SUPPLEMENT

To the Topical Report Entitled "SONGS-1 LTS Seismic Reevaluation Program, Technical Basis for Stress-Strain Correlation," SCE Report No. 01-0310-1459, Revision 1, January 1986

Prepared for

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1.0 INTRODUCTION

This Supplement to the topical report entitled "SONGS-1 Long Term Service Reevaluation Program, Technical Basis for Stress-Strain Correlation," [1] incorporates additional responses and resolutions to the comments raised by the NRC's consultants (Mr. E.C. Rodabaugh, et.al.) at the November 26, 1985 NRC meeting [2] and discussed further during a phone conversation among the NRC, Mr. E.C. Rodabaugh, SCE and Impell on January 31, 1986. The objectives of this Supplement are three-fold:

- to clarify the actual strain limit used for stainless steel when the application limits as discussed in Section 5.2 of the Report [1] are imposed,
- to present the results of the SONGS-1 LTS piping problems that were qualified with the stress-strain correlation method,
- to respond to the comments and questions entitled "Displacement and Loadings of Piping Systems," on page 7 of Mr. Rodabaugh's notes presented at the November 26, 1985 NRC meeting [2].

2.0 ACTUAL STRAIN LIMIT FOR STAINLESS STEEL

The strain limits established for SONGS-1 LTS piping evaluation are 1 percent for carbon steel and 2 percent for stainless steel. Stainless steel has two additional checks which are simultaneously imposed to address the following concerns as discussed in Section 5.2 of the Report [1]:

- Compressive Wrinkling Check: Table 2-1 summarizes the strain limits of the compressive wrinkling check for commonly used pipe sizes and schedules at SONGS-1. For Schedule 40 pipe, the strain limit required by this check is less than 2 percent for nominal pipe sizes 6 inch and larger. There is no impact for Schedule 80 pipe and higher.

- Low-Cycle Fatigue Failure Check: The strain limit based on Markl's correlations for moment-loading fatigue tests is 1.54%. This strain limit is based on the following concepts (all parameters are defined in the Report [1]):

  - Five significant cycles for Modified Housner Earthquake (n).
  - 0.25 allowable usage factor for Modified Housner Earthquake (Ua).
  - Loads other than earthquake assumed to give stress of 0.5 S_h in calculating σe.
  - Stainless steel material is SA312 TP304 and the maximum operating temperature is 600°F (S_h = 15.9 ksi, E = 25.3 x 10^3ksi).

  Thus,

$$N = \frac{n}{Ua} = \frac{5}{0.25} = 20 \text{ cycles}$$

$$075i \frac{M}{Z} = 91.875\ N^{-0.2} = 50.5 \text{ ksi}$$

$$\sigma e = 0.5\ S_h + 0.75\ i \frac{M}{Z} = 8.0 + 50.5 = 58.5 \text{ ksi}$$

$$\epsilon_t = Ks \frac{2.0\ \sigma e}{E} = 3.33 \frac{2.0 \times 58.5}{25.3 \times 10^3} = 0.0154 = 1.54\%$$

Conclusion: The actual strain limit for stainless steel in the SONGS-1 LTS piping evaluation is dependent on pipe sizes and schedules, but it is not more than 1.54 percent (not 2 percent). The reduced limit is due to the compressive wrinkling and low-cycle fatigue failure checks. The allowable usage factor for Modified Housner Earthquake is limited to 0.25.

Nominal Pipe Size and Schedule	Wall Thickness t (inch)	Mean Radius R (inch)	Strain Limit (1) $0.2\ \frac{t}{R}$ (%)
2" Sch. 40	0.154	1.111	2%
Sch. 80	0.218	1.079	2%
4" Sch. 40	0.237	2.132	2%
Sch. 80	0.337	2.082	2%
6" Sch. 40	0.280	3.173	1.77%
Sch. 80	0.432	3.097	2%
8" Sch. 40	0.322	4.152	1.55%
Sch. 80	0.500	4.063	2%
10" Sch. 40	0.365	5.193	1.41%
Sch. 80	0.593	5.079	2.%
12" Sch. 40	0.406	6.172	1.32%
Sch. 80	0.687	6.032	2%
14" Sch. 40	0.438	6.781	1.29%
Sch. 80	0.750	6.625	2%

Note: (1) If $0.2\frac{t}{R}$ is greater than 2%, 2% is used as the limit for compressive wrinkling check.

