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Screening Dynamic Evaluation of SRS Cooling Water Line

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ABSTRACT

The production reactors at the Savannah River Site (SRS) have been shut down due to perceived safety concerns. A major concern is the seismic integrity of the plant. A comprehensive program is underway to assess the seismic capacity of the existing systems and components and to upgrade them to acceptable levels. The evaluation of the piping systems at the SRS is a major element of this program.

Many of the piping systems at the production reactors were designed without performing dynamic analyses. Instead their design complied with good design practice for dead weight supported systems with proper accommodation of thermal expansion effects. In order to gain some insight as to the seismic capacity of piping installed in this fashion, dynamic analyses were performed for some lines. Since the piping was not seismically supported, the evaluations involved various approximations and the results are only used as a screening test of seismic adequacy.

In this paper, the screening evaluations performed for the Raw Water Inlet Line are described. This line was selected for evaluation since it was considered typical of the smaller diameter piping systems at the plant. It is a dead weight supported system made up of a run of small diameter piping which extends for great distances over many dead weight supports and through wall penetrations. The results of several evaluations for the system using different approximations to represent the support system are described.

INTRODUCTION

The production reactors at the Savannah River Site (SRS) are used to produce nuclear materials. The reactors were designed and built in the early 1950's by E.I. du Pont de Nemours & Company, using the 1946 Uniform Building Code with a plant specific supplement. The site is currently operated by Westinghouse Savannah River Company for the U.S. Department of Energy. Concerns about the seismic qualification of the reactor facilities led to their shutdown in April 1988 and the undertaking of an extensive seismic re-evaluation program.

The reactors at the site are significantly different from commercial nuclear plants. They are low pressure, tube-type reactors using heavy water as the moderator and primary coolant, and basin retained river water as the secondary coolant. The primary or process water cools the reactor through six parallel heat removal loops each cooled in heat exchangers by the secondary cooling water. The cooling water is pumped from the reservoir basin to two headers, which provide the cooling water for the process water heat exchangers, and for all other equipment of greater or lesser importance. There is sufficient water in the basins and their elevation is great enough that cooling can be provided by gravity feed to satisfy the cooling requirements for 72 hours after shutdown.

Seismic effects were not considered in the original design of the piping systems at SRS. Instead they were designed in accordance with good design practice for that era to accommodate thermal expansions and to support dead weight loads. Seismic analyses and upgrades have been performed for selected piping systems since that time. In particular, all process water piping will be qualified to current seismic standards before restart. For smaller diameter cooling water lines, on the other hand, the qualification for startup consists of assuring through walkdown that the lines are properly designed to support the dead weight and thermal loads and do not incorporate design features that are considered deleterious.

In order to gain some insight as to the seismic adequacy of piping qualified through the walkdown procedures, Brookhaven National Laboratory (BNL) performed screening dynamic analyses for several pipe lines considered representative of the cooling water lines in the reactors. The evaluations performed for one of these lines, the Raw Water Inlet line for the Caterpillar diesel generators, is the subject of this discussion.

System Description

The Raw Water Inlet line consists of main piping originating at a header, continuing through a wall penetration and splitting into two branch lines which provide cooling water. The line includes a short branch that terminates at a larger diameter header, near the wall penetration. The piping material is ASTM A53, Grade B, Schedule 40. The design conditions are 60 psig pressure and 85°F temperature. The line is dead weight supported at many locations with rod type hangers of various configurations. It is considered typical of the many small diameter lines at the SRS that extend long distances and appear very flexible.

The finite element analysis model of the system is shown in Figure 1. The portion of the system which was analyzed for this evaluation consisted of the main pipe run extending from the header to the branch runs. The length of the piping is approximately 250 feet and contains 18 elbows, two tees and one valve. The run is considered to be anchored at the header connection (Node 87) and at the connection to the larger header (Node 128). The branch runs were not carried to true anchors. Instead they were continued for a sufficient length (with associated restraints) so that any change in length or type of restraint had an insignificant effect on the response of the main pipe run. The various support configurations are shown in Figure 2 with a legend that indicates their location on the finite element model.

The line was evaluated in October 1988 by walkdown and its qualification is documented on the line specific Screening and Walkdown (SEWS) work sheets. The reviewers recommended the addition of seismic restraints to protect flexible joints used at the boundary connections. Other deficiencies were reconciled through evaluations, as part of the walkdown review.

