Effect of Soil–Structure Interaction on the Dynamic Stability of Self-Supporting and Guyed Chimneys with Applications in Industrial Environmental Safety

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ABSTRACT

In the present study, 72m tall self-supporting and guyed chimneys are analysed for earthquake and wind loads considering three different soil conditions using SAP2000. Earthquake analysis is performed as per IS 1893-2016 and wind analysis is done as per IS 875(Part 3)-2015. Three methods, i.e., Seismic coefficient method, Response spectrum method & time history method are used for the seismic analysis. The response of chimney is derived in the form of displacement and base shear for different soil conditions. From the study, it is concluded that underlying soil plays important role on dynamic behaviour of tall self-supporting and guyed chimneys.

Keywords: *Environment pollution, Self-supporting chimney, Guyed chimney, Soil structure interaction, Lateral displacement.*

I. INTRODUCTION

Scientific detections have led to the establishment of several kind of industries. These industries emit dangerous gases into the atmosphere. For a more desirable control of environmental pollution, the creation of tall smokestack has taken place. With increase in chimney height, the seismic activity and wind effect have become vital. Smokestacks are established at least 5m higher than the highest building in locality areas with in its 150m radius. Various materials are utilized for the construction of self-supporting and guyed chimneys.

In self-supporting steel smokestacks, lateral forces are transmitted to the foundation by the cantilever action of the stacks. In guyed smokestacks, the steel wire ropes or guys are attached to transmit the lateral loads.

Varma and Reddy [1] carried out analysis of self-supported and guyed steel chimneys under wind and seismic forces considering various heights by using STAAD Pro software and observed that lateral displacement decreases in guyed chimney as compared to self-supported chimneys. Kharade et al. [2] analysed tall sky-pod structure considering soil structure interaction and concluded that displacement increases at top due to SSI effect. Prasad et al. [3] found that wind loads are predominant in the steel chimney. Sagar and Gudadappanavar [4] analysed steel chimney having height of 65m and concluded that displacement is more in Zone 5 as compared to other Zones. Sreerath and Basheer [5] indicated that seismic forces are the governing factor for reinforced concrete stack.

II. OBJECTIVES OF STUDY

The main objectives of the study are summarized below:

- To study time history analysis of guyed and self-supporting chimneys.
- To study dynamic behaviour of chimneys considering fixed base and different kinds of soils such as stiff clay, dense sandy and stiff hard.
- To study effect of wind load on guyed and self-supporting chimneys at different wind speed.
- To compare result of guyed and self-supporting chimneys.

III. VALIDATION OF RESULTS

For validation purpose, comparison has been made with results of paper titled "Computerized virtual study on self-supporting and guyed steel chimney" Varma& Reddy[1]. In this paper, authors have carried out work on self-supporting and guyed chimneys. Both 54m tall chimneys are modelled in finite element software considering basic wind speed of 33m/s, 47m/s and 55m/s. The diameter of both chimneys is as 3m taken. Soil structure interaction is not considered in this study. The outcome of maximum lateral displacement for both chimneys is compared. For steel chimney, uniform thickness is considered throughout the case. Comparison between results of software and Varma & Reddy[1] are shown in Figures 1 & 2.

Figures:

