DYNAMIC ANALYSIS OF R.C.C CHIMNEYS

M.SHIVAJI & V.S.N.RAJU
CIVIL ENGINEERING WING
A.P.S.E.BOARD,
HYDERABAD, ANDHRA PRADESH
INDIA

ABSTRACT.

Chimneys are symbols of industrial growth in any country. Most current chimney design standards require analysis of dynamic response of chimney due to influence of earth-quake or wind induced loads. Because of changes in the dimensions of chimney structural analysis such as response to earth quake and wind oscillations have become more critical. This paper discusses the dynamic analysis of 220m high R.C.C. chimney for free vibration analysis and response spectrum analysis using MSC/NASTRAN. Analysis has been carried out for a) fixed base case and b) base soil structure interaction case. Apart from showing appreciable differences in eigen values and eigen vectors with respect to fixed base, the interaction model has shown large reduction in values of Bending Moment and Shear Force due to seismic forces at the base of the chimney. Analysis has also been carried out for SRSS, NRL & ABS methods and results are compared. Effect of damping is also studied.

INTRODUCTION :-

Chimneys are symbols of Industrial growth in any country. The primary function of chimney is to discharge pollutants into atmosphere at such heights and velocities that the concentration of pollutants deemed harmful to the environment are kept within acceptable limits at ground level. Due to increasing demand for controlling air pollution , height of chimney has been increasing since the last few decades, and these are valid reasons to believe that this trend towards construction of taller chimneys will continue. The demand for tall chimneys together with the use of slipform construction has resulted in the adoption of reinforced concrete chimneys.

Becuase of the changes in the dimension especially the incresing height of chimneys, structural analysis such response to earth quake and wind oscillation have become more critical. The height of the chimney as well as the diameter at the top are normally chosen so that exit velocity and dispersion of gases are within the specified limits. The bottom diameter is mainly controlled by the structural reqyuirements of both the concrete shell and the foundation.

The present paper discusses the free vibration analysis and response spectrum analysis of R.C.C. chimney using MSC/NASTRAN. Since the base rotation could change frequency and mode shapes appreciably, the soil structure interaction has also been considerd as an important parameter.

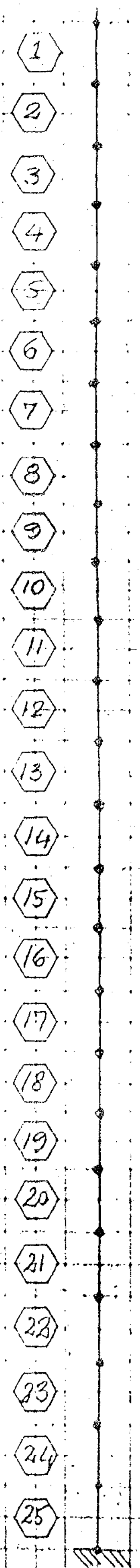
PROBLEM DEFINITION :

The problem taken for analysis is the R.C.C. multiflue chimney under construction for Stage-i of 2x210MW, units of Rayalaseema Thermal Power Projects, Muddunur, A.P.S.E.B., India. The chimney consists of R.C.C. annuler shell of 220M height, 630mm thick at bottom and 250mm thick at top with thickness varying linearly from top to bottom. The shell rests on R.C.C. mat foundation of circular shape. Two flues with fire resistant/acid resistant bricks are provided inside the shell, one for each unit, to discharge the flue gases.

SALIENT FEATURE AND IMPORTANT CENTRELINE DIMENSIONS :

1.	Height of chimney	–	220m
2.	Outer dia at bottom	–	20.2m
3.	Outer dia at top	–	13.0m
4.	Thickness of shell at bottom		0.63m
5.	Thickness of shell at top		0.25m
6.	Grade of concrete		M25
7.	Exit velocity of gas at top		28.887M/sec.
8.	Flue gas volume from the flue		363 Cum/Sec.
9.	Maximum flue gas temperature		150 degrees centigrade.

