International Conference on Case Histories in Geotechnical Engineering

(1993) - Third International Conference on Case Histories in Geotechnical Engineering

03 Jun 1993, 2:00 pm - 4:00 pm

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Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 3.14

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SYNOPSIS Seismic qualification of large and complex mechanical systems is a tedious task in itself. It not only involves high computational cost, but also becomes cost ineffective in case repeated runs are required from safety considerations. Seismic analysis of one bank of Main PHT System of a typical Nuclear Power Plant has been attempted. Besides analysing the complete system, an attempt has also been made to divide the complete system into logical subsystems and analyse the same for the prescribed seismic loads. The results thus obtained have been compared with those of the complete system and a fairly good degree of agreement has been achieved. The subsystem approach has resulted in substantial reduction of the computational cost.

INTRODUCTION

Seismic safety of equipment is a relatively new field and analysis of seismic safety of mechanical equipment is a complex task. The complexity increases with the increased size of the mechanical system and the task becomes even more tedious if the seismic qualification is required for Nuclear Power Plant where safety requirements are very stringent. Seismic qualification involves computation of stresses under various load cases (namely thermal, self weight, pressure, seismic, etc.), stress combination and safety checks in accordance with the applicable codal provisions. Any change pertaining to geometrical parameters, material properties or supporting arrangement warranted by the safety check calls for reanalysis of the entire system for all the load cases and the complete exercise of the safety check is to be repeated. If the system under consideration is pretty large, it involves very high engineering cost in addition to high computational cost. The analyses for all load cases other than seismic are normally confined to static domain whereas seismic analysis invariably requires dynamic analysis. The computational cost of a dynamic analysis is many times more than that of a static analysis. Therefore, seismic analysis turns out to be very expensive in case reruns on account of modifications are needed.

For the problems under reference, similar difficulties were encountered by the authors. From safety considerations, it called for many reruns for seismic analysis alone resulting in large computational cost. It was decided at this stage to divide the complete system into logical subsystems. The logical division into subsystems was so chosen as to provide results having a close agreement with those obtained using complete system analysis. The methodology develpoed by the authors is presented in this paper with a view to providing guidelines for tackling very large mechanical systems subjected to seismic loads.

It is worthwhile to mention that such difficulties of analysing very large systems have been more or less overcome by the use of commercially available general purpose packages namely NASTRAN, ANSYS, COSMOS, etc. where facilities like building block approach or substructuring techniques are available. One could take advantage of these facilities provided such packages are easily accessible. It is needless to mention that the costs of these packages even on license basis are exorbitant and specially so for developing countries. It is in light of this fact that the present approach is presented here wherein effective use of commonly available packages could be made without sacrificing on the accuracy of the results.

SYSTEM DESCRIPTION

One bank of Main PHT System as shown in fig.1 has been considered for analysis. This comprises the following seven main components:

1. Feed Water
2. Relief Pipe
3. Steam Generator
4. Steam Pipe
5. Heavy Water Pipes including Headers
6. Emergency Core Cooling System (ECCS)
7. Standby Pipe

The complete system is supported at six elevations and, therefore, calls for multi-support excitation analysis. The complete system has been mathematically idealised using straight pipe and bend pipe elements. Necessary rigid links and spring elements have been used to represent appropriate boundary conditions. The mathematical model thus conceived comprises 542 nodes and 445 straight and bend pipe elements. Seismic response spectra at each floor level in 'X', 'Y' and 'Z' directions have been applied simultaneously for all the six support levels.

ANALYSIS, RESULTS & DISCUSSIONS

The analysis has been done using the KWUROHR programme implemented on a VAX 11/750 system. It took about 170 hrs of CPU time to carry out a single analysis of the complete system. It may not be out of place to mention that the time taken to solve this problem was too high. For a similar problem size pertaning to building structures, one would expect a solution time of about 5 to 8 CPU hrs. Though one would expect to get all the building structure frequencies (upto 33 Hz) within 20 to 30 modes quite distinctly spaced, the mechanical system (as in the present case) results in about 140 closely spaced frequencies (upto 33 Hz) on account of coupling of various subsystems as described above. In the present case another factor resulting in more computer time was the large number of blocks (8 blocks) used to group the number of equations during the course of analysis.

As mentioned earlier, a few repeated runs were required based on safety considerations and it worked out to be too expensive from the point of view of computational cost. It was decided to divide one complete system into subsystems and analyse each subsystem separately.