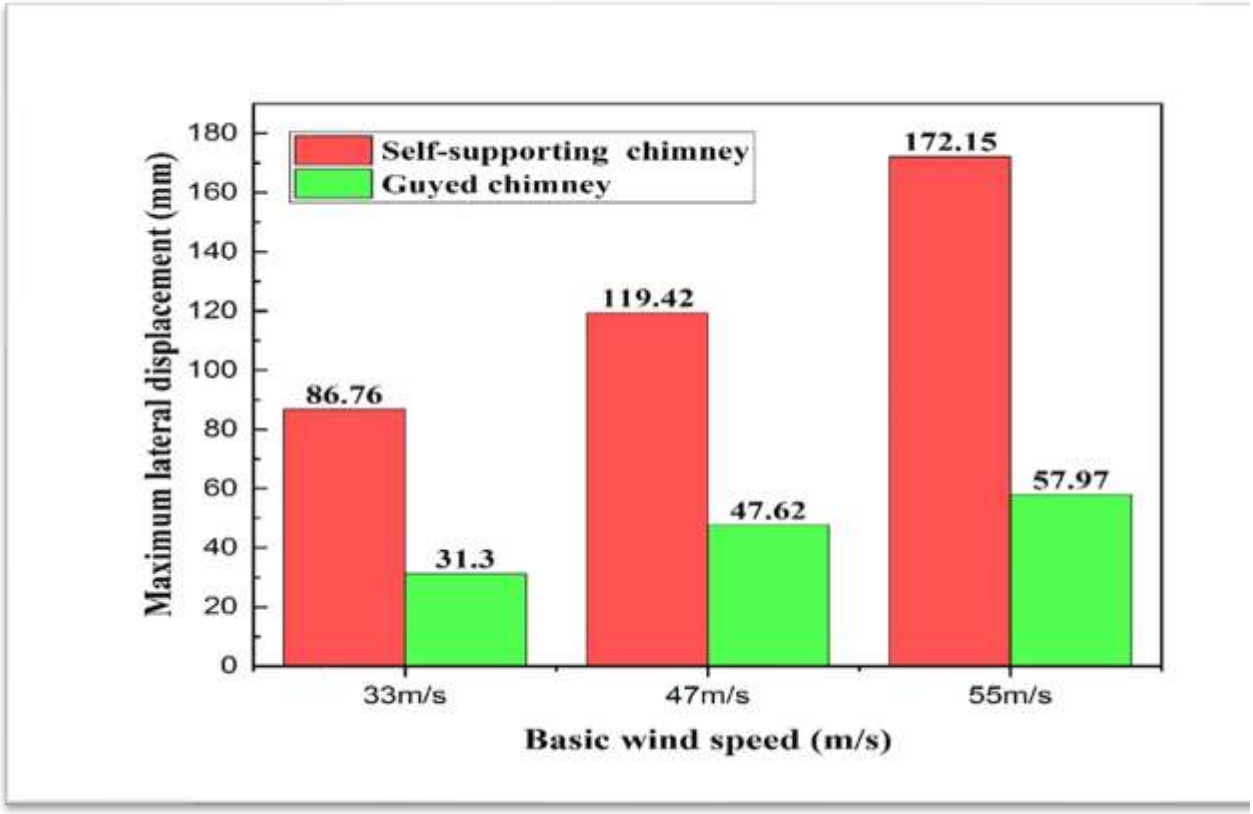

Figure 1. Software result

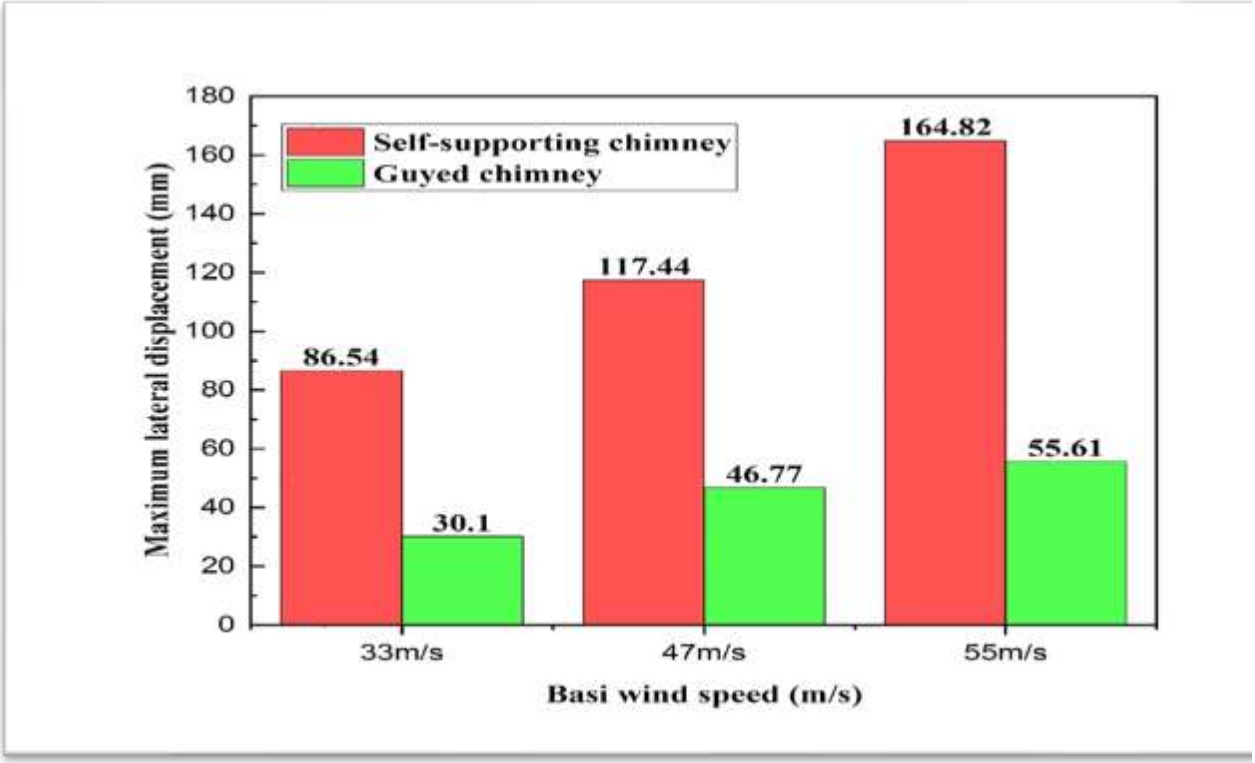

Figure 2. Varma& Reddy [1] result

IV. SOIL STRUCTURE INTERACTION

For current study, the soil is represented as solid in finite element software as shown in Figures 3 and 4. Various categories of soil like thestiff clayey, dense sandy and stiff hard are considered in the study. The several required properties of soil shown in Table 1 are taken from Kharade et al. [2].

Table:

Table 1. Soil Properties for Model

Soil type	Stiff Clayey	Dense Sandy	Stiff Hard
Poisson's ratio	0.45	0.40	0.30
Elastic Modulus (kN/m^2)	135000	200000	320000
Shear Modulus (kN/m^2)	46550	71425	123000

V. WIND LOAD

In the present case, 72m tall self-supporting and guyed chimneys are modelled in finite element software considering basic wind speed of 33m/s, 44m/s and 50m/s. The diameter is 3m taken for both chimneys. Soil structure interaction is considered in this study. So, $k_1$the risk coefficient, k_3 topography factor, and k_2 are calculated utilizing IS:875(Part 3)-2015.

VI. EARTHQUAKE LOAD

In this problem, 72m tall self-supporting and guyed chimneys modelled in finite element software are taken. The diameter is taken as 3m for both chimneys. Bhuj earthquake of 2001 is applied on both chimneys. The response of

Table 2. Displacement for self-supporting at wind speed of 33m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
24				
48				
72				

Table 3.Displacement for guyed at wind speed of 33m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)