STRUCTURAL IDEALIZATION



NODE	ELEVATION
1	240.000
2	214.000
3	204.000
4	194.000
5	184.000
6	174.000
7	164.000
8	154.000
9	144.000
10	134.000
11	124.000
12	114.000
13	104.000
14	94.000
15	84.000
16	74.000
17	64.000
18	54.000
19	44.000
20	34.000
21	24.000
22	21.850
23	14.150
24	12.000
25	0.000
26	(-)2.100

Fig-(1)

ANALYSIS :

The analysis of R.C.C. chimney is carried out for free vibration analysis and for response to sesmic forces using response spectrum method (Sol.63) of MSC/NASTRAN.

The chimney is idealised as a multi-degree freedom lumped mass system with masses lumped at various levels. Legranges method is used for calculation of Natural frequencies. First 5 modes are requested from the analysis. The average accelaration spectra of IS code along with zone factor, post seismic importance factor and soil factor is used for determination of forces and moments in each mode and are combined in the square root of the sum of the squares (SRSS) manner.

The chimney is modelled as vertical cantilever fixed at base having varying cross section area, inertia mass along the height using beam element of MSC/NASTRAN. The number of segments should be atleast double the number of modes. The 220m height of chimney is devided into 25 elements. The masses are lumped at grid points using CONM elements of MSC/NASTRAN. The effect of shear deformation is considerd in the analysis. The discretization of chimney is shown in figure (1).

Since the R.C.C. chimney is a stiff axi symmetric structure, and it is resting through rigid R.C.C. mat on soil, the effect of soil structure interaction can be significant. Hence analysis is also carried out considering the soil structure interaction using elastic spring elements to represent the foundation soil at the base of chimney.

Damping is one of the important parameters which affects the final design forces of chimney. Analysis is carried out for 2% and 5% of critical damping and results are compared.

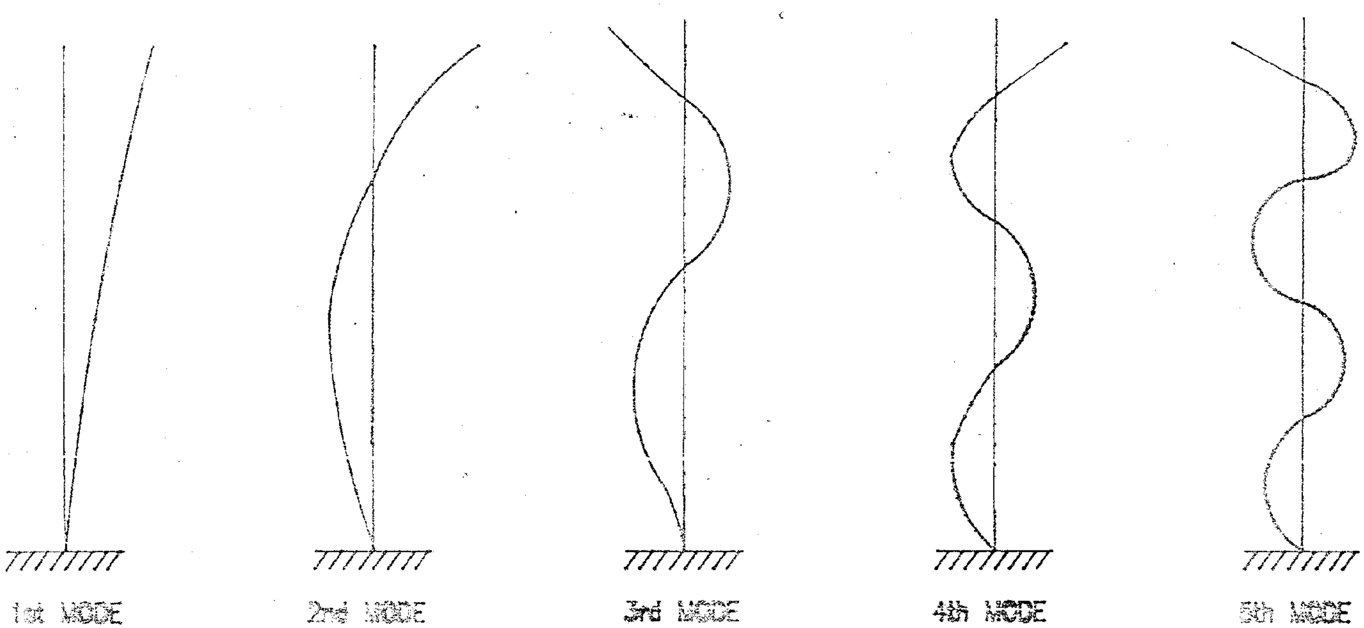
The analysis of chimney is carried out for the following cases and results are compared.

