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Application of new developments in coupled seismic analysis of piping systems

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1 INTRODUCTION

The current practice of calculating the seismic response is to perform the analysis of the primary structure (buildings) and the secondary systems (piping) separately. Earthquake input to the primary system is defined in terms of a design response spectrum. An acceleration time history compatible with the design response spectrum is developed (a non-unique process) and primary system is analyzed to obtain the acceleration histories at the desired floors. Floor time histories are used for generating the corresponding instructure response spectrum (IRS). The instructure response spectra are used as input at the supports of secondary systems. Further, In case of multiple supports, an envelope spectrum (introducing conservatism) is obtained from the individual support IRS. The effect of relative support motion is incorporated by a worst-case separate static analysis (adding to the conservatism). In the above method, mass interaction between the secondary and primary system is ignored, which may have significant effect at resonant frequencies (further adding to the conservatism). The calculated response may be an order of magnitude higher than they should be.

Two computer programs, CREST and CREST-IRS, were developed at Center for Nuclear Power Plant Structures, Equipment and Piping. Any one of the two computer programs together with a piping analysis program can be used to perform an accurate coupled seismic analysis of piping systems. The two computer programs have been validated against the time history analysis for simple problems (Gupta 1992). In the present study, we have applied CREST to analyze two real-life piping systems (Gupta and Gupta 1994). The piping analysis program used in this research is the commercial software PIPESTRESS , developed by DST Computer Services of Geneva, Switzerland (DST 1992).

2 CREST - PIPESTRESS INTERFACE

The source code of PIPESTRESS (DST 1992) was provided to us by DST Computer Services. CREST and PIPESTRESS were interfaced to make them interact with each other. Fig.1 describes the flow of information between CREST and PIPESTRESS. This flow chart describes a conceptual relationship between the

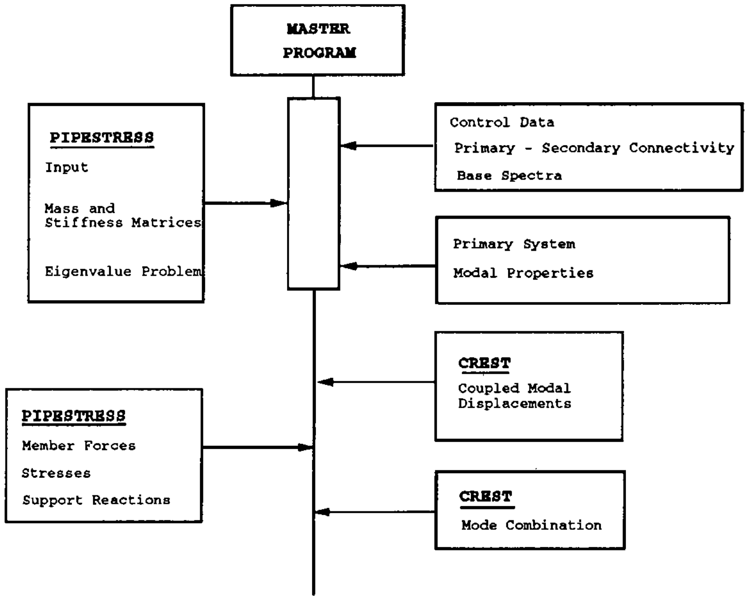

Figure 1: Generalized Flow Chart for Interaction of CREST and PIPESTRESS

CREST and any piping analysis program. The modal responses from the coupled analysis are combined in the CREST program using the mode combination procedure given in (Megahed and Gupta 1992).

The interfaced CREST and PIPESTRESS have been validated using simple problems. In this research, these programs are applied to a Pressurizer Spray Line and a Main Steam Piping. The results from the coupled response spectrum analysis of these piping systems are compared with those from the conventional (envelope spectrum) analysis. The floor spectra for performing conventional analysis were evaluated using the computer program CREST-IRS for zero mass ratio. The individual floor response spectra were enveloped and the envelope spectra used as the input spectra at all the supports. The effect of relative support motion is incorporated by a separate static analysis and the results from the two analyses are combined using SRSS rule.