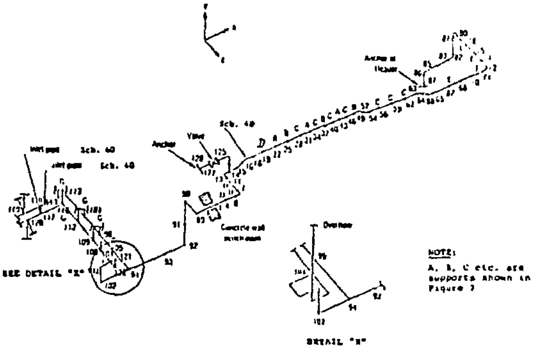

FIGURE 1: RAW WATER INLET LINE

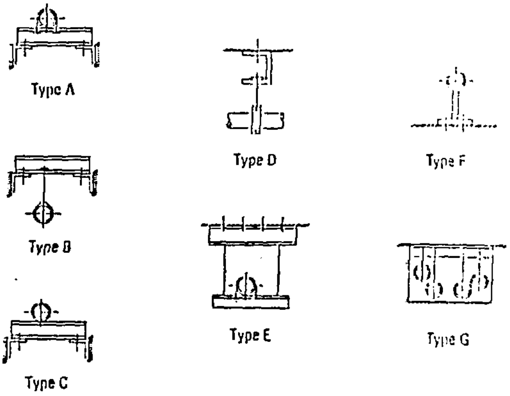

FIGURE 2: TYPES OF SUPPORTS

Analysis Description

As noted above, the main run terminates at anchors at nodes 87 and 128, corresponding to the header and the larger header, respectively. The branch lines terminate at nodes 119 and 120, which are at a sufficient distance from the main run so that the boundary conditions do not affect the main run. The main run valve is defined by nodes 125-127. The additional mass associated with the valve was introduced as a concentrated mass lumped at the valve node. The pipe elements used to simulate the valve were assigned section properties chosen to match the valve body properties. Supports were included in the model at locations consistent with their true location. Each of these supports and the anchors were modeled using spring elements. For rigid supports the spring element was assigned a high but finite stiffness (1.0E12) while for flexible support elements actual spring stiffnesses were calculated.

At the concrete wall penetration a 1.25 inch radial clearance exists around the main pipe. This displacement limitation was modeled at Node 1 by introducing a spring element of sufficient stiffness to permit a 1.25 inch displacement under seismic loading. In actuality, impact will occur at this location during seismic loading and overall system response will be nonlinear.

In addition, the main pipe run at the junction with the branch lines has a relatively complex configuration, including an overflow line (Detail "X" on Figure 1) which was not explicitly modeled. The effect of these modeling simplifications were evaluated by adding an 800 lb. concentrated load, to simulate the overflow line, at Node 121. This addition was found to have no effect on the results for the main pipe, substantiating the modeling assumptions. The results included are those developed with the simplified model excluding the 800 lb. load.

Many of the supports in this piping system were rod type hangers. In the evaluation, these supports were assumed to provide vertical restraint as linear springs with stiffnesses consistent with the rod geometries and a lateral stiffness corresponding to the following three bounding cases: (A) no lateral constraint; (B) lateral constraint consistent with pendulum action; and (C) lateral constraint consistent with considering the rod hanger a cantilever beam fixed at its anchorage. The results for these three cases are included.

The definition of the lateral stiffness for cases A and C were developed in accordance with conventional modeling techniques. Case B on the other hand is unusualy and the lateral stiffnesses were derived in the following fashion. The tributory mass (m) supported by a given rod hanger was first defined. Next, the natural frequency of a pendulum with the same length as the rod hanger is computed (i.e., $\omega=g/l$). Finally, the lateral spring is selected such that the natural frequency associated with the tributory mass for the hanger is equal to the computer pendulum frequency (i.e., $K = mg/l$). The lateral spring is assigned this stiffness.

The piping was evaluated using the ASME Class 2 equations considering dead weight, 60 psig pressure, 85^0F temperature and a seismic loading. The seismic loading was developed independently by BNL using the R.G. 1.60 definition of the free field motion normalized to 0.2 G peak horizontal ground acceleration and 5% damping. This criteria provided a response spectra which was comparable to the Housner 1% spectra used at the site.

Analysis Results

Some results from the analyses are presented in Tables 1 through 4. Each of the tables has three columns which represent the three modeling assumptions for the rod hangers. These assumptions were that the rod hangers act as:

A - vertical restraints only, providing no lateral restraint

B - vertical restraints and lateral restraint consistent with pendulum action

C - vertical restraints and lateral restraint consistent with rod acting as a cantilever

Table 1 presents the natural frequencies of the system for the first ten modes. As can be seen, the natural frequencies of the system are quite low. There is no significant difference between the no lateral constraint and pendulum lateral constraint cases while the cantilever assumption results in a 15% increase.

Table 1

Raw Water Inlet Line

Natural Frequencies, Hz

Mode	A	B	C
1	.86	.89	1.0
2	.93	1.03	1.82
3	1.0	1.19	2.0
4	1.40	1.56	2.42
5	1.54	1.67	2.64
6	2.82	3.10	4.13
7	3.0	3.30	4.30
8	3.30	3.62	4.40
9	4.0	4.14	4.74
10	4.40	4.40	5.77

Table 2 presents the forces on the supports and anchors due to deadweight and seismic loads for selected locations with high loads. Although the support adequacy for these loads was not evaluated, the U-bolts used in the Type A supports appear marginal for the apparently high lateral loads (Node 43) for cases A and B. As would be expected the lateral loads on these U bolts are reduced when more lateral restraint is introduced into the system with the cantilever assumption. Of significance is the fact that the anchor loads are not greatly different.