A) Free vibration Analysis:

1. For fixed base case
2. For soil structure case.

B) Response spectrum Analysis:

1. With fixed base using SRSS, ABS & NRL metheds of MSC/NASTRAN.
2. Considering the soil structure interaction for 2% damping.
3. With fixed base considering 2% & 5% of critical damping



NORMAL MODES OF THE RCC CHIMNEY FOR FIXED BASE

TABLE-1

COMPARISON OF B.M & S.F BETWEEN FIXED BASE MODEL AND INTERACTION MODEL AT SELECTED GRID POINTS.

S.NO	ELEVATION IN METERS	BENDIG MOMENT KNM FIXED BASE	BENDIG MOMENT KNM INTERACTION MODEL	SHEAR FORCE IN KN. FIXED BASE	SHEAR FORCE IN KN. INTERACTION MODEL
1	220.00	0.00	0.00	97.49	83.83
2	214.00	584.96	502.95	310.95	271.02
3	204.00	3693.30	3212.21	481.86	430.41
4	194.00	8489.20	7499.36	574.86	527.95
5	184.00	14133.00	12703.38	618.18	582.78
6	174.00	20014.50	18319.36	638.20	613.99
7	164.00	25770.88	24019.33	647.95	632.95
8	154.00	31209.60	29609.80	652.02	644.65
9	144.00	36216.70	34971.10	658.92	654.48
10	134.00	40729.20	40029.12	680.89	669.49
11	124.00	44759.00	44758.59	723.42	693.61
12	114.00	48411.30	49186.30	783.36	725.75
13	104.00	51866.30	53376.80	858.27	764.65
14	94.00	55357.00	57414.20	950.00	812.94
15	84.00	59172.50	61404.48	1058.24	874.47
16	74.00	63655.60	65491.80	1178.37	950.68
17	64.00	69162.20	69859.33	1306.30	1041.61
18	54.00	75999.00	74719.45	1439.55	1146.91
19	44.00	84396.45	80317.54	1574.81	1265.45
20	34.00	94487.30	86924.53	1706.87	1395.35
21	24.00	106310.50	94805.35	1770.87	1467.74
22	21.85	109067.30	96686.82	1827.41	1534.24
23	14.15	119551.90	104018.00	1863.38	1583.16
24	12.00	122631.30	106218.00	1913.19	1654.40
25	0.00	140922.90	119831.10	1918.04	1665.24
26	-2.10	144265.00	122396.00	1918.04	1665.24

B.M = BENDING MOMENT

S.F = SHEAR FORCE

KN = KILO NEWTON

KN-M = KILO NEWTON-METRE

TABLE-2
COMPARISION OF B.M & S.F FOR SRSS.ABS,NRL METHODS
FOR FIXED BASE MODEL.

