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Non Liner Dynamic Analysis of RCC Chimney

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***Abstract* - The effect of earthquake and wind loads on the RCC chimney will plays a significant role in the dynamic analysis and design of the chimneys with extreme heights. The dynamic behaviour of the RC chimney will vary in wider range with respect to the height and longitudinal section of the chimney as the load exerted by the wind and earthquake on the chimney are dynamically sound and effective and tending the chimney to undergo peak displacement and acceleration. Because of its slenderness chimneys are the structures supposed to retain the critical loads by seismic and wind effects This project presents the study of along wind load and earthquake load effects on RC chimneys in zone I (basic wind speed 33m/sec).seismic analysis is carried out by time history analysis as per IS 1893(part 4):2005 and wind analysis by along wind effects by gust factor method as per draft code CED 38(7892):2013 (third revision of IS 4998(part 1:1992) for different heights varying from 150 to 300m and for different longitudinal sections such as uniform, tapered and uniform-tapered by using the software SAP-2000 This study presents the resulting peak displacement and acceleration for the wind analysis, and the joint displacements and base shear for the seismic analysis, period and frequency with respect to mode by time history analysis. The RC chimney with more height and uniform section will be critical compared to other types and best suitable section will be uniform tapered for both seismic and wind load effects exhibiting minimum displacement.**

Key Words: RCC Chimney, , Dynamic Analysis, SAP2000,and Time History Analysis.

1. INTRODUCTION

Chimneys are tall slender structures which accomplish an important function. They had a humble beginning as a household vents and over the years, as vents grew larger and taller, they came to be known as chimneys. A cluster of them is stack. During early days the term "stack" was used to describe the extension piece added to a flue duct to convey and discharge combustion gases away from the operating area of the industry. A stack which was scientifically designed to take cognizance of gas temperatures and velocity effects, corrosion aspect, etc. was called a chimney. By usage the term "stack" has gained popularity and today it also signifies a chimney. Chimneys are the structures which built to greater heights as tall slender structures. In early days, as household vents and over the years; they are popularly known as chimneys. Chimneys or stacks are used as a medium to transfer highly contaminated polluted gases to atmosphere at a greater height.

1.1 Scope and Objective

- To determine the nonlinear behaviour of chimney structures without opening at section utilizing nonlinear dynamic analysis.
- To validate the result obtained from the nonlinear dynamic analysis using SAP 2000 in comparison with the result from manual analysis.
- To carry out the dynamics analysis for various deformation levels.

1.2 Methodology

To achieve the above objective following step-by-step procedures are followed

- Carried out literature study to find out the objectives of the project work.
- Understand the wind analysis and design procedure of a RCC chimney as per Indian Standard IS 4998(part1):1992.
- Analyse all the selected chimney models using manual calculations and finite element analysis (SAP 2000).
- Evaluate the analysis results and verify the requirement of the geometrical limitations.

2. DIMENSIONAL DESCRIPTION OF RCC CHIMNEY

For the present studies, twelve models of RC chimney are chosen with four different heights of uniform, tapered and uniform-tapered sections. The heights of the chimney selected are 150m, 200m, 250m and 300m.Grade of concrete is taken as M30 and basic wind speed for the wind zone of Bangalore as 33m/sec. seismic zone is zone II and soil is taken as hard soil.

For uniform chimney, the diameter of the chimney is taken as 14m[d] and thickness of the RC shell at the bottom is 0.45m and at the top it is 0.3m.

For tapered chimney, the diameter of the chimney at the bottom is 14m and is varying uniformly up to the top diameter 8m. The thickness of the RC shell is same as uniform chimney. The slope of tapering is 1 in 50.

For uniform-tapered chimney diameter of the chimney from the top will be uniform upto one-third of the total height of the chimney taken from the top and get tapered upto the bottom of the chimney.[according to IS 4998 part 1-1992]