Table 2-1: Strain Limit Due to Compressive Wrinkling Check

3.0 APPLICATION RESULTS

Table 3-1 is a reprint from Appendix II of SONGS-1 LTS Seismic Scope Chart [9], which summarizes the current results of applying the stress-strain correlation to SONGS-1 LTS large-bore piping. There are a total of 15 large-bore piping problems qualified using the stress-strain correlation (12 for carbon steel material and 3 for stainless steel material). For each problem, the application of stress-strain correlation is at isolated pipe locations. A breakdown of strain ranges is summarized below:

Strain Range	No. of Piping Problems
below 0.7%	2
0.7 - 0.8%	5
0.8 - 1.0%	5
1.0 - 1.2%	2
1.2 - 1.28%	1
TOTAL	15

Conclusion: The maximum strain for SONGS-1 LTS large-bore piping problems qualified using the stress-strain correlation as shown on Table 3-1 is 1.28 percent.

Piping Problem	Type	Strain (%)
AC-01	Carbon Steel	0.74
AC-06	Carbon Steel	0.90
AC-13	Carbon Steel	0.76
AC-127/AC-128/AC-129	Carbon Steel	0.79
AC-131	Carbon Steel	0.89
AC-132	Carbon Steel	0.67
MW-03/MW-05	Carbon Steel	0.98
SI-51	Stainless Steel	1.11
AF-02	Stainless Steel	1.16
FW-05	Carbon Steel	0.76
FW-07	Carbon Steel	0.69
FW-124	Carbon Steel	0.99
MS-363	Carbon Steel	0.85
MS-03	Carbon Steel	0.72
RC-102/CV-100/CV-101	Stainless Steel	1.28

Table 3-1: SONGS-1 Stress-Strain Correlation Application Results

4.0 PIPE BOUNDARY LOADS

To address concerns on the accuracy of linear analysis for defining pipe boundary loads, i.e. nozzle loads, support loads, valve accelerations at valve operators and the loads on bolted-flanged joints (Page 7, Questions (2), (3), (4) and (5) of Mr. E.C. Rodabaugh's notes in [2]), additional backup information is presented below.

4.1 SONGS-1 Specific Piping Nonlinear Analysis

A SONGS-1 specific piping nonlinear analysis study was performed to establish the acceptable strain limits and to correlate elastically calculated stresses to the strain limits [3]. Two piping problems were selected for the study: one for piping problem AC-19 with carbon steel material and the other for piping problem MW-01 with stainless steel material. Linear analyses (response spectra method) were also performed with inputs matching the nonlinear analyses.

For AC-19, all the linear results enveloped the nonlinear results with percent changes ranging from 10 to 51 percent. The percentage change is defined as (linear results-nonlinear results)/linear results.

For MW-01, the linear results enveloped the nonlinear results at peak values. There are instances where the linear results are less than the nonlinear results, but the magnitudes at these locations are relatively small compared with the peak values. Table 4-1 is a reprint from Table 5-11 of [3] and it shows three support design capacities where the linear results are less than the nonlinear results. Code Level D support capacities for all three supports are greater than the nonlinear results with margins ranging from 14 percent to 319 percent.

A significant conservatism in the comparison is that for MW-01 linear and nonlinear analyses, the seismic response spectrum and time history input were increased from the SONGS-1 Level D earthquake (Modified Housner Earthquake) by a factor of 7.85 in order to arrive at the 2 percent strain level at critical components in the piping system. Thus, the results from this study are much higher than the results from SONGS-1 actual Level D earthquake. A similar factor with lower magnitude was also applied to AC-19 linear and nonlinear analyses.

4.2 Piping System Test Programs

Numerous testing programs have been conducted, or are in progress, to study the behavior of piping systems under earthquake or other dynamic loadings. Unfortunately, most of these tests did not correlate the test data with analytical results using a production piping analysis approach (linear analysis). Also, due to the limitation of test apparatus, many of these tests did not reach input levels which could cause the piping system to develop gross plasticity.