S.NO	ELEVATION IN METERS	BENDING MOMENT IN KN-M			SHEAR FORCE IN KN.		
		SRSS METHOD	ABS METHOD	NRL METHOD	SRSS METHOD	ABS METHOD	NRL METHOD
1	220.00	0.00	0.00	0.00	97.49	204.85	137.27
2	214.00	584.96	1229.07	823.65	310.95	646.78	439.20
3	204.00	3693.30	7696.87	5214.70	481.86	967.34	681.20
4	194.00	8489.20	17370.28	12005.20	574.86	1067.62	808.09
5	184.00	14133.00	28046.49	19965.80	618.18	1083.28	862.67
6	174.00	20014.50	37947.68	28169.50	638.20	1156.08	893.64
7	164.00	25770.88	45991.58	36095.42	647.95	1166.63	915.81
8	154.00	31209.60	53571.55	43573.50	652.02	1280.68	921.43
9	144.00	36216.70	59814.50	50603.90	658.92	1276.03	930.46
10	134.00	40729.20	67498.43	57178.47	680.89	1257.71	956.48
11	124.00	44759.00	71784.98	63192.50	723.42	1223.56	1014.77
12	114.00	48411.30	73942.96	68448.29	783.36	1423.88	1102.33
13	104.00	51866.30	82574.09	72760.23	858.27	1667.27	1212.35
14	94.00	55357.00	88318.92	76009.52	950.00	1776.29	1343.31
15	84.00	59172.50	89863.57	78216.41	1058.24	1889.61	1496.54
16	74.00	63655.60	91022.27	79672.52	1178.37	2012.53	1658.52
17	64.00	69162.20	89423.82	81598.77	1306.30	2292.81	1826.91
18	54.00	75999.00	97654.30	87919.35	1439.55	2441.69	2008.83
19	44.00	84396.45	113923.70	101713.30	1574.81	2758.15	2203.52
20	34.00	94487.30	127098.50	120051.80	1706.87	3153.22	2399.24
21	24.00	106310.50	150463.00	140870.40	1770.87	3384.14	2494.52
22	21.85	109067.30	155491.70	145573.10	1827.41	3576.17	2578.09
23	14.15	119551.90	178858.30	162999.00	1863.38	3698.76	2631.01
24	12.00	122631.30	186430.60	167990.20	1913.19	3862.33	2703.64
25	0.00	140922.90	232778.60	196694.40	1918.04	3879.07	2710.70
26	-2.10	144265.00	240924.60	201789.70	1918.04	3879.07	2710.70

B.M = BENDING MOMENT
S.F = SHEAR FORCE
KN = KILO NEWTON
KN-M = KILO NEWTON-METRE

TABLE-3

COMPARISION OF B.M& S.F FOR 2% & 5% DAMPING

FOR FIXED BASE MODEL

S.NO	ELEVATION IN METERS	BENDING MOMENT IN KNM		SHEAR FORCE IN KN.	
		2% DAMPING	5% DAMPING	2% DAMPING	5% DAMPING
1	220.00	0.00	0.00	97.49	68.74
2	214.00	584.96	412.44	310.95	217.82
3	204.00	3693.30	2589.73	481.86	336.22
4	194.00	8489.20	5934.21	574.86	400.06
5	184.00	14133.00	9852.32	618.18	431.90
6	174.00	20014.50	13933.95	638.20	451.90
7	164.00	25770.88	17963.43	647.95	468.24
8	154.00	31209.60	21851.32	652.02	482.10
9	144.00	36216.70	25557.95	658.92	497.77
10	134.00	40729.20	29069.30	680.89	521.98
11	124.00	44759.00	32416.30	723.42	556.43
12	114.00	48411.30	35681.38	783.36	598.11
13	104.00	51866.30	38972.20	858.27	645.72
14	94.00	55357.00	42407.69	950.00	702.12
15	84.00	59172.50	46120.97	1058.24	769.15
16	74.00	63655.60	50269.45	1178.37	844.35
17	64.00	69162.20	55021.02	1306.30	925.98
18	54.00	75999.00	60524.21	1439.55	1012.80
19	44.00	84396.45	66902.77	1574.81	1103.68
20	34.00	94487.30	74251.73	1706.87	1194.42
21	24.00	106310.50	82629.10	1770.87	1240.98
22	21.85	109067.30	84562.67	1827.41	1281.15
23	14.15	119551.90	91874.36	1863.38	1307.50
24	12.00	122631.30	94014.28	1913.19	1343.20
25	0.00	140922.90	106689.00	1918.04	1346.87
26	-2.10	144265.00	109003.30	1918.04	1346.87