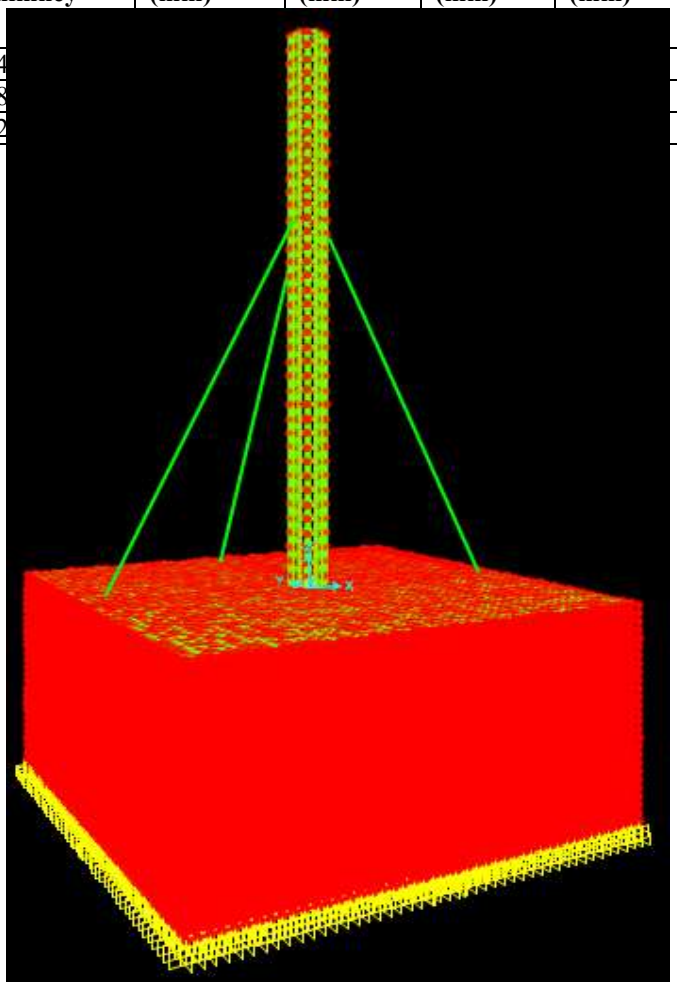

Figure 3. Model of Guyed chimney with different Soil

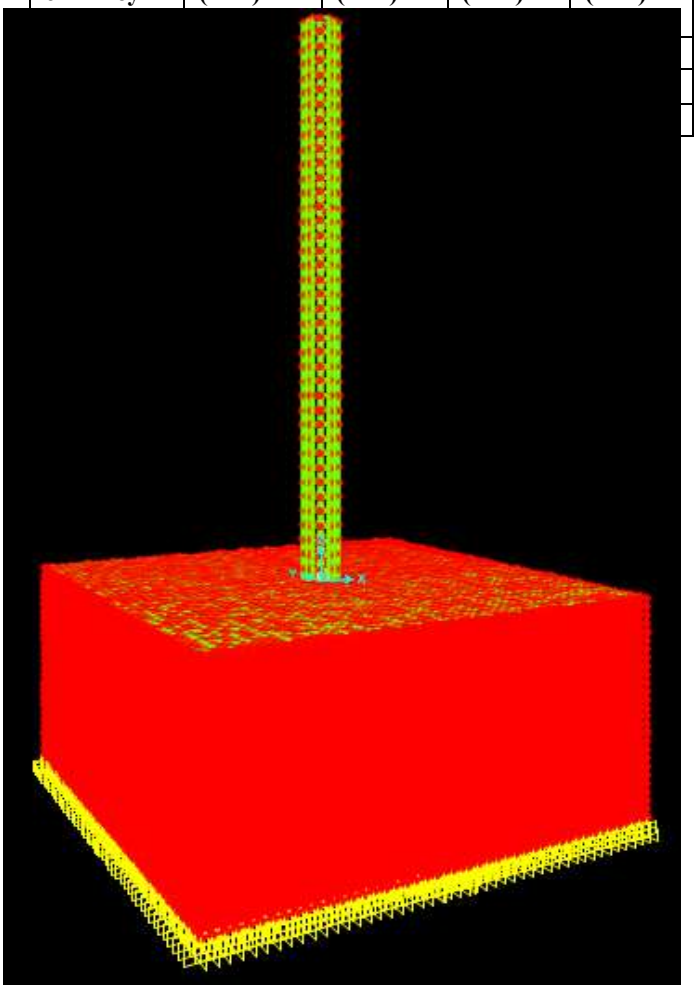

Figure 4. Model of Self-supporting chimney with different Soil

smokestacks is derived in the form of displacement and base shear for different soil conditions. Earthquake analysis is performed as per IS 1893-2016.

Figures:

VII. RESULTS AND COMPARISON

Result of lateral displacement for self-supporting and guyed chimneys considering different soil conditions at different height of chimneys are shown in Tables 2-7.

Tables:

Table 4. Displacement for self-supporting at wind speed of 44m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
24m	28.32	250.01	188.43	134.19
48m	89.78	533.71	411.04	302.95
72m	160.58	827.32	643.54	481.60

Table 5. Displacement for guyed at wind speed of 44m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
24m	19.39	78.03	69.06	58.38
48m	58.62	157.72	142.67	124.84
72m	109.03	251.89	230.37	204.92

Table 6.Displacement for self-supporting at wind speed of 50m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
24m	36.58	322.84	243.33	173.29
48m	115.94	689.2	530.78	391.24
72m	207.36	1068.33	831.023	621.91

Table 7.Displacement for guyed at wind speed of 50m/s

Different height of chimney	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
24m	25.04	100.76	89.19	75.39
48m	75.70	203.67	184.23	161.2
72m	140.79	325.28	297.48	264.6

Results of maximum lateral displacement forself-supporting and guyed chimneys considering different soil conditions are represented graphically in Figures 5 and 6.