One conclusion which can be reached from these tests is that nuclear piping systems are able to sustain extreme earthquake loads without loss of pressure-retention capability (no leakage or plastic hinge) and therefore, have inherent reserve margins under earthquake loadings.

Below, we briefly discuss two of the recent piping system test programs performed by ANCO for the NRC and EPRI:

- Laboratory Study: Dynamic Response of Prototypical Piping Systems [4].

  The piping system tested was a 70 ft. long, 6 and 8 inch diameter, Schedule 40, ferritic material piping system with numerous elbows, reducers, welding neck flanges and pipe supports. The piping was pressurized to 1150 psig and driven with simulated earthquake time histories having various input ZPAs (highest ZPA was 8.4g). Maximum ASME Code Class 2 SIF-based piping stresses were calculated from the measured strains, using linear analysis assumptions. The conclusion from the test report [4] is quoted below:

  > "It may be seen that this severe test was about a factor of four greater than the input necessary to match the Level D stress limits in the frequency region of interest for the piping system. That is, the piping system successfully withstood an earthquake input about four times greater than the Code design rules would indicate to be acceptable. The piping system, in fact, withstood several severe dynamic tests with no gross distortion or loss of pressure retaining capacity."

- Dynamic Response of Pressurized Z-Bend Piping Systems Tested Beyond Elastic Limits and with Support Failure (5).

  The piping system tested was a 20 ft. long, 4 inch diameter, Schedule 40, ferritic material pipe segment with two elbows and three supports. The piping run was designed in accordance with ASME Code Class 2 rules and was excited with earthquake-like dynamic motions to various response levels while under the Code maximum allowable internal pressure. The conclusion from the test report [5] is quoted below:

  > "The tested piping systems successfully withstood repeated earthquake-like loading at input levels from three to five times those necessary to exceed the ASME Class 2 Level D stress limit for primary loads. Even with midpoint support failure, piping pressure integrity was maintained. The tests demonstrated the difficulty of inducing pressurized piping failure (leakage or plastic collapse) with dynamic loads and provided evidence of the large safety margins that are believed to exist for nuclear power plant piping subjected to seismic loads. In addition, the seismic testing of the piping indicated that the snubber hardware used had apparent failure loads that were two to four times the manufacturer's specified load limit."

4.3 Actual Earthquake Experiences

Numerous actual earthquake experiences for operating power plants have demonstrated that operating nuclear power plant structures, equipment and piping, such as those in SONGS-1, have considerable seismic reserve margins capable of sustaining an earthquake which far exceeds its nominal design capacity. The Addendum to NUREG 1061, Volume 2 entitled "Summary and Evaluation of Historical Strong-Motion Earthquake Seismic Response and Damage to Aboveground Industry Piping" [6] also concluded that the inertia response of piping due to a real earthquake does not cause pipes to fail and, in general, the behavior assumptions, methods, procedures, and acceptance criteria currently used to design nuclear power plant piping greatly over-estimate the seismic response of piping.

Below we briefly discuss one of the recent earthquake experiences studied by the NRC and LLNL:

- El Centro Steam Plant Earthquake Experience for the 1979 Imperial Valley Earthquake [6 and 7].

  The El Centro Steam Plant was inspected by an NRC team following the October 15, 1979 Imperial Valley Earthquake [6]. When the earthquake occurred, Units 3 and 4 of the four-unit non-nuclear plant were operating. The operating units tripped off-line when the station's power was lost. Unit 3 was restored to service within 15 minutes after the main shock. Unit 4 was restored to service within 2 hours. The inspection was of interest to the NRC because the plant is similar to older operating nuclear power plants in both design and types of equipment installed. The NRC team observed only minor damage to the plant's structural and mechanical systems despite the estimated 0.5g peak horizontal ground acceleration produced at the site.

  The plant's original design criteria specified a static lateral load equivalent to 20 percent of the dead and live loads. Following the earthquake, the NRC engaged LLNL to analyze Unit 4 [7]. To accurately predict the actual response of the plant from the earthquake, the LLNL study used realistic assumptions for the analysis, thus eliminating many of the conservatisms that are used in the analysis of nuclear power plants.