Though the complete system could have been subdivided into seven subsystems, it was decided initially to divide the complete system into two subsystems viz. subsystem I and subsystem II. Subsystem I, comprises the first five main components and the subsystem II, comprises the remaining two. This division was quite logical as it resulted in substantial reduction in the number of blocks needed to store the solution equations (subsystem I needed 4 blocks and subsystem II needed 2 blocks). Subsystem analysis on VAX 11/750 system has taken about 24 hrs and 6 hrs for subsystem I and II respectively where as the time taken to solve the complete system was 170 hrs. This obviously is a tremendous saving in computer cost.

For the complete system, 141 modes have been obtained upto cut-off frequency of 33 Hz and some of the selected values have been produced below:

Mode	Freq(Hz)	Mode	Freq(Hz)	Mode	Freq(Hz)
1	5.460	50	12.740	100	22.890
5	6.138	55	12.900	105	24.300
10	7.626	60	14.420	110	24.800
15	8.748	65	15.290	115	25.810
20	9.944	70	16.650	120	27.190
25	11.290	75	18.570	125	29.240
30	11.650	80	19.520	130	31.470
35	12.090	85	20.040	135	32.220
40	12.260	90	20.470	140	32.840
45	12.550	95	21.670	141	33.050

Besides frequency, main response parameters like deflections, snubber reactions and nozzle forces have been computed from subsystem analysis and compared with those of the complete system analysis. The comparison of the results given are as under:

The predominant modes related to main components and their associated frequencies as obtained from the complete system analysis as well as from sub-system analysis are as under:

Components	Complete System Mode	Complete System Freq.(Hz)	Sub-system Mode	Sub-system Freq.(Hz)
Feed Water	1	5.46	1	5.42
	4	6.04	4	6.02
Relief Pipe	6	7.06	6	7.06
	37	12.25	28	12.25
Steam Generator	12	7.937	11	7.937
	59	14.45	39	14.45
Steam Pipe	23	11.29	17	11.27
Heavy Water	68	17.0	46	16.72
ECCS	18	9.669	4	9.54
	33	12.09	7	11.95
Standby Pipe	10	7.626	1	7.623
	48	12.71	14	12.71

From the above, it is observed that natural frequencies corresponding to main components as obtained from subsystem analysis are in fairly good agreement with those obtained from complete system analysis. The variations are well below 2%.

Comparison of response parameters namely, maximum deflections and snubber reactions have been plotted and presented in fig.2 & fig.3 respectively. It is seen from these figures that the results obtained by subsystem analysis are in close agreement with those obtained from total system analysis. Such a close agreement could be achieved only after assigning proper stiffness and mass parameter at the interface of each subsystem. These stiffness and mass parameters were computed separately in 'X', 'Y' and 'Z' directions, using static analysis. It is worthwhile to mention that when stiffness and mass parameters were earlier computed based upon static analysis results in one direction only namely gravitational direction, the variations observed in the results were substantial.

Nozzle forces as obtained from the subsystem analysis and from the complete system analysis are shown in table given below:

Nozzle Forces

	Force (T) Fx	Force (T) Fy	Force (T) Fz	Moment (TM) Mx	Moment (TM) My	Moment (TM) Mz
Steam Nozzle						
Subsystem II	1.04	75.17	76.70	3.88	55.03	55.63
Comp. System	1.07	73.72	75.72	3.69	54.32	54.55
Feed Water Nozzle						
Subsystem II	0.99	1.20	1.79	0.90	0.94	0.52
Comp. System	0.76	1.24	1.56	0.79	0.83	0.55
Heat Exchanger Nozzle						
Subsystem II	0.01	0.01	0.08	0.06	0.06	0.01
Subsystem I	0.06	0.05	0.08	0.06	0.06	0.01

It is observed from the comparison of results that the variation in the results is well within 2 to 5%.

CONCLUSIONS

From the foregoing study, the following conclusions are drawn:

1. It is desirable to analyse each subsystem separately before the complete system analysis is attempted.
2. The subsystem approach, besides providing better insight into the physical behaviour, also provides results within acceptable accuracy limits and at much reduced computational cost.
3. It also provides a feel about the level of dependence of one subsystem over another. The benefit derived could be substantial in case repeated dynamic results are required from safety considerations.
4. The accuracy of the results is dependant upon mass and stiffness parameters at the interface which in other words represents the effect of adjoining system on system under consideration. Utmost care should be taken to assign logical values to these parameters from the overall behaviour of the system.