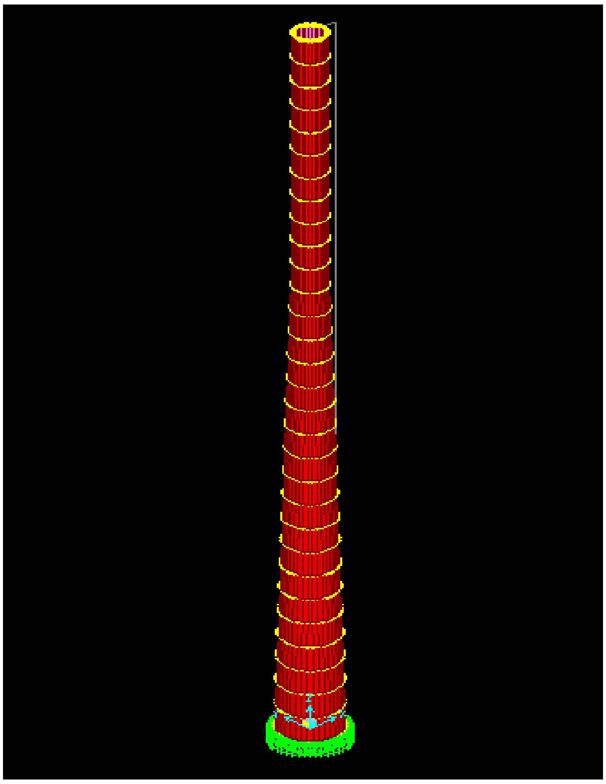

Fig: 1 Uniform-tapered chimney model [SAP 2000]

2.1 Basic Data For Modeling

- Typical grid spacing in X direction = 2m, Y= 1m, Z = 3m.
- Wind speed =33 m/sec
- Type of soil = hard soil
- Seismic zone = 2
- Taper of chimney = 1 in 50
- Top dia of chimney = 8m
- Height of chimney = 150m, 200m, 250m, 300m.
- Grade of concrete f_{ck} = M_{30}
- Grade of steel f_y = fe_{500}
- Shell thickness at top = 0.3m
- Shell thickness at bottom = 0.45m

Table 1: Twelve typical model series of different heights

TYPE	Series1	Series2	Series3	Series4
Uniform section	M1A	M2A	M3A	M4A
Tapered section	M1B	M2B	M3B	M4B
Uniform-tapered section	M1C	M2C	M4C	M4C
HEIGHT	150m	200m	250m	300m

2.2 Wind Load Calculation

Along wind analysis:

The along-wind loads are caused by the drag component of the wind force on the chimney. This is accompanied by gust buffeting causing a dynamic response in the direction of mean flow. Here along wind load calculation is done using Excel spread sheet and MATLAB programming.

From, IS 875 (Part-3): 1987,

Design wind speed $V_z = V_b \times k_1 \times k_2 \times k_3$

Where, k_1 risk coefficient (probability) for 33 m /sec (wind speed), k_2 terrain factor and k_3 topography factor(from IS875 part-3)

$k_1 = 1$

$k_2 = 1$

$k_3 = 1.36$

Therefore, V_z = 44.88 m/sec

Design Wind pressure (P_z) = 0.6 x V_z^2 = 1.208 kN/m^2

The along wind load per unit height at any height z on a chimney shall be calculated from the equation:

$$F = F_z + F_z'$$

Where, F_z'= is the wind load in N/m height due to HMW at height z and is given by

$$F_z = p_z . C_d . D_z = 7.68 \text{ kN}$$

F_z' = is the wind load in N/m height due to the fluctuating component of wind at height z

$$F_z' = 3. (G-1)/H^2. (Z/H)\int_0^h F_z .z .dz$$

$$G = \text{gust factor} = (1+ g_f\, r_t \sqrt{(B + [SE/\beta])}) = 2.48$$

$$g_f = \sqrt{(2Ld(V_T) + (0.5777/\sqrt{(2 X Ln(V_T)}))} = 3.62$$

f_1 = natural frequency of chimney in the first mode of vibration in Hz = 0.482 Cps.

V_{10} = hourly mean wind speed in m/set at 10 m above ground level = $V_b.k_2$ = 33.

Where, V_b and k_2, are as defined in IS 875 (Part 3): 1987

S=Size reduction factor = $(1+ 5.78\,(f_1/V_{10})1.14H^{.98})^{-.8}$

=0. 173

E = A measure of the available energy in the wind at the natural frequency of the chimney = $[123\,(f_1/ V10)\, H^{0.21}]$ / $[1+ (330f_1/V10)^2\, H^{.42}]^{.83}$ = .065

B=Back ground factor indicating the slowly varying component of wind load fluctuation = $[1+ (H/265)^{.63}]^{-.88}$

= 0.627

r = Twice the turbulence intensity = $0.622-.178\log_{10}H$

= 0.243

$$F'_Z = 3(G-1)/H^2\,[Z/H] \int_0^h F_Z\, z\, dz$$
$$=11.78 kN/m$$
$$F= (F_z+F'_z)$$
$$=19.46 kN/m$$