3 PRESSURIZER SPRAY LINE

This piping system consists primarily of a 2.5 inches diameter, schedule 160 pipe. Fig.2 describes the piping configuration in detail. The piping system has a total of 3 anchors, 19 snubbers and 5 springs supports in the piping. The spring constants of the spring supports are very small compared to the stiffness of snubbers. These supports have not been shown in fig.2, however, they are included in the analysis. The pressurizer spray line is connected to the building (primary structure) at various elevations between 574 ft. 6 inches and 638 ft. 4 inches. The pressurizer is considered rigid and the piping is assumed to be anchored at the point of connection to the pressurizer. This anchor is connected to the base of pressurizer support by a rigid

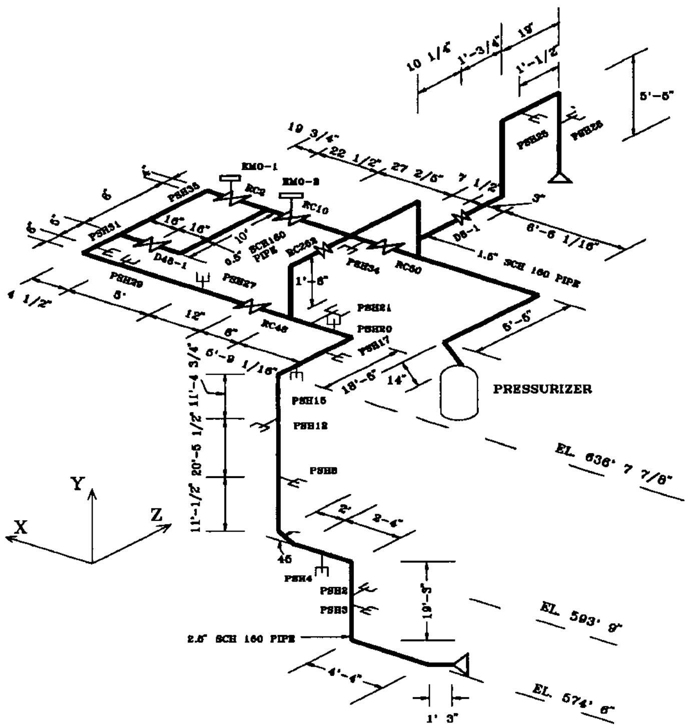

Figure 2: Pressurizer Spray Line Piping System (Not to Scale)

link. The input in the coupled analysis is the OBE spectra at the base of building and has a rigid frequency of 25 Hz. The uncoupled piping system has 26 modes that have frequencies ranging from 1.31 Hz. to 24.18 Hz. The damping ratio is 5%. The building is relatively stiff and has only two modes below the rigid frequency that have frequencies of 10.2 Hz. and 12.03 Hz., respectively. The damping ratio for the building model is 2%. Separate analyses are performed in the three global directions and the results are combined using the SRSS rule. Table 1 compares significant member forces and support reactions in the piping system from the coupled and the uncoupled analyses.

4 MAIN STEAM PIPING

The main steam piping starts from top of the steam generator inside the reactor building and ends in the turbine building. The piping on the two sides of the reactor building wall is connected with a bellow. Since the bellow does not possess significant bending, shear or axial stiffness, the present piping model terminates at the wall. The part of the piping system analyzed is shown in fig.3. The main steam piping consists of two concentric pipes, the internal pipe and the guard pipe. The internal pipe has two segments made of 32 inch and 34 inch diameter pipes that are connected through a reducer. The guard pipe is a 42 inch diameter pipe. The

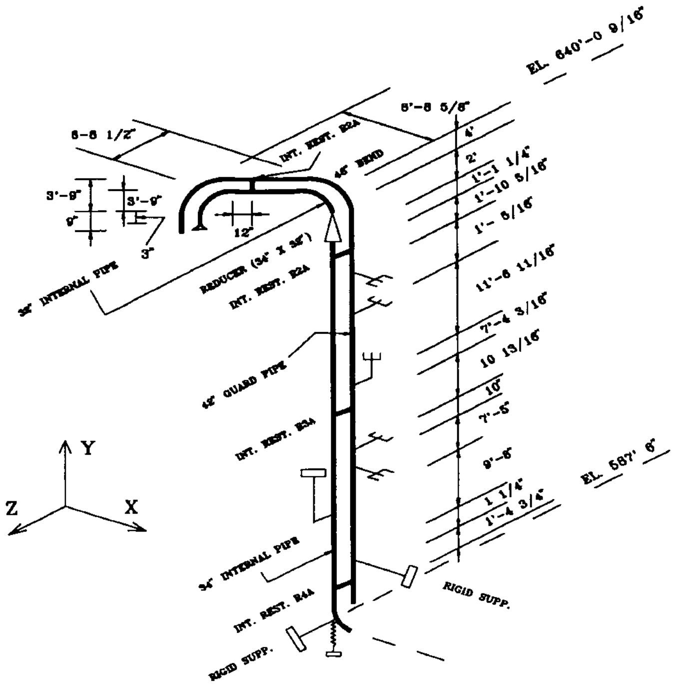

Figure 3: Main Steam Piping System (Not to Scale)

two pipes are connected by internal restraints that are modeled as rigid links. The guard pipe is supported on five snubbers and two rigid support. The internal pipe has one rigid support and one hanger type support. The connection of the internal pipe with the steam generator is modeled as an anchor.