B.M = BENDING MOMENT

S.F = SHEAR FORCE

KN = KILO NEWTON

KN-M = KILO NEWTON-METRE

TABLE-4
COMPARISION OF B.M & S.F
OF MSC/NASTRAN RESULTS & IS 1893-1975 RESULTS
FOR FIXED BASE.

S.NO	ELEVATION IN METERS	BENDING MOMENT IN KNM: MSC/NASTRAN RESULTS(SRSS	BENDING MOMENT IN KNM: IS 1893-1975 RESULTS	SHEAR FORCE IN KN.: MSC/NASTRAN RESULTS(SRSS	SHEAR FORCE IN KN.: IS 1893-1975 RESULTS
1	220.00	0.00	0.00	97.49	0.00
2	214.00	584.96	15096.97	310.95	107.08
3	204.00	3693.30	24654.85	481.86	280.34
4	194.00	8489.20	31438.29	574.86	447.10
5	184.00	14133.00	37022.08	618.18	607.36
6	174.00	20014.50	41914.24	638.20	761.13
7	164.00	25770.88	46369.43	647.95	908.39
8	154.00	31209.60	50548.40	652.02	1049.16
9	144.00	36216.70	54570.00	658.92	1183.43
10	134.00	40729.20	58532.67	680.89	1311.20
11	124.00	44759.00	62525.18	723.42	1432.48
12	114.00	48411.30	66632.13	783.36	1547.25
13	104.00	51866.30	70937.32	858.27	1655.53
14	94.00	55357.00	75525.74	950.00	1757.31
15	84.00	59172.50	80484.93	1058.24	1852.59
16	74.00	63655.60	85905.87	1178.37	1941.37
17	64.00	69162.20	91883.53	1306.30	2023.66
18	54.00	75999.00	98517.42	1439.55	2099.44
19	44.00	84396.45	105911.90	1574.81	2168.73
20	34.00	94487.30	114176.14	1706.87	2231.52
21	24.00	106310.50	123424.91	1770.87	2287.81
22	21.85	109067.30	125553.38	1827.41	2299.07
23	14.15	119551.90	133613.97	1863.38	2336.91
24	12.00	122631.30	135992.20	1913.19	2346.78
25	0.00	140922.90	150367.79	1918.04	2396.40
26	-2.10	144265.00	153086.33	1918.04	2404.12

B.M = BENDING MOMENT
S.F = SHEAR FORCE
KN = KILO NEWTON
KN-M = KILO NEWTON-METRE

TABLE-5
COMPARISION OF TIME PERIODS FOR
FIXED BASE MODEL & INTERACTION

S.NO	MODES	FIXED BASE IN SECONDS	INTER ACTION MODEL IN SECONDS
1	1st. mode	2.594	3.330
2	2nd mode	0.580	0.713
3	3rd mode	0.245	0.281
4	4th mode	0.140	0.153
5	5th mode	0.094	0.099

Results & Discussions :

1. Period of Vibration

The period of vibration in first five modes obtained from 2D analysis are shown in tab. For fixed base and interaction model, it can be seen from the below table that emperical formulae give time periods very close to those obtained analytically in the first mode for fixed base.

As per I.S:1893-1975	As per ASC 307-1979	MSC/NASTRAN 1st mode
2.41 Sec.	2.74 Sec.	2.59 Sec.