3 RESULTS AND DISCUSSIONS

3.1 Along wind analysis:

Table 2 Displacement values for the Chimney

SL NO.	LEVEL	M4A	M4B	M4C
1	10	2.541316	1.93181	1.787426
2	20	6.968718	5.456475	5.151503
3	30	14.43335	11.56493	11.08204
4	40	24.53699	20.04231	19.44906
5	50	37.25418	30.95801	30.39091
6	60	52.42809	44.28061	43.94965
7	70	69.89105	59.97097	60.15921
8	80	89.45526	77.97032	79.03783
9	90	110.9383	98.21333	100.6027
10	100	134.1725	120.6316	124.8733
11	110	159.0059	145.1558	151.8736
12	120	185.2974	171.7154	181.6305
13	130	212.9137	200.2381	214.1721
14	140	241.7278	230.6492	249.525
15	150	271.6179	262.8699	287.7119
16	160	302.4674	296.8151	328.7489
17	170	334.1648	332.3932	372.6438
18	180	366.6039	369.5059	419.3875
19	190	399.6842	408.0475	468.9622
20	200	433.3099	447.9052	521.2877
21	210	467.3899	488.9588	575.2569
22	220	501.8372	531.0815	631.3684
23	230	536.5685	574.1406	689.2578
24	240	571.504	617.9993	748.5543
25	250	606.5681	662.5177	808.9295
26	260	641.695	707.5552	870.0901
27	270	676.8416	752.9651	931.7759
28	280	711.9882	798.5829	993.7375
29	290	747.1355	844.2539	1055.765
30	300	782.2595	889.8928	1117.76

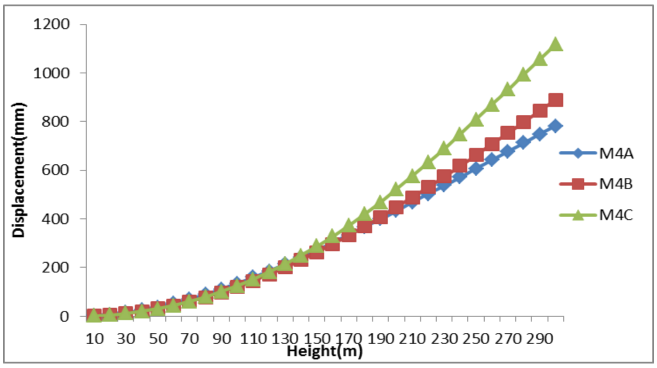

Fig-2 Graph for Displacement Vs Height

Observations and discussions: At one third height of 300m chimney, displacement of 433.30mm for uniform, 447.9mm for tapered and 521.2877mm for uniform tapered is observed. Whereas for 250m height, displacement of 782.25mm for uniform, 889.8928mm for tapered and 1117.76mm for uniform tapered is observed which indicates that in uniform-tapered section the displacement values were lesser than other two sections up to one third height and then displacement increases gradually up to 300m

3.2 time history analysis

Table 3 Mode and Frequency

MODE	M4A-cyc/sec	M4B- cyc/sec	M4C cyc/sec
1	0.14468	0.1578	0.1578
2	0.14468	0.1578	0.1578
3	0.87025	0.73808	0.73808
4	0.87025	0.73808	0.73808
5	1.7716	1.8378	1.8378
6	2.0726	1.8378	1.8378
7	2.0726	2.5632	2.5632
8	2.0989	2.8835	2.8835
9	2.0989	2.8835	2.8835
10	2.2366	3.1406	3.1406
11	2.2366	3.36	3.36
12	2.3011	3.36	3.36

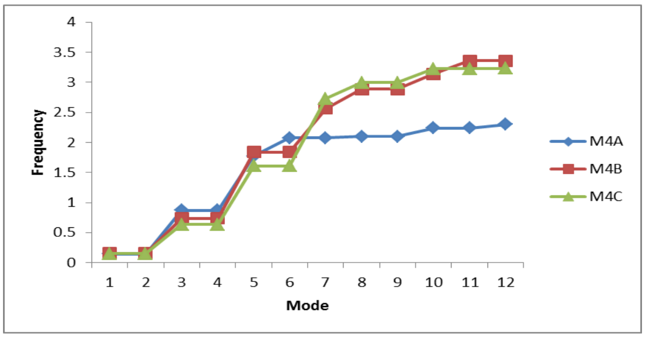

Fig-3 Graph for mode VS Frequency

Table-4 Mode and Period

MODE	M4A(sec)	M4B(sec)	M4C(sec)
1	6.91181	6.33724	6.712504
2	6.91181	6.33724	6.712504
3	1.149098	1.354875	1.579017
4	1.149098	1.354875	1.579017
5	0.564477	0.544141	0.621754
6	0.482488	0.544141	0.621754
7	0.482488	0.390143	0.366949
8	0.476449	0.346801	0.334069
9	0.476449	0.346801	0.334069
10	0.447111	0.318406	0.310359
11	0.447111	0.297623	0.310359
12	0.434566	0.297623	0.309793

