Client: Duquesne Light/PLG, Inc. Calculation No. 93C1783-13

Title: SEISMIC FRAGILITY (SPRA) ANALYSIS, BEAVER VALLEY UNIT #1, REACTOR COOLANT PUMP

Project: BEAVER VALLEY SEISMIC FRAGILITY ANALYSIS FOR INDIVIDUAL PLANT EXAMINATIONS FOR EXTERNAL EVENTS

Method:

Acceptance Criteria:

Remarks:

REVISIONS

No.	Description	By	Date	Chk.	Date	App.	Date
0	Initial Issue	YZ	1-31-94	PRW	1-31-94	PRW	1-31-94

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CALCULATION COVER SHEET

FIGURE 1.3

CONTRACT NO. 93C1783

Reactor Coolant Pump RC-P-1A, 1B, 1C

1. Basic Information Summary (Reference 1)

The reactor coolant pump is a large vertical pump locaded at the pressure boundary. Only pressure boundary and support failure are pertinent to the risk study. The pump pressure boundary is governed primarily by the high operating pressure and (the) seismic loading is a less significant contributor. The seismic spectrum analyses was performed with the floor response spectra at EL.767' of the containment internal structure. The frame model of the reactor coolant pump support is an integral part of the entire support system with the steam generator.

The analyses in Reference 1 indicate that the side restraint of the pump foot support components is the most critical part of the support system. For the main weld of the side restraint the stress state is primarily bending with a safety factor of 1.02 for DBE + Pipe Break + Dead weight. The pipe break contributed more than 75% of the total load. The seismic load is about 15% of the total load. The design allowable stress is 90% of the minimum yield strength of the material.

The side restraint is made of A36 Carbon Steel with minimum $\sigma_y = 36$ ksi

2. Determination of Median Capacity, Am

In Reference 1 no input spectra value was found for the seismic analysis. Since the reactor coolant pump and steam generator are supported on the same entire support system, the seismic spectrum used for the steam generator support in Reference 2 may be employed for the analysis of the reactor coolant pump support. The spectrum is a broadened envelope floor response spectrum with a resonant range of about 2Hz to 8 Hz. The corresponding (DBE) peak spectrum value is 6.0g and ZPA value is 1.5g. A typical fundamental frequency for the coolant pump may be found to be 5Hz from Reference 3. Therefore, the peak spectrum value used in the horizontal direction could be assumed to be 6.0g. It is noted that the floor response spectrum is an enveloped spectrum for lower and upper support of the steam generator.

From the basic information summary made previously, the strength ratio, σ_y/σ_d, is $1/0.9 = 1.111$, the total stress ratio, σ_t/σ_d, is $(0.25/1.0)\cdot(1/1.02) = 0.245$, the normal stress ratio, σ_n/σ_d, is $(0.1/1.0)(1/1.02) = 0.098$. then the strength factor, F_S, is computed as

$$F_S = \frac{\frac{\sigma_y}{\sigma_d} - \frac{\sigma_n}{\sigma_d}}{\frac{\sigma_t}{\sigma_d} - \frac{\sigma_n}{\sigma_d}} = \frac{1.111 - 0.098}{0.245 - 0.098} = 6.89$$

Reference 4 gives a ductility value from 2.5 to 10 for steel loaded primarily in bending or tension. 6.25 may be considered to be a median value, 2.5 is a minus two logarithmic standard deviation value. Then the median ductility factor, F_μ, can be computed as

$$F_\mu = \sqrt{2 \times 6.25 - 1} = 3.39$$

At the fundamental frequency, 5Hz, (at EL. 767' of containment internal structure that is close the elevation of the steam generator upper support,) the UHS spectrum value is about 0.42g. The corresponding ZPGA value for the UHS spectrum is 0.15g. The median value for the yield stress of carbon steel is 1.2 times the minimum one that was used to calculate the capacity of the side restraint. Considering the strength factor of

6.89 and the median ductility factor of 3.39, the median capacity, A_m, may be determined as

$$A_m = \frac{0.42g}{0.4\,g} \times 6.89 \times 3.39 \times 1.2 \times 0.15g = 4.41g$$

where, 0.42g is an aximate value (actually used) for the upper support of the pump at EL. 740'-3" that is scaled from a value of 0.37g for the reactor vessel support at EL. 738'

3. Logarithmic Standard Deviation Values of Variables

3.1 Ground Motion

Response Spectrum Shape:

The spectrum is anchored to PGA at 7 Hz. The spectrum has been broadened and enveloped. Since the fundamental frequency of the pump is 5Hz that is locaded within the spectral resonant frequency range, higher values may be assumed as 0.4 and 0.3, respectively for the peak and valley randomness, β_r, and the spectral shape uncertainty, β_u.

Horizontal Direction Peak Response:

The β_r and β_u values are taken from Reference 5 as 0.10 and 0.0 for the two identical horizontal response spectra

Vertical Component Response:

Since the ground vertical spectrum value is equal to 2/3 of the ground horizontal spectrum value, the β_r and β_u may be determined from Reference 5 as 0.10 and 0.0, respectively.

3.2 Damping

A viscous damping was assumed for the linear analysis of the containment building and the reactor coolant pump. the UHS spectrum a median 5% damping was assumed for the building and pump. Then $\beta_r = 0.0$ and $\beta_u = 0.035$ may be assumed using Reference 5

3.3 Modeling

Frequency:

The modal frequencies of the containment building and reactor coolant pump depend on the masses and stiffness of the structural elements. Since the fundamental frequency of the pump is (governed by the primary loop system) assumed to be within the resonant range of the floor response spectrum that was broadened and enveloped, extra uncertainty might be introduced. Then the β_r and β_u values may be assumed to be 0.0 and 0.45, respectively.

Mode Shape:

Using the experience and judgement provided in

Reference 5, the randomness β_r value may be assumed to be 0.0 and the uncertainty β_u value may be taken as 0.15 that is the upper bound of the uncertainty β_u value range because the model of the coolant pump complex system has complicated mode shapes.

3.4 Mode Combination

In general individual modal responses are correlated. A SRSS combination of modes is based on the assumption of independent modes. The reactor coolant pump complex system is a complicated model that might give closely-spaced modes. Then the randomness β_r value may be assumed to be 0.20 using Reference 5.

3.5 Direction Combination

The failure mode of the side restraint is primarily in bending which may be governed also by the vertical excitation, because no modal information was found from Reference 1. Then the randomness β_r value may be assumed to be 0.40 according to the recommendation in Reference 5.

3.6 Strength

Material properties:

For A36 steel of the side restraint the yield stress value of 36 ksi used is ~~the~~ minimum value.

β_u may be assumed to be 0.05 and β_r to be 0.0

Strength Equation:

The stress state is primarily bending and the formulation for the bending is simple and complete. Therefore, the effect of the β_r and β_u is negligible.

3.7 Inelastic Energy Absorption

Since the median inelastic energy absorption factor, Fu, is 3.39 corresponding to the median ductility of 6.25. The logarithmic standard deviation is equal to 1.875. Then the minus one standard deviation inelastic energy absorption factor, $F_{u-1\sigma}$, can be computed as

$$F_{u-1\sigma} = \sqrt{2(6.25-1.875)-1} = 2.78$$

Therefore the randomness parameter β_r may be determined as (Reference 5)

$$\beta_r = 0.4\left[0.06 + 0.03(3.39-1)\right] = 0.05$$

and the uncertainty parameter β_u as (Reference 5)

$$\beta_u = \ln(F_u / F_{u-10})$$
$$= \ln(3.39 / 2.78)$$
$$= 0.20$$

4. Summary of Variables

Variable	β_r	β_u
<u>Response</u>		
Ground Motion		
Response Spectrum Shape	0.4	0.3
Horizontal Direction Peak	0.1	0.0
Vertical Component	0.1	0.0
Damping	0.0	0.035
Modeling		
Frequency	0.0	0.45
Mode Shape	0.0	0.15
Mode Combination	0.2	0.0
Direction Combination	0.4	0.0
<u>Capacity</u>		
Strength		
Material Properties	0.00	0.05
Strength Equation	0.0	0.0
Inelastic Energy Absorption	0.05	0.20
Combined	0.62	0.600

5. Seismic Fragility

From above analyses one can obtain

$$A_m = 4.41g, \quad \beta_r = 0.62, \quad \beta_u = 0.600$$

then the SPRA seismic fragility, $HCLPF_{50}$, is determined as

$$HCLPF_{50} = A_m \, Exp[-1.65(\beta_r + \beta_u)]$$

$$= 4.41 \cdot Exp[-1.65(0.62 + 0.600)]$$

$$= 0.61g$$

The SMA seismic fragility, $HCLPF_{84}$, is computed by (Reference 5)

$$HCLPF_{84} = HCLPF_{50} \cdot Exp[\beta_{rs}]$$

in which

$$\beta_{rs} = \sqrt{(\beta_r^{hs})^2 + (\beta_u^{hs})^2}$$

β_r^{hs} — β_r value due to horizontal component response spectrum shape

β_u^{hs} — β_u value due to horizontal component response spectrum shape

in this case

$$\beta_r^{hs} = 0.4, \quad \beta_u^{hs} = 0.3$$

then $\beta_{rs} = \sqrt{0.4^2 + 0.3^2} = 0.5$

and $HCLPF_{84} = 0.61 \cdot Exp[0.5] = 1.01\,g$

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CLIENT PLG Inc. IPEEE JOB No. 9301783 SHEET 10 OF 10

SUBJECT Seismic Fragility (SPRA) Analysis, Beaver Valley Unit #1

Reactor Coolant Pump

REVISIONS: 0 YK 1-31-94; PRW 1-31-94

Reference:

1. "Stress Report Reactor Coolant Pump Support," P. O. No. BV-245, J. O. No. 11700, Fabrication Specification No. BVS-349, Duquesne Light Company, Beaver Valley Power Station, Unit 1, December 1971
3. "Handbook of Nuclear Power Plant Seismic Fragilities," NUREG/CR-3558, June 1985
2. Westinghouse Electric Corporation Nuclear Energy Systems, "Steam Generator Stress Report Duquesne Light Company, Beaver Valley Power Station No. 1," Westinghouse General Order PG-88301-AR6/AR5, December 1974
4. Newmark, N. M., "Inelastic Design of Nuclear Reactor Structures and Its Implications on Design of Critical Equipment," SMiRT 4, K4/1, 1977
5. Reed, J. W. and Kennedy, R. P., "Methodology for Developing Seismic Fragilities," (Draft) EPRI NP-XXXX, RP 2722-23, August 1993

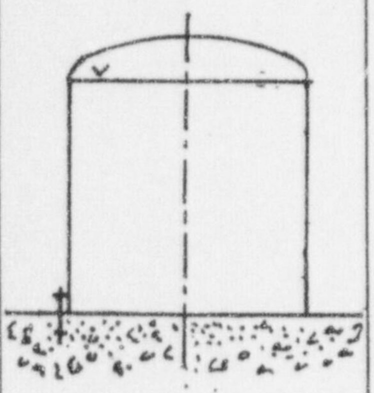
ATTACHMENT C

Description of Stevenson & Associates Program TANKV

Computer Software Systems and Services

TANKV Software System

The **TANKV** software system calculates the seismic response of vertical cylindrical liquid storage tanks and estimates their seismic capacity in terms of seismic margins. These calculations give a High-Confidence-Low-Probability-of-Failure Seismic Margin Earthquake (**HCLPF SME**) capacity of the tank following the Conservative Deterministic Failure Margin (**CDFM**) approach. The results can also be used to estimate seismic fragility capacity and design code capacity of the tank. **TANKV** is designed to perform an interactive analysis of vertical cylindrical liquid storage tanks subjected to base seismic excitations. Some Program Features and Capabilities Include:



- *Supplied Database Containing:*
  - *ASME Materials and Material Properties*
  - *Anchorage Materials and Details*
  - *Various Types of Input Response Spectra*
  - *Properties for Many Common Liquids*
  - *Ability for USER Additions to the Database*
- *Capability to Evaluate Anchored or Unanchored Tanks*
- *Capability to Evaluate Bottom Uplift and Liquid Hold-down Forces*
- *Consideration of Flexible Foundation and Tank Interaction*
- *Capability to Evaluate Roofed and Unroofed Tanks*
- *Capability to Consider Fixed and Internal Floating Roofs*

The following provides a basic description of the program technical basis. The seismic analysis of vertical cylindrical liquid storage tanks consists of two phases: a seismic response analysis and a seismic capacity assessment. The response analysis in **TANKV** is mostly based on works of Veletos and Haroun and Housner. The capacity assessment is primarily based on the work of Kennedy. For anchored tanks small displacement theory is used to compute the liquid hold-down forces. For tanks with minimum anchorage and for unanchored tanks, the use of small displacement theory to evaluate liquid hold-down forces will result in excessively conservative HCLPF's. Therefore for these tanks a more appropriate upper bound theory is used for the evaluation.

The program is presently operable on **PC** under **DOS** (version 2.0 or higher) and Microsoft **Windows.** The program is highly user friendly, with a screen menu driven input system.

S&A
Stevenson and Associates

for more information.........

Write....

Stevenson and Associates
9217 Midwest Avenue
Cleveland, Ohio 44125

Call....(216) 587-3805
Fax....(216) 662-6273

ATTACHMENT D

HCLPF Calculations for BVPS-2 Flat Bottom Tanks