The primary structure for this pipe consists of the reactor building and the reactor coolant loop. The reactor coolant loop has few bumper type supports that offer different resistance in different directions. Therefore, there are three different models for the primary structure, one in each of the three global directions. The results from the uncoupled analysis of all the three primary structure models were provided by B & W Nuclear Technologies. The input spectra used in the coupled analysis is the OBE spectra at the base of primary structure and has a rigid frequency of 33.33 Hz. The main steam piping system has 6 modes in the frequency range of 11.0 - 33.26 Hz. The primary structure has 50, 57 and 49 non rigid modes in the X, Y, and Z directions respectively. The non rigid frequencies for the three models lie between 4.45 Hz. - 32.72 Hz. in X - direction, 2.68 Hz. - 32.48 Hz. in Y - direction and 5.61 Hz. - 31.56 Hz. in Z - direction, respectively. The damping ratio for the primary structure is 5% and that for the piping system is 2%. Separate analyses are performed in the three directions and the results are combined using SRSS rule. Table 2 compares the significant member forces and support reactions in the piping system from the coupled and the uncoupled analyses.

Table 1: Member and Support Responses from Uncoupled and Coupled Analyses of Pressurizer Spray Line Piping System   F = Force (lb)   M = Moment (ft-lb)

Member		Response	Uncoupled	Coupled	Ratio
End Nodes	Type		U	C	U/C
1 - 2	Straight	F_z	219	43	5.09
		M_y	940	165	5.70
9 - 10	Straight	M_x	468	239	1.96
2 - 9001	Elbow	F_z	219	43	5.09
		M_y	764	146	5.23
23 - 24	Straight	M_z	264	210	1.26
35 - 37	Straight	F_y	198	85	2.33
56 - 57	Straight	F_x	160	107	1.50
65 - 66	Valve RC-2	F_x	95	50	1.90
70 - 71	Valve RC-10	F_x	141	54	2.61

Support		Response	Uncoupled	Coupled	Ratio
Node	Type		U	C	U/C
1	Anchor	F_x	55	25	2.20
		F_z	219	43	5.09
		M_y	940	165	5.70
88	Anchor	F_y	40	19	2.11
		M_x	123	65	1.89
10	Snubber	F_z	199	79	2.52
57	Snubber	F_x	233	160	1.46
131	Snubber	F_z	138	66	2.09
133	Snubber	F_z	125	53	2.36

Table 2: Member Responses from Uncoupled and Coupled Analyses of Main Steam Piping   F = Force (lb)   M = Moment (ft-lb)

Member		Response	Uncoupled	Coupled	Ratio
End Nodes	Type		U	C	U/C
11 - 9001	Straight	M_x	159544	72130	2.21
14 - 15	Straight	M_z	195504	47850	4.09
101 - 102	Straight	F_x	44950	5743	7.83
		F_z	39640	9234	4.29
		M_y	209733	116700	1.80
102 - 103	Elbow	F_x	44611	5742	7.77
111 - 9006	Straight	F_y	37228	17810	2.09
		M_y	27137	5381	5.04

Support		Response	Uncoupled	Coupled	Ratio
Node	Type		U	C	U/C
101	Anchor	F_x	44966	5743	7.83
		M_y	209733	116700	1.80
10	Snubber	F_x	51828	37680	1.38
11	Snubber	F_z	51795	34010	1.52
15	Snubber	F_z	45398	16260	2.79
170	Rigid	F_x	27591	6009	4.59
115	Spring	F_y	6226	3259	1.91
115	Rigid	F_z	25002	4829	5.18

5 CONCLUSIONS

The conventional uncoupled response spectrum method used for seismic analysis of piping systems introduces excessive conservatism. Seismic response of piping systems evaluated using coupled response spectrum analysis can be an order of magnitude lower than that calculated from an uncoupled analysis. Two computer programs, CREST and CREST-IRS, were developed at North Carolina State University to perform coupled response spectrum analysis of secondary systems. The two computer programs have already been validated against the time history analysis for simple problems. Comparison of coupled responses for two real piping systems with those obtained from uncoupled analyses shows that the coupled responses (member forces and support reactions) can be significantly lower than the uncoupled responses. This demonstrates the excessive conservatism that can be introduced in the piping response by an uncoupled analysis and points to the advantage of using a coupled analysis.

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