ACKNOWLEDGEMENT

The authors wish to express their thanks to Shri K.P. Mathur, General Manager, Advanced Research Projects Group, Bharat Heavy Electricals Ltd., New Delhi, for his constant encouragement and permission to publish this work.

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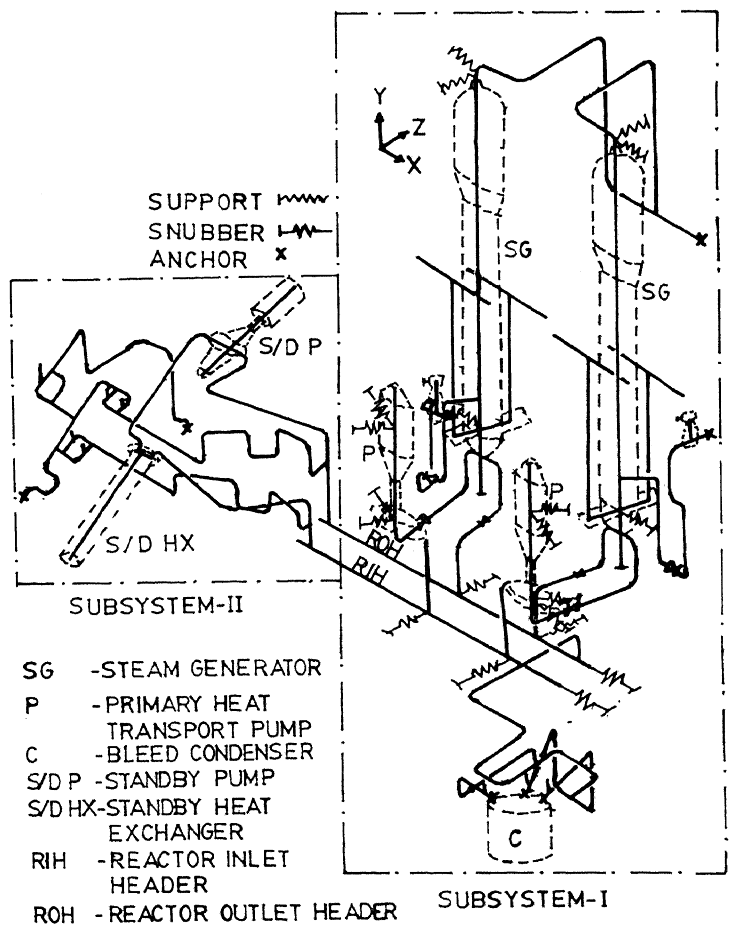

FIG.1- MAIN PHT SYSTEM

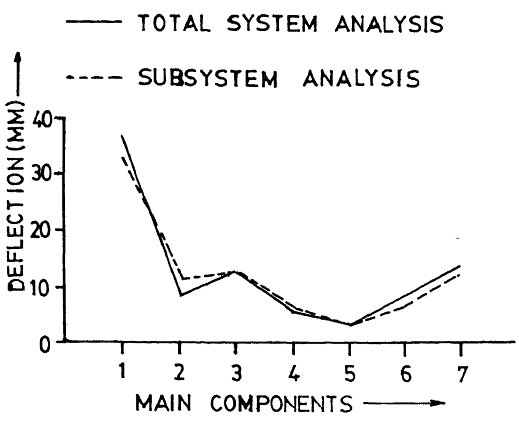

FIG. 2 - MAXIMUM DEFLECTION

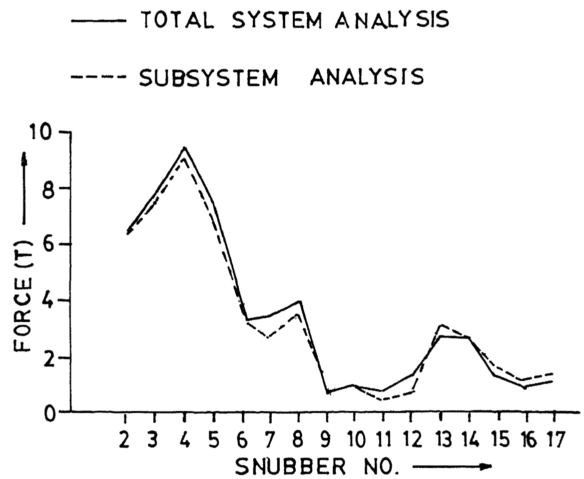

FIG. 3 - SNUBBER FORCES