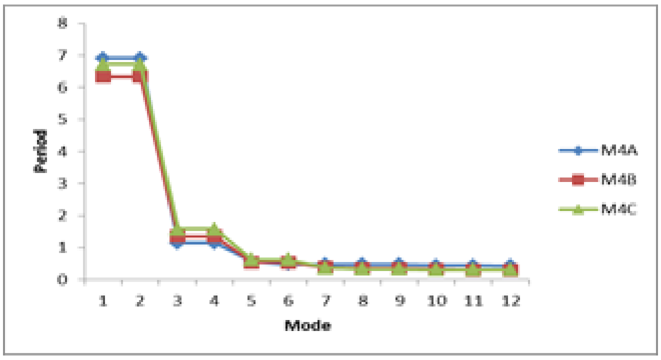

Fig-4 Graph for mode Vs Period

Observations and discussions: From the graph plotted for frequency v/s mode and period v/s mode number we can notice that mode 1 is with least frequency and higher period. For mode 1, uniform section frequency is 0.144cycs/sec and period is 6.911sec which depicts that for mode 1 we have least frequency and higher period value compared to other sections and it indicates that uniform section will be within permissible standards by time history analysis. The observed results which are tabulated indicate that uniform section is with first preference and then its uniform tapered and tapered.

Table 4 Max Shell Stress in Chimney

SL NO.	MODEL NO.	SHELL STRESS (kN/m^2)
1	M4A	10154.94
2	M4B	7671.68
3	M4C	7205.3

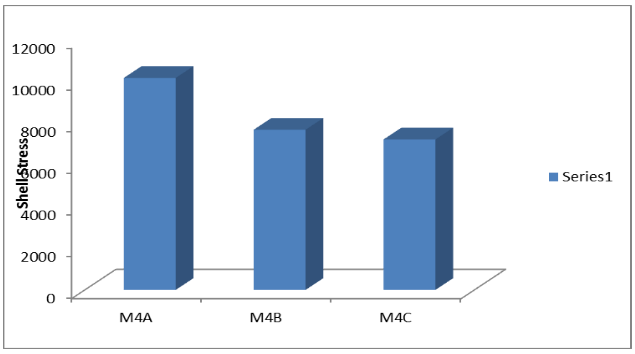

Fig-4 Bar chart for max shell stress in chimney

Observations and discussions: from the plotted bar chart for shell stress of the RC chimney under wind loads, the uniform sectioned RC chimneys are subjected to more shell stress as compared with other models and the shell stress increases with the increase in height. Shell stress will be at its peak for models with 300m height and for uniform sections 10154.94KN/m^2 will be the extreme shell stress noticed in 300m height chimney of uniform section.

Table- 3 Displacement due to earthquake load with respect to height

SL NO.	LEVEL	M4A	M4B	M4C
		(mm)		
1	10	1.057389	0.740677	0.659427
2	20	2.935566	2.115676	1.920572
3	30	6.082177	4.491032	4.136381
4	40	10.31319	7.775326	7.249869
5	50	15.60284	11.98896	11.30624
6	60	21.88693	17.12268	16.32571
7	70	29.11053	23.17172	22.33435
8	80	37.21682	30.12739	29.35642
9	90	46.14973	37.97881	37.41594
10	100	55.85345	46.71224	46.53603
11	110	66.27272	56.31099	56.73869
12	120	77.35284	66.75521	68.04442
13	130	89.03989	78.02168	80.47182
14	140	101.2808	90.08362	94.03706
15	150	114.0236	102.9106	108.7533
16	160	127.2174	116.4682	124.6299
17	170	140.8129	130.7183	141.6719
18	180	154.7622	145.6185	159.8772
19	190	169.0194	161.1227	179.2412
20	200	183.5405	177.1807	199.734
21	210	198.2837	193.7388	220.9084
22	220	213.2099	210.7398	242.9563
23	230	228.2825	228.124	265.72