Figures:

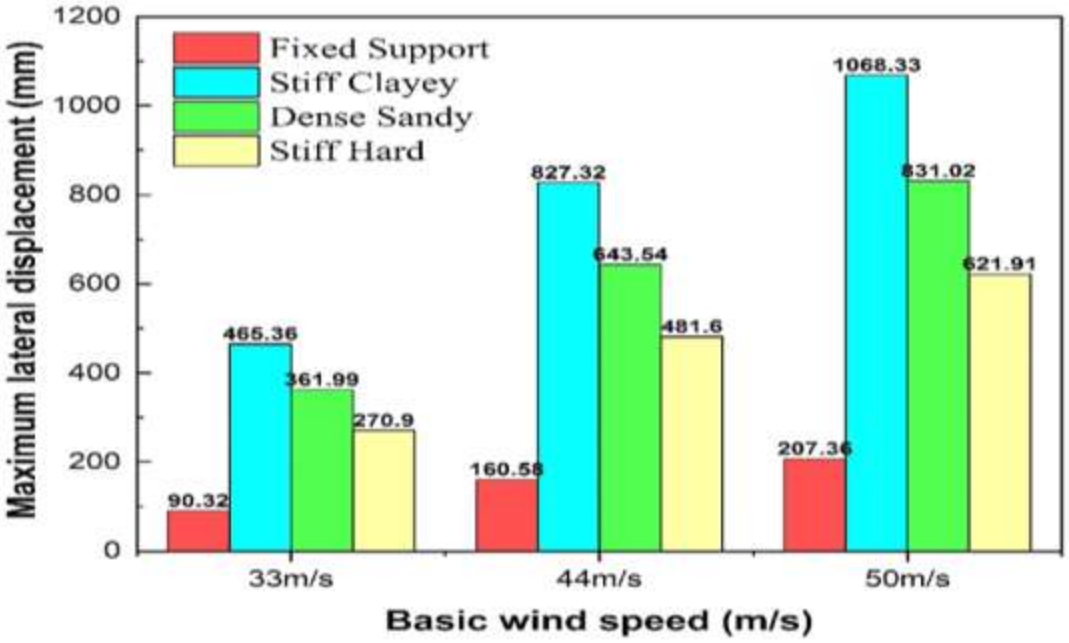

Figure 5. Maximum lateral displacement for self-supporting chimney

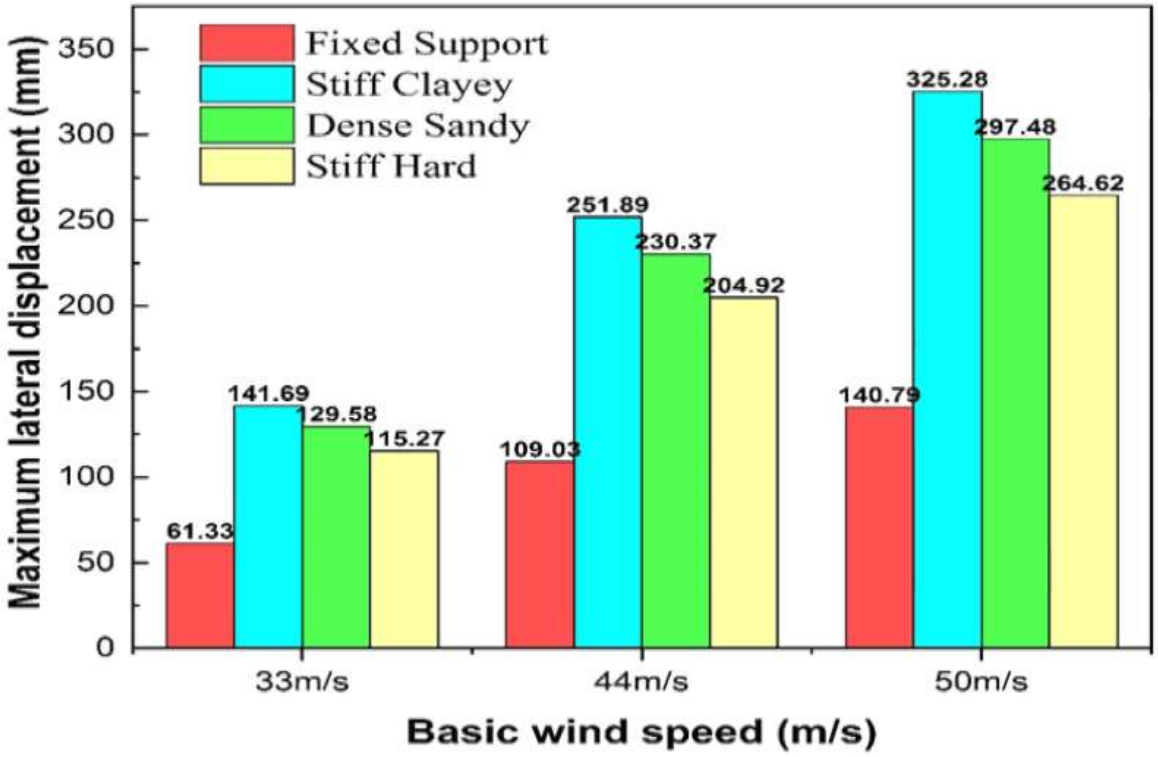

Figure 6. Maximum lateral displacement for Guyed chimney

Comparisons of time period for self-supporting and guyed chimneys considering different soil conditions are tabulated in Table 8.

Table:

Table 8.Comparisons of Time period

Type of Chimney	Fixed Support	Stiff Clayey	Dense Sandy	Stiff Hard
Self-Supporting Chimney	1.301	2.886	2.541	2.193
Guyed Chimney	1.174	1.980	1.852	1.700

Results of Earthquake Load

Results of Maximum lateral displacement for self-supporting and guyed chimneys considering different soil conditions are tabulated in Tables 9 & 10.

Tables:

Table 9. Maximum displacement for self-supporting chimney

Method	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
Seismic coefficient method	51.18	89.93	79.91	69.90
Response spectrum Method	30.55	65.97	58.12	50.90
Time history analysis	99.32	132.10	153.26	147.75

Table 10. Maximum displacement for guyed chimney

Method	Fixed Support (mm)	Stiff Clayey (mm)	Dense Sandy (mm)	Stiff Hard (mm)
Seismic coefficient method	46.32	62.07	58.58	54.50
Response spectrum method	27.59	45.18	42.46	39.25
Time history analysis	82.96	126.96	124.2	110.4

Figures 7 & 8 show maximum lateral displacement for self-supporting and guyed chimneys considering different soil conditions.

Figures:

