. Simplified methods for across wind load calculation presented in the latest revised Indian code of practice shall be required to study on the behavior of Chimney.

V. SUMMARY

The present paper focused on the research literature established on the structural behavior of the RCC chimney with the effect of lateral loads and consideration of soil flexibility.

From the present paper, conclusions could be drawn that procedures mentioned in the latest revised code of practice across the design world are to be taken into effect in the upcoming design and analysis of chimney structures. The use of latest codes plays major role in the design industry for increase in the optimization of structural elements and also increase in the stability, strength along with over all behavior of the chimney structure.

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