  The LLNL study concluded that the forces experienced by the plant equipment were on the order of 2 to 9 times greater than the 0.2g specified design load. The reserve seismic capacity in the plant equipment is then at least on the order of 100 percent. Note that because of the highly damped soil properties used in the soil-structure interaction analysis by LLNL (soil damping ratios as high as 100 percent of critical were used), the forces calculated from analysis represent a low estimate if compared with the forces that would be obtained using more conservative assumptions, as was done for SONGS-1. The reserve margin would be even greater if analysis techniques such as those used for SONGS-1 were used.

> The above conclusion was confirmed by observations of the actual response of piping systems at the plant. Post-earthquake inspection indicated that no high-temperature or high-pressure piping failed during the earthquake. Piping failures were observed only in two lines, at locations that had been either weld-repaired or had been excessively corroded.

Conclusion: With the support of the conservatisms in design, piping system test results and actual earthquake experiences, it is concluded that at the strain levels as calculated with the SONGS-1 stress-strain correlation method, the linear piping response analysis will predict reasonably accurate piping boundary loads. The piping systems at the calculated strain levels may experience local yielding, but the system as a whole remains essentially elastic and no plastic hinges will be formed.

		Support Load, k		
Node(1)	Direction(1)	Linear(1)	Nonlinear(1)	Design Capacity(2)
11	Y	2.00	3.37	3.83
	Z	0.89	0.99	1.13
19	X	11.30	8.31	
	Y	1.64	1.25	
20	X	4.64	2.59	
	Z	1.50	1.16	
24	Y	0.41	0.91	1.16
	Z	2.09	2.47	9.05
28	X	3.82	4.60	5.70
	Z	1.38	1.40	5.86

Notes: (1) From Table 5-11 of [3].

(2) Support design capacities are presented only for supports where the linear results are less than the nonlinear results.

Table 4-1: MW-01 Support Load Comparison

5.0 PIPE DISPLACEMENTS

To address concerns that the pipe displacements are much greater than those estimated by the linear elastic analysis and the piping may hit some safety-related equipment (Page 7, Question (1) of Mr. E.C. Rodabaugh's notes in [2]), additional backup information and a further action to avoid any potential seismic interferences are presented below.

5.1 Displacements from SONGS-1 LTS Linear Analysis

Table 5-1 presents the seismic displacements from linear analysis (response spectra method) in the vicinity of the locations of SONGS-1 piping problems qualified using the stress-strain correlation. The term "vicinity" is defined in Note (1) of Table 5-1. The maximum seismic displacement is 4.8 inches in one direction for piping problem MS-363 (pipe size is 3 inch).

5.2 Scale Factor to Increase Seismic Displacements from Linear Analysis

Based upon the SONGS-1 specific piping nonlinear analysis study [3], a review of key seismic displacements between the linear elastic (response spectrum method) and the nonlinear analyses for one of the two piping problems (MW-01) shows that pipe displacements from the nonlinear analysis are not much greater than those estimated from the linear analysis. Furthermore, there are insufficient test data to compare the seismic displacements between test results and analytical results using a production piping analysis approach (linear analysis). Nevertheless, for pipe interference checks, seismic displacements will be multiplied by a factor of 3.33 whereever the stress-strain correlation is applied. This factor is based on the following two concepts:

- Conservatively increase the displacements by a factor of 5.0, which is the maximum ratio of displacements for the following cases:

  (1) between a fixed - fixed beam with a hinge in the middle and the same beam without a hinge for mid-point static loading:

$$\frac{PL^3}{48\ EI} \Big/ \frac{PL^3}{192\ EI} = 4.0$$

  (2) between a fixed - fixed beam with hinges at both ends and the same beam without hinges for mid-point static loading:

$$\frac{PL^3}{48\ EI} \Big/ \frac{PL^3}{192\ EI} = 4.0$$

  (3) between a fixed - fixed beam with hinges at both ends and the same beam without hinges for uniformly distributed static loading:

$$\frac{5\ WL^4}{384\ EI} \Big/ \frac{WL^4}{384\ EI} = 5.0$$

- Reduce the displacements by a factor of 1.5, which is the ratio of the dynamic margin against failure to the static margin against failure as discussed in [8].