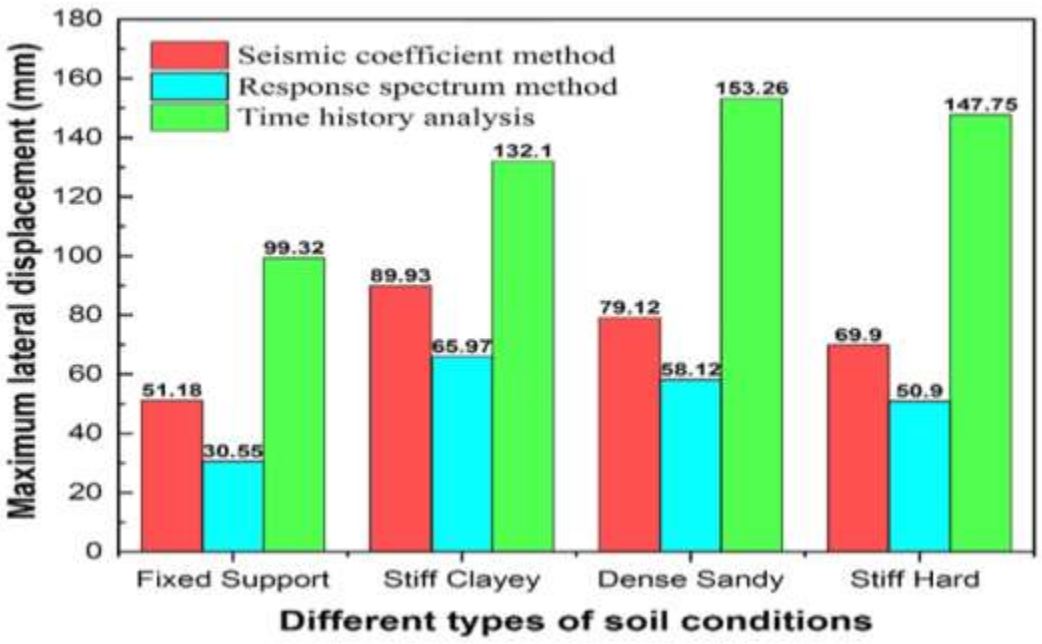

Figure 7. Maximum lateral Displacement for self-supporting chimney

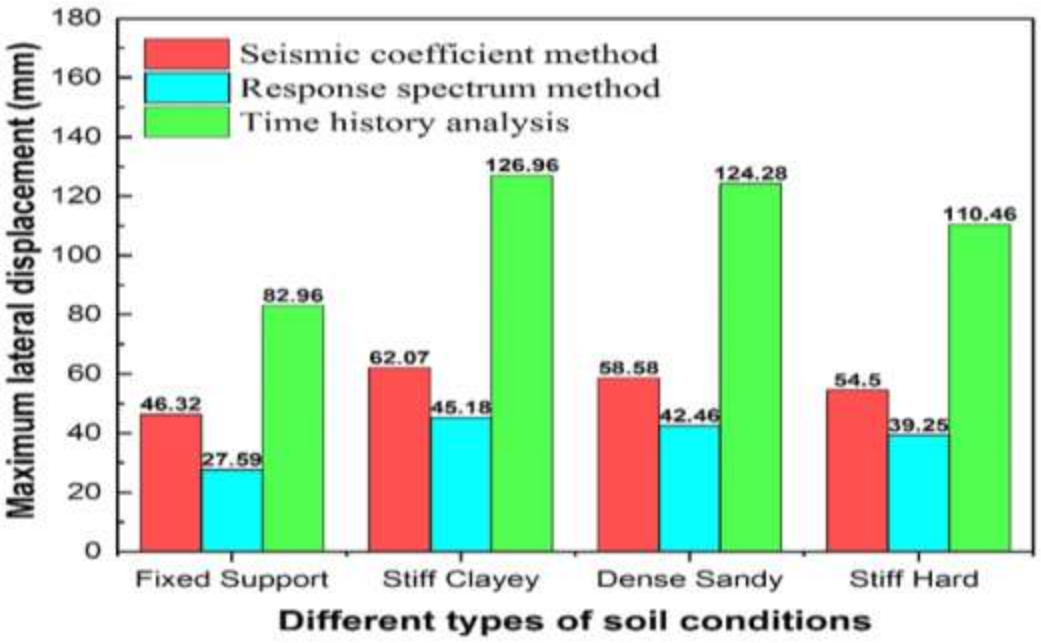

Figure 8.Maximum lateral Displacement for Guyed chimney

Results of base shear in self-supporting and guyed chimneys considering different soil conditions are tabulated in Tables 11& 12.

Tables:

Table 11.Base shear in self-supporting chimney

Method	**Fixed Support (kN)**	**Stiff Clayey (kN)**	**Dense Sandy (kN)**	**Stiff Hard (kN)**
Seismic coefficient method	62.81	29.00	32.88	38.00
Response spectrum method	45.97	29.02	31.13	34.34
Time history analysis	124.45	82.02	90.16	94.71

Table 12. Base shear in guyed chimney

Method	**Fixed Support (Kn)**	**Stiff Clayey (Kn)**	**Dense Sandy (Kn)**	**Stiff Hard (Kn)**
Seismic coefficient method	76.35	52.11	54.59	58.02

Response spectrum Method	53.56	42.75	44.32	46.20
Time history analysis	168.99	109.64	121.80	138.00

Figures 9 & 10 show base shear in self-supporting and guyed chimneys considering different soil conditions.

Figures:

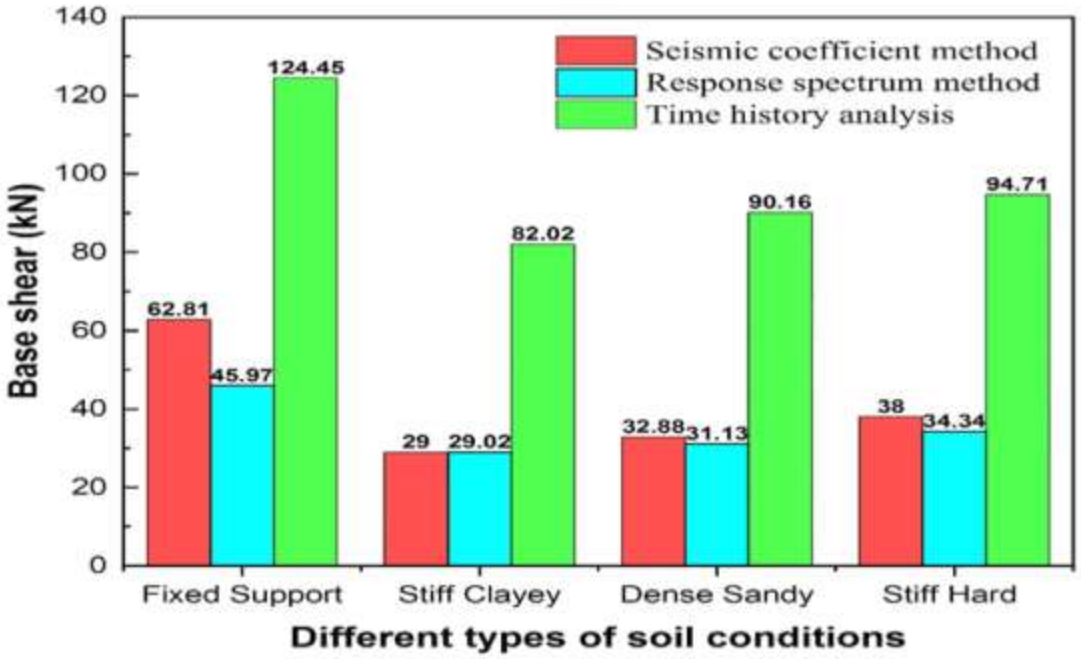

Figure 9. Base shearfor self-supporting chimney

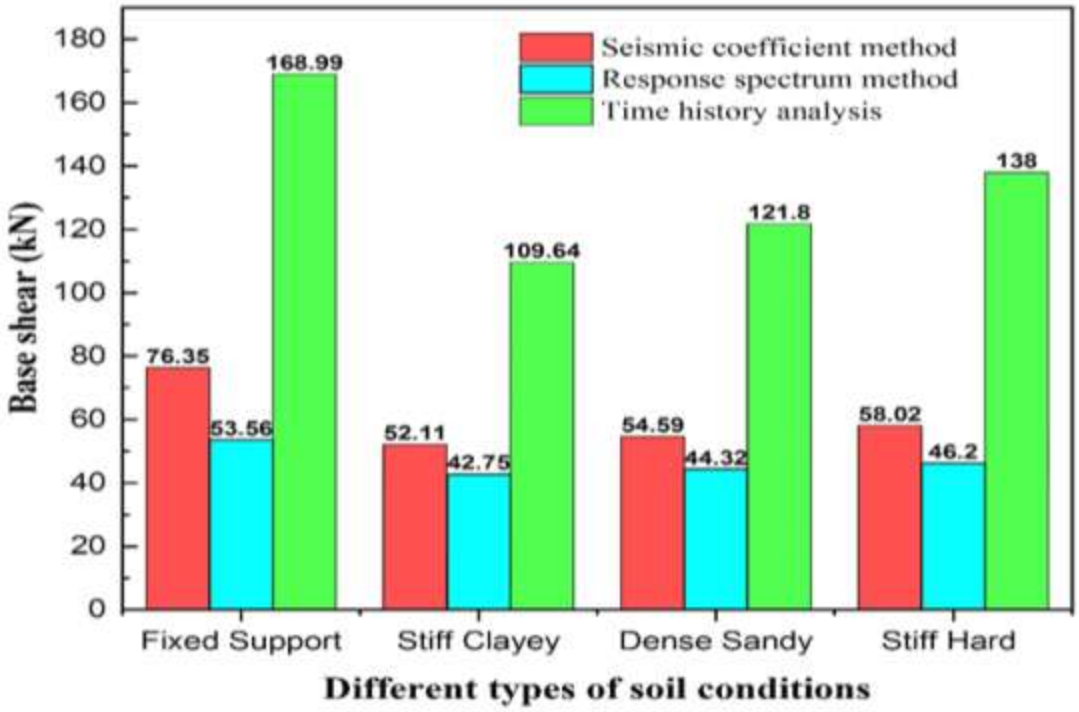

Figure 10. Base shearfor guyed chimney

VIII. CONCLUSIONS

In the present study, 72m tall self-supporting and guyed chimneys are modelled in SAP2000 consideringthree different soil conditions below the foundation and analysed for earthquake and wind loading.From the present study, following conclusions may be drawn:

- Time period of chimney is more in stiff clayey condition in comparison to fixed support, dense sandy & stiff hard soil conditions.
- The maximum lateral displacement at the top of both chimneys is higher due to wind forces as compared to seismic forces.
- Base shear inboth chimneys under Bhuj earthquake, 2001 is more as compared to response spectrum method.
- The maximum lateral displacementisless in guyed chimney as compared to self-supported chimney.

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