While scrutinizing the results of eigen solution of 220m height RCC chimney for both fixed base as well as soil structure inter action model, following variation in fundamental frequencies has been observed i.e. f1 for fixed base model is .3855 cycles/sec and f1 for inter action model is .3002 cycles/sec which corresponds to variation in fundamental time period T1 from 2.6 sec to 3.33 sec for two different cases respectively. Similarly all the subsequent higher modes frequencies and corresponding time periods changed. The value of spring constant (Kx) used in the analysisi is 1.0 x 10^9 Kn/m. This high value is taken because of the hard soil/rock present at the site. If the foundation soil is soft then the difference between time period for these two cases will be high.

2) **B.M. & S.F.**

The B.M. & S.F. distribution for 220m high RCC Chimney for different cases are shown in table No: 1 to 4.

Apart from showing appreciable difference in eigen values and eigen vectors with respect to fixed base case, the interaction model has shown (Tab. 5) large reduction in values of B.M and SF due to seismic forces at the base portion of the chimney and subsequent increase in rotation about any one of the two horizontal axes of foundation raft. In reality the rotation and translation of the top of the chimney under design sesmic response will be closer to the value indicated by the interaction model. Hence instead of designing the chimney segments unnecessarly for higher hypothetical bending moment and shear forces at its base for fixed base condition, it will be prudent to develop gradually a better and realistic mathematical computer model for dynamic analysis of chimney under earthquake or wind action.

It can be seen from table 4 that the IS moment & sher distrubtion is conservative for all heights as compared to SRSS method of MSC/NASTRAN.

Further, ABS & NRL methods give very conservative values for BM & SF as compared to SRSS method, which is commonly used for response Spectrum analysis for seismic forces of RCC Chimney as same from the table 2.

As seen from the table 3 the effect of increasing the % of damping is to reduce the B.M & SF at all levels.

CONCLUSION

Since the reinforced concrete chimney shaft is a stiff axisymmetric structure, and is resting through RCC mat and soil, the effect of soil structure interaction is significant. It is observed that the coupling between structure and its supporting soil generally results in a system which has a longer foundamental period than the same structure fixed to a rigid base. It has also been observed from this study that the effect of consdering soil structure interaction on the stresses originating from earthquake response analysis in the reinforced concrete chimney structure is highly beneficial.

