Southern California Edison Company
P. O. BOX 800
2244 WALNUT GROVE AVENUE
ROSEMEAD, CALIFORNIA 91770

F. R. NANDY
MANAGER OF NUCLEAR LICENSING

TELEPHONE
(818) 302-1896

May 31, 1989

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555

Gentlemen:

Subject: Docket No. 50-206
Additional Information Regarding Crankshaft
Transient Response (Report No. FaAA-84-12-14)
Standby Diesel Generators
San Onofre Nuclear Generating Station
Unit 1

Reference: Letter dated January 13, 1989, from F. R. Nandy (SCE) to NRC, Standby Diesel Generators

By the referenced letter, Southern California Edison (SCE) transmitted four reports prepared by Failure Analysis Associates dealing with the San Onofre Unit 1 standby diesel generators. Report No. FaAA-84-12-14 (Revision 1.0) evaluated the transient response of the crankshaft under various assumed conditions and contained conservative predictions regarding the rate of propagation of a pre-existing crack at the highest-stressed oil holes.

During a telephone conversation with the NRC on April 27, 1989, some of the methods and assumptions of Report No. FaAA-84-12-14 were discussed. The NRC staff requested that the oral information provided in the telephone conversation be followed up by a written response. Enclosure I satisfies this NRC request. It consists of a paraphrase of each NRC question followed by SCE's response, which incorporates information provided by Failure Analysis Associates and Enterprise Engine Services (successor to TDI).

A001
1/1

If you have any questions, please call me.

Very truly yours,

Enclosure

cc: J. B. Martin, Regional Administrator, NRC Region V
F. R. Huey, NRC Senior Resident Inspector, San Onofre Units 1, 2 and 3

Enclosure I

RESPONSES TO NRC QUESTIONS
OF APRIL 27, 1989 ON
REPORT NO. FaAA-84-12-14, REV. 1.0

Q1. Explain what fatigue crack growth model was used in developing the crack propagation analysis of Section 5 of the report.

R1. The relationship between the crack growth per cycle (da/dN) and the cyclic stress intensity factor ($\Delta K_{eff}$) defines the crack growth law for the analysis of fatigue crack growth. The da/dN data as a function of $\Delta K_{eff}$ for the analysis are shown below:

| da/dN (inches/cycle) | $\Delta K_{eff}$ (ksi $\sqrt{in}$) |
|---|---|
| $1 \times 10^{-8}$ | 5.0 |
| $1 \times 10^{-7}$ | 8.0 |
| $1 \times 10^{-4}$ | 80.0 |
| $5 \times 10^{-4}$ | 100.0 |

The Hop-Rau relation (Reference 1) was used to account for the influence of the stress ratio, R, on the crack growth rate. This relationship is shown below:

$$\Delta K = [(1.78 - R) / 1.78]\ \Delta K_{eff}$$

where $R = \sigma min/\sigma max$, and at R=0, $\Delta K = \Delta K_{eff}$. The data analysis also includes the presence of a threshold, in which case da/dN is taken to be zero if $\Delta K$ is less than the value of $\Delta K_{th}$. For the current analysis, $\Delta K_{th}$ for R=0 was set at 5.5 ksi $\sqrt{in}$ which is a typical value for steel (Reference 2).

Q2. What was the source of the data for the model?

R2. FaAA developed the data based upon reviewing literature for low strength steel materials and FaAA's experience in performing crack growth studies. These data are compared with data from literature for low strength steel materials in Figure 1. The data fall well within the range of crack growth data available for low strength, medium carbon steels (References 2 and 3).

Q3. Explain how the fatigue crack growth model is applicable to the San Onofre Unit 1 crankshafts based on (i) operating environment, (ii) material, and (iii) heat treatment of the crankshaft.

R3. (i) The material data used for the analysis was for steel in an air environment. The oil environment of the engine would not be considered a corrosive environment and is expected to be more benign than the air environment of the test data. Environmentally accelerated fatigue crack growth is strongly influenced by the material's yield strength. The crack growth rate of steels with low yield strengths, below 100 ksi, is typically not affected by environment. Since the material used in these crankshafts has an average yield strength of 62 ksi, little if any change in the crack growth rate data would be warranted for the engine environment.

In addition, the operating environment for this crankshaft material is limited to temperatures less than 200°F. The fatigue growth rate data for the low strength steels is not significantly affected by temperatures within this range. Paris et al (Reference 3) show this effect for the temperature ranges in question.

(ii) The material certificates for the crankshafts at San Onofre Unit 1 indicate that the crankshafts were forged from vacuum degassed, medium carbon, low strength steel. The average yield strength of the test specimens was 62 ksi (with a low value of 58 ksi), the average tensile strength was 95.5 ksi (with a low of 94.5 ksi), the average % elongation in a 2" specimen was 24.3% and the average reduction in area was 46.6%.

Material fatigue crack growth properties for steels with a variety of chemical compositions and tensile properties were reviewed and show a relatively small variation in their fatigue crack growth rates. The crack growth data used for the current analysis is plotted along with the scatter bands for other ferrite-pearlite steels in Figure 1.

(iii) After forging, the crankshafts received the following heat treatments:

1. Heated to the normalizing temperature of 1600-1650°F, followed by air cooling;

2. Heated to a temperature of 1550-1600°F, followed by quenching in oil;

3. Heated to the tempering temperature of 1100-1200°F, followed by air cooling.

The effect of heat treatment on the crack growth rate of a material is relatively unimportant at values of $\Delta K$ greater than $\Delta K_{th}$.

Q4. Section 3 of the report describes the results of a torsiograph test to measure the dynamic response of the crankshaft under transient conditions. Explain whether or not the measurements are expected to change adversely over time due to factors such as component wear and component modifications, e.g., recent piston skirt changeover.

R4. The response of the crankshaft (torsional vibration amplitudes and stresses) is dependent upon the natural frequencies and mode shapes of the crankshaft mass elastic system and the forcing function imposed on that system.

Changes in the natural frequencies and mode shapes of the crankshaft mass elastic system will only occur if there is a physical change in a component of the crankshaft mass elastic system such as modification to the flywheel or counterweight changes. Component wear or replacement of components with like components (those of the same mass and stiffness) will not affect the crankshaft mass elastic system.

The forcing functions applied to the crankshaft consist of the reciprocating inertial loads of the connecting rod and piston, the gas pressure loads, and frictional loads and other losses. The stresses in the crankshaft resulting from small changes in the reciprocating inertial loads (e.g., small changes in the mass of a piston) do not change significantly. The cylinder pressures and exhaust temperatures are monitored during engine operation and compared with the manufacturer's allowable ranges. Any significant deviations from the allowables warrant investigation to determine the cause of the deviation. The stresses on the crankshaft resulting from the frictional loads and other losses are small compared to those caused by the inertial and gas pressure loads. Thus, changes in frictional loads and other losses are not expected to significantly affect the response of the crankshaft system.

Q5. Explain why the 1 degree of freedom (DOF) crack growth model with nominal material properties was used in developing the inspection criteria for the diesel generators at San Onofre Unit 1.

R5. The results of the analysis with the 3-DOF crack growth model resulted in crack growth lives that were longer than expected based upon the crankshaft inspection data. In addition, the 3-DOF model did not yield aspect ratios (surface length of crack divided by crack depth) consistent with the actual ratios of cracks found in the crankshaft oil holes at San Onofre Unit 1.

To reconcile this, a more conservative 1 DOF model was investigated. The crack growth life predicted with this model provided a reasonable correlation with the best estimate of the crack growth life obtained from the crankshaft oil hole inspection data.

In an attempt to reproduce the observed aspect ratios with the 3-DOF model, the possible existence of residual stresses and/or martensite was considered. Including yield level residual stresses on the oil hole surface did indicate faster growth; however, the aspect ratio did not differ appreciably from the previous 3-DOF analysis. The computer code was unable to model the finite size of a martensite layer which might be expected if grinding took place in the oil hole at elevated temperatures. However, comparing the crack growth laws for martensite with the nominal material, aspect ratios of up to 6:1 could be explained if martensite was found to exist. For completeness, the effect of residual stresses and martensite utilizing the 1-DOF model was included in the report. However, the results obtained for these 1-DOF model analyses were not consistent with the best estimate of the crack growth life obtained from the crankshaft oil hole inspection data.

References:

1) Yuen, A.; Hopkins, S. W.; Leverant, G.R. and Rau, C. A., "Correlation Between Fracture Surface Appearance and Fracture Mechanics Parameters for Stage II Fatigue Crack Propagation in Ti-6AL-4V," Metallurgical Transactions, Paper 1833, Volume 5, August 1975.

2) Rolfe, S. T. and Barsom, J. M., Fracture and Fatigue Control in Structures, Applications of Fracture Mechanics, Prentice-Hall Inc., 1977.

3) Paris, et al, "Extensive Study of Low Fatigue Crack Growth Rates in A533 and A508 Steels," Proceedings of the 1971 National Symposium on Fracture Mechanics, Part 1, ASTM Special Technical Publication 513.

IAA:FaAA

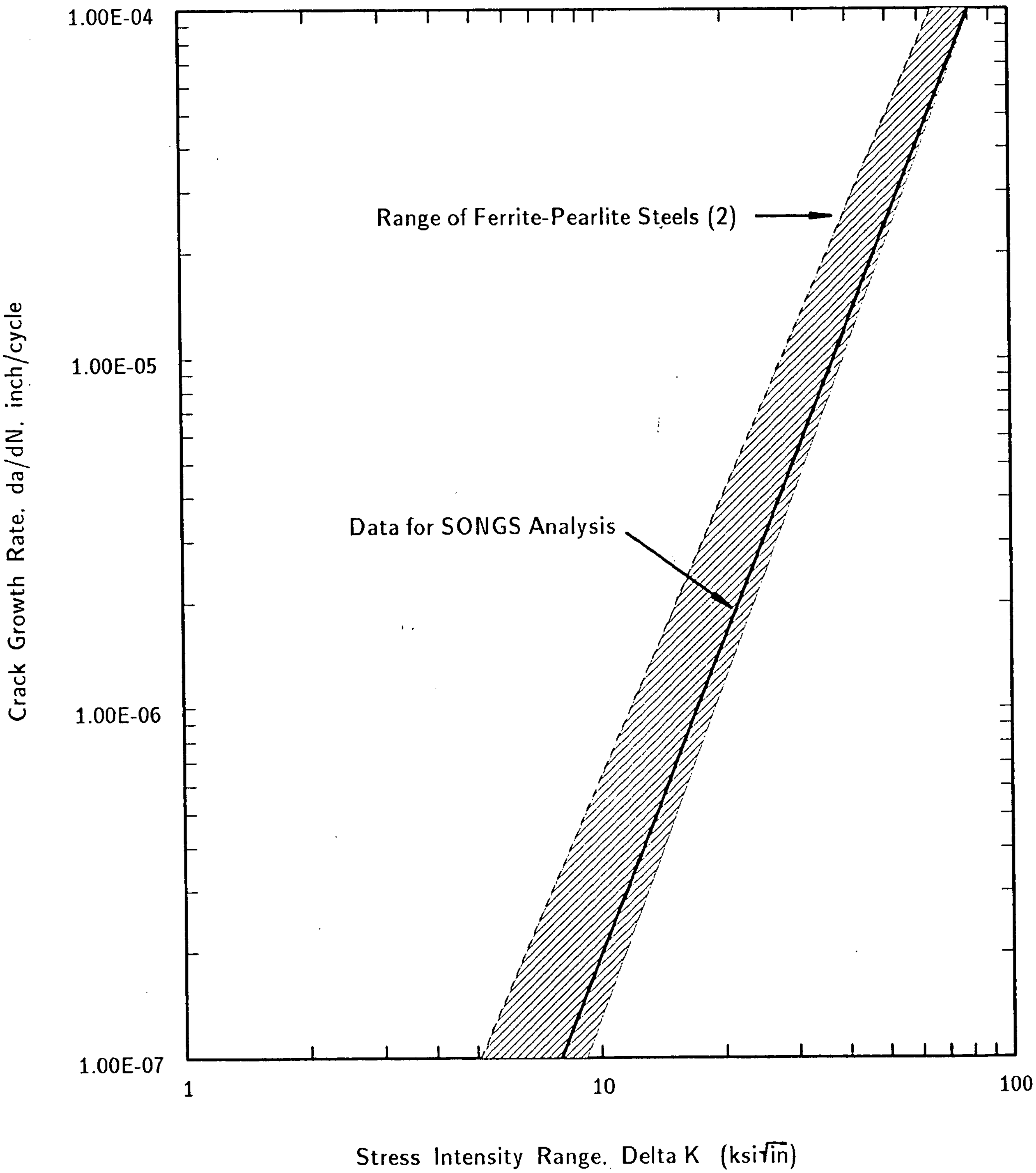


Figure 1. Fatigue crack growth data for low strength steels.