24	240	243.4682	245.8294	289.0404
25	250	258.7367	263.7932	312.7786
26	260	274.0617	281.9533	336.8116
27	270	289.4206	300.2502	361.0357
28	280	304.795	318.6294	385.3668
29	290	320.171	337.0456	409.7428
30	300	335.5406	355.467	434.1254

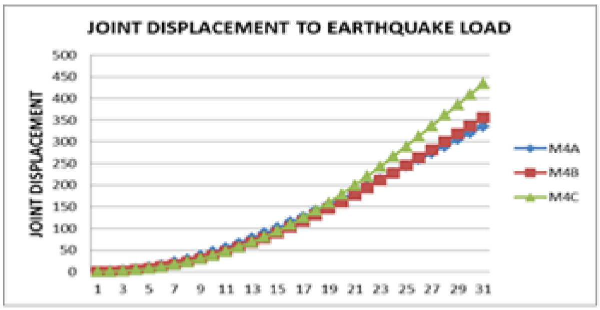

Fig-5 Graph for joint displacement Vs Height

Observations and discussions: At one third height of 300m chimney, joint displacement of 169.01mm for uniform section, 161.12mm for tapered and 179.2412mm for uniform tapered is observed where as for 200m height, joint displacement of 161.61mm for uniform, 166.13mm for tapered and 215.28mm for uniform tapered is observed which indicates that in uniform-tapered section the displacement values were lesser than other two sections upto one third height and then displacement increases gradually upto 300m

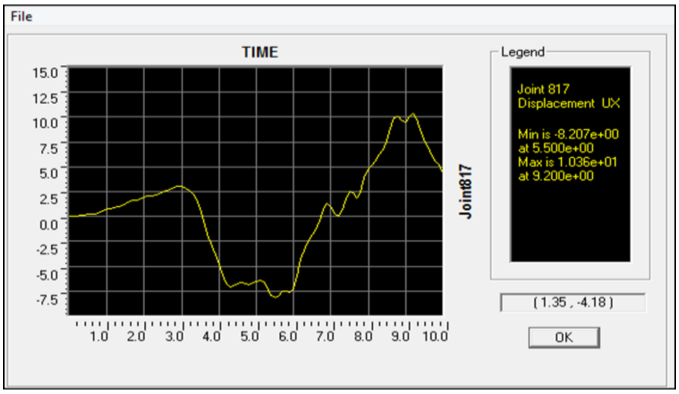

Fig 6: Time history graph showing peak displacement for M4A chimney model

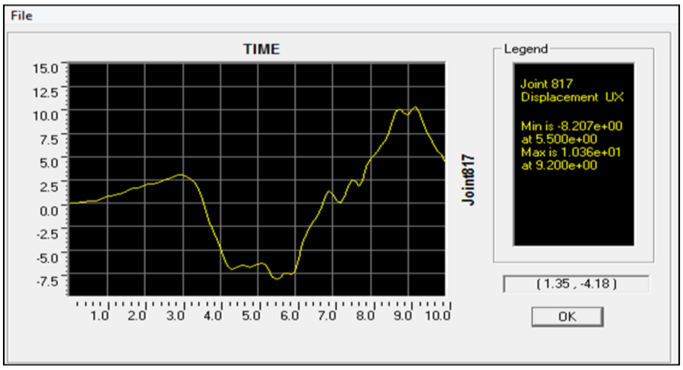

Fig 7: Time history graph showing peak displacement for M4B chimney model

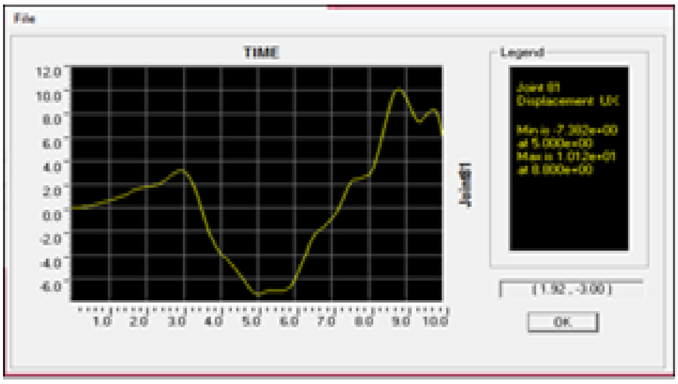

Fig 8: Time history graph showing peak displacement for M4C chimney model

Observations and discussions: From the time history analysis carried out bar chart for peak displacement has been plotted. By the graph it is noticed that Peak displacement for M4C is 8.2mm is maximum for 300m height model; comparatively 150m models are with least displacement and the displacement is incremental with respect to height. The graph for peak displacement by time history analysis has been extracted from SAP-2000 for in comparison with the manual results