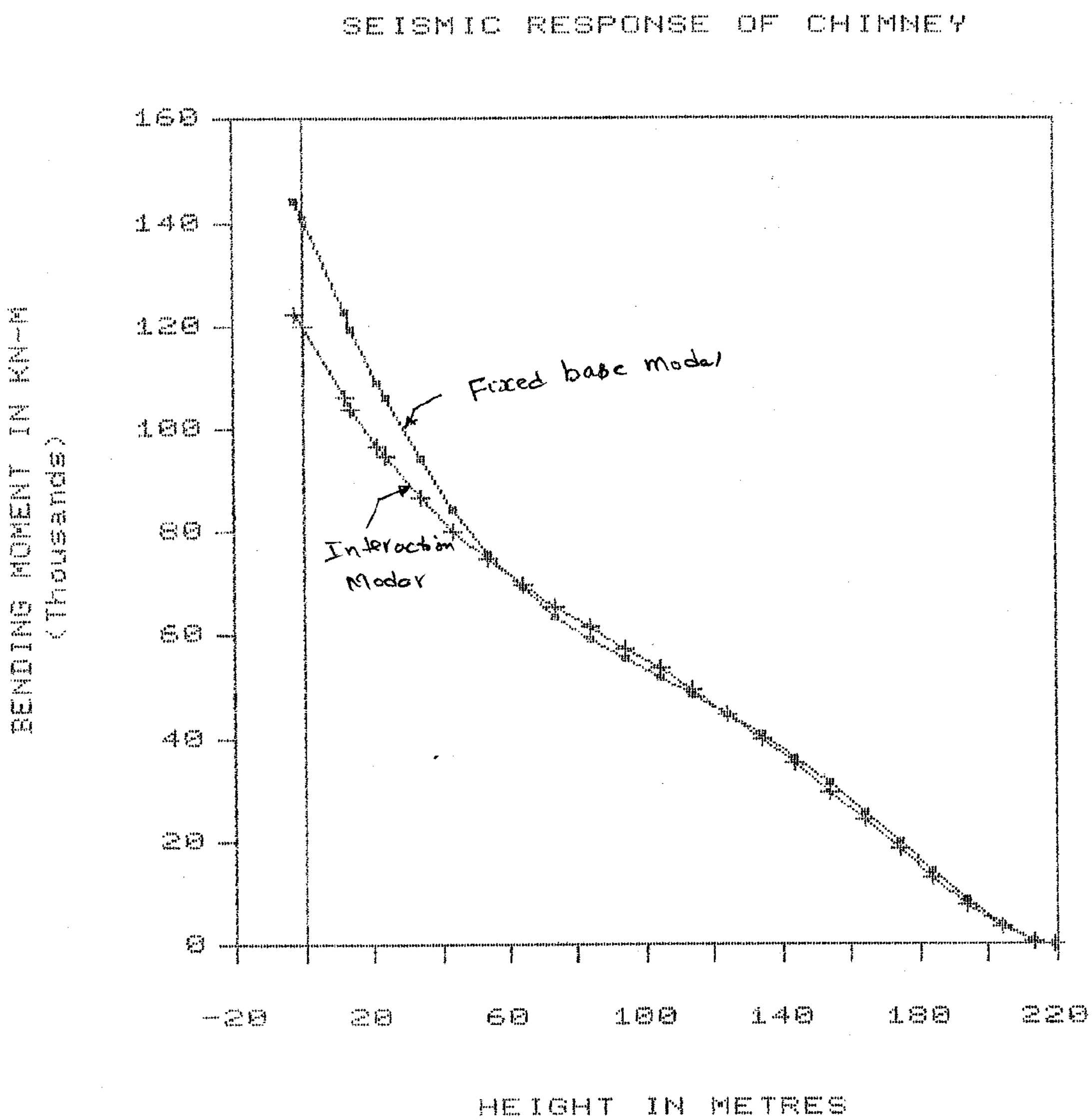
From the aforesaid analysis it may be suggested that instead of adhering to conventional fixed base model for the dynamic analysis of tall reinforced concrete chimney for gust wind or seismic condition, more improved mathematical model may be considered which also include the beneficial effect of adding soil structure. This has become almost mandatory while considering dynamic analysis of tall reinforced concrete chimney resting on alluvial soil through a large rigid mat which may be either octogonal or circular.

ACKNOWLEDGMENTS:

The author would like to thank ANDHRA PRADESH STATE ELECTRICITY BOARD for its kind permission and encouragement to submit this paper.

REFERENCES:

1. IS: 1893-1975, "Criteria for Earthquake resistant design of structures".
2. IS: 499-1975, "Criteria for design of reinforced concrete Chimneys".
3. ACI 307-1979, Specification for the design and Construction of R.C.Chimney; American Concrete Concrete institute,1979
4. Clough, R.W. & Penzier, J., Dynamics of structure McGraw-Hill 1975.
5. MSC/NASTRAN user's Manual, Version 67. The Macneal-Schewendler Corporation, Los Angles, CA.
6. MSC/NASTRAN application Manual, Version 67. The MacNeal-Schwendler Corporation, Los Angles, CA.


SEISMIC RESPONSE OF CHIMNEY
BENDING MOMENT IN KN-M
(Thousands)
160
140
120
100
80
60
40
20
0
-20
20
60
100
140
180
220
HEIGHT IN METRES
Fixed base modal
Interaction Modal

Graph-1