Therefore, the displacement scale factor for pipe interference checks is

$$\frac{5.0}{1.5} = 3.33$$

5.3 Further Actions

To ensure that there are no pipe interferences with safety-related equipment under seismic loading, walkdowns will be performed in the vicinity of all locations which satisfy the following three conditions:

- Pipe is qualified using the stress-strain correlation
- Nominal pipe size is greater than 2 inch
- Seismic displacements are greater than 1.0 inch in any direction. The seismic displacements are those calculated from linear analysis multiplied by a factor of 3.33.

Piping Problem	Nominal Pipe Size	Seismic Displacement (± inch)(1)(4)			Note
		X (N-S)	Y (Vert.)	Z (E-W)	
AC-01	1"				(3)
AC-06	3"	.89	.04	.24	
AC-13	8"				(2)
AC-127/AC-128/AC-129	3"	.69	.49	1.22	
AC-131	3"	1.31	.95	1.62	
AC-132	3"				(2)
MW-03/MW-05	6"				(2)
SI-51	6"	.31	.46	.22	
AF-02	6"	.78	.84	.17	
FW-05	3"	2.61	1.96	.92	
FW-07	3"	.31	.08	.28	
FW-124	10"	.08	.70	.08	
MS-363	3"	2.02	3.71	4.81	
MS-03	8"	.13	.03	.22	
RC-102/CV-100/CV-101	2"				(3)

Note: (1) The displacement for each direction is taken at worst location in adjacent piping spans up to the first complete X-Y-Z restraints at both sides of the location where the stress-strain correlation is applied.

(2) Insignificant seismic displacements.

(3) Since the nominal pipe size is 2 inch or less in the vicinity of the location where the stress-strain correlation is applied, no pipe interference check is required.

(4) The displacement does not consider the existing supports which are postulated "yielding" under the earthquake loading (Type C supports).

Table 5-1: Seismic Displacements from Linear Analysis

REFERENCES

[1] SCE Report No. 01-0310-1459, "SONGS-1 LTS Seismic Reevaluation Program, Technical Basis for Stress-Strain Correlation," Revision 1, dated January 1986.

[2] NRC Letter from E. McKenna to SCE, "Meeting Summary - Seismic Reevaluation Criteria," dated December 9, 1985.

[3] Impell Report No. 04-0310-0063, "SONGS-1 Functionality Criteria for Piping Systems in Response to the DBE Event," Revision 2, December 1983 (Transmitted to the NRC in SCE Letter to NRC, from K. Baskin to D. M. Crutchfield, dated December 23, 1983).

[4] NUREG/CR-3893, "Laboratory Studies: Dynamic Response of Prototypical Piping Systems," Prepared by ANCO Engineers, Inc. for the USNRC and EPRI, August, 1984.

[5] EPRI Report No. NP-3746, "Dynamic Response of Pressurized Z-Bend Piping Systems Tested Beyond Elastic Limits and with Support Failures," Prepared by ANCO Engineers, Inc. for EPRI, December 1984.

[6] Levin, H.A., Martore, J.A., Reiter, L., Jeng, D., Heller, L.W., "Reconnaissance Reports - Imperial Valley Earthquake, October 15, 1979," U. S. Nuclear Regulatory Commission, Washington D.C., Memorandum for Darrel G. Eisenhut (November 2, 1979).

[7] NUREG/CR-1665 "Equipment Response at the El Centro Steam Plant during the October 15, 1979 Imperial Valley Earthquake," prepared by LLNL for the Office of Nuclear Reactor Regulation, October 1980.

[8] R.D. Campbell, R.P. Kennedy, and R.D. Thrasher, "Development of Dynamic Stress Criteria for Design of Nuclear Piping System," SMA 17401.01, prepared for PVRC by Structural Mechanics Associates, Inc., March, 1983.

[9] SONGS-1 LTS Seismic Scope Chart, SWR No. 3016, Revision E, dated February, 13, 1986.