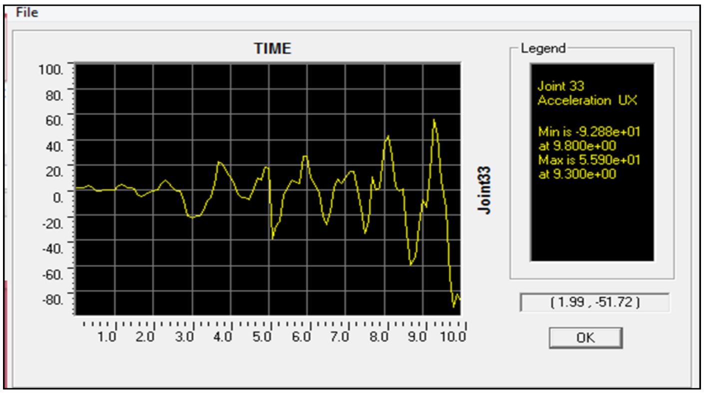

Fig 9: Time history graph showing peak acceleration for M4A chimney model

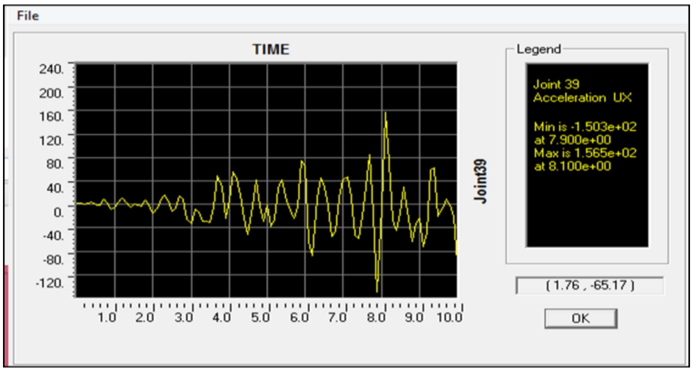

Fig 10: Time history graph showing peak acceleration for M4B chimney model

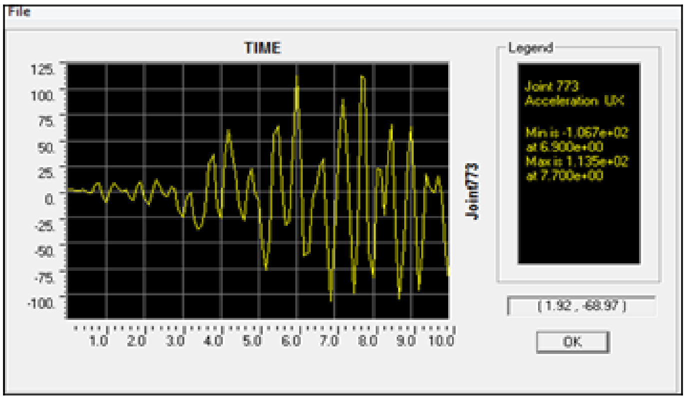

Fig 11: Time history graph showing peak acceleration for M4Cchimney model

Observations and discussions: From the time history analysis conducted for all the models, the bar chart has been plotted and it is noticed that the uniform sections will exhibits more acceleration that is for M4A it is 9.2m/sec^2. But the uniform-tapered section will depicts least acceleration of 1.14m/sec^2 compared to other models.

CONCLUSION

- The uniform tapered section subjected to wind analysis exhibits more displacement as observed by the displacement graphs for all heights. And it can be concluded that the displacements obtained for chimneys increases with the increase in height of the slender structure.
- Up to one third height of 300m chimney, all types of displacement values[displacement by wind analysis, joint displacement by seismic analysis, peak displacement by time history analysis] are in decremented order as uniform section, uniform tapered, tapered. After that the displacement values will initiate to increase up to extreme height 300m of the chimney. The displacement by wind analysis as 1117.76mm, joint displacement as 215.28mm and Peak displacement as 8.2mm for uniform tapered section of 300m height which indicates that the uniform tapered section has to be designed by taking into consideration the extreme displacement values.
- By considering proper design parametric considerations it necessitates to overcome the effects of maximum displacement which is in divergence with other models.

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