Table 2

Raw Water Inlet Line
Maximum Support Loads, lbs.

Type of Support	Node Number	A			B			C		
		Fx	Fy	Fz	Fx	Fy	Fz	Fx	Fy	Fz
Wall Penetration	3	-	-	2130	-	-	2159	-	-	1254
D	4	-	1670	-	-	1256	-	-	755	-
D	11	-	738	-	-	610	-	-	430	-
A	35	701	-	1262	700	10	1010	709	10	406
A	43	812	27	1523	743	27	1340	753	28	668
E	70	-	1759	7	-	1649	63	-	1600	90
E	76	-	869	-	10	946	-	12	812	-
Anchor	87	819	430	1874	800	641	1849	783	626	2031
Anchor	120	957	199	723	959	199	715	710	185	662

Table 3 presents a listing of displacements at selected locations on the piping system where relatively large displacements occur. The largest displacements were found to be in the lateral (z) direction between Nodes 60-81. This appears to be caused by the relative lack of lateral restraints between the anchor at Node 87 and the Type A support at Node 43. Again of significance, is the fact that the displacements in the vicinity of anchor point 87 are not greatly different.

Table 3
Raw Water Inlet Line

Displacement, Inches

Node Number	A			B			C		
	x	y	z	x	y	z	x	y	z
1	4.0	0.1	1.2	2.0	0.1	1.0	1.6		0.5
5	4.0		0.4	3.0	0.2	0.4	1.6		0.4
10	2.3		0.9	1.8	0.1	0.8	1.0		0.6
16		0.1	1.3			1.0		0.1	0.8
26			0.7			0.6		0.1	
52			3.5			3.3			0.1
60			8.5			8.2			5.4
65			9.5			9.3			7.5
70			7.0			4.9			6.9
78	1.1	0.2	5.1	1.1	0.2	5.5	1.0	0.2	8.5
81	0.5	0.5	5.5	0.4	0.5	5.4	0.5	0.5	5.8

Table 4 presents a listing of the stresses for the locations on the piping system where the highest stresses occur. BNL performed an ASME Class 2 evaluation of the system in accordance with Equations 8, 9, 10, and 11. The stresses which are listed in Table 4 are those calculated using Equation 9. The highest stress, found at Element 80, is 26,500 psi.

Table 4

Raw Water Inlet

Maximum Stresses, psi

Equation (9)

Element Number	A	B	C
1	9990	8989	4070
6	18560	15290	8566
13	21280	15773	9377
15	19935	15474	10565
43	11370	10687	3030
63	15709	15050	12782
77	14700	14356	14980
80	24910	24388	26530
82	19565	19262	21037

As noted, in all evaluations the rod hangers were assumed to act as linear springs in the vertical direction. A review of the support load results indicated that for most rod hangers the downward vertical gravity load exceeded the vertical seismic load. These hangers will remain in a state of tension and the linear spring assumption is good. Exceptions were noted for rod hangers in the vicinity of mode 87. In this region the vertical seismic loads exceeded the vertical gravity loads by as much as a factor of two. Clearly, for these hangers the assumption may be inappropriate. Although the actual impact of this modeling deficiency was not evaluated, it is noted that the peak system stresses are probably associated with the large lateral displacements in the vicinity of mode 87. Since these are lateral displacements they should not be greatly affected by the vertical constraint assumptions. It is, therefore, concluded that likewise the peak stress results should not be greatly affected by this modeling deficiency.

CONCLUSIONS

As can be seen from the tabulated results, system response is affected by the assumption used to model the rod hangers. Maximum support reaction forces occur in the model that exhibits the greatest displacements, Case A. Apparently, the greater displacements associated with this no lateral support assumption imposes a greater lateral constraint requirement on the few existing lateral constraints. This softest model also exhibits the lowest natural frequencies, as would be expected. Surprisingly, only a small increase in natural frequency occurs when the pendulum restraint assumption is adopted. More surprising, however, is the fact that the peak stresses are very comparable for all three cases. These peak stresses occur in the bends in the vicinity of the anchor at node 87. As noted above, the displacements in this vicinity were only slightly affected by the restraint assumptions and these stress results reflect this. Apparently, none of the lateral restraint assumptions provided enough stiffness to control the lateral displacement near the anchor.

The peak stress of 26,530 psi exceeds the normal equation 9 allowable of 15,960 psi (1.2 S_H), but is within the allowable of 31,920 psi (2.4 S_g) for faulted conditions, in accordance with Code Case 1606. As such, the line should survive a seismic input. This conclusion, however, is based on the critical assumption that rod hangers can support both tension and compression loads. How valid this assumption is bears further investigation.

Two observations from the study should be applicable to all the small diameter, dead weight supported lines in the plant. First, the fundamental natural frequencies of these lines should be low enough so that the lines will not experience the peak magnitude of the input excitations, thus lowering their response. Secondly, the few lateral supports within each line will be subjected to substantial loads, and in fact will be the chief members preventing the build-up of unacceptable stress levels in the piping. All such supports should receive a critical inspection to assure their integrity, anchorage and seismic capacity.

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