GENERAL ELECTRIC

NUCLEAR ENERGY
ENGINEERING
DIVISION

GENERAL ELECTRIC COMPANY, P.O. BOX 460, PLEASANTON, CALIFORNIA 94566

April 14, 1980

Mr. E. Igne
Advisory Committee on Reactor Safeguards
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Igne:

Attached are responses to the comments, questions and recommendations that have been made by consultants to the GETR Subcommittee of the Advisory Committee on Reactor Safeguards following the November 14, 1979 meeting. The first of these responses is to Merit P. White's questions dated February 18, 1980; the second, the recommendations made by Shailer S. Philbrick, December 14, 1979; and the third responds to comments or questions raised by Paul W. Pomeroy in his December 21, 1979 letter.

Dr. Pomeroy's questions are responded to in two parts. The first having to do with site seismicity, which is the subject of the enclosed report by Bruce A. Bolt. This report responds to questions 1a through e and 2a and b of Dr. Pomeroy's letter. The information in the report by Dr. Bolt is thought not to alter the basis for design or evaluation of GETR, but simply documents added information relating to the site. Similarly, it is thought that the answers to questions 1f through i are noncontroversial in nature.

With regard to the questions about surface offset (3a, b and c), resolution of the value for this parameter is being actively worked on by the NRC Staff and ourselves. The General Electric probability study has been reviewed with the NRC Staff, modifications made to the model, and new probabilities calculated. It has been said by members of the NRC Staff that if the probability model is shown to be valid and the probability calculated to be reasonable, then a change in the value of offset from 2-1/2 meters in the SER is planned. It is hoped that NRC reviewers and consultants will find the probability analysis acceptable and this difference resolved. Should that not occur, General Electric will respond fully to questions 3a, b, and c at the next ACRS Subcommittee meeting.

If you, or the ACRS consultants or members, have questions about any of the enclosed information, please let me know.

Very truly yours,

RW Darmitzel

R. W. Darmitzel, Manager
Irradiation Processing Operation
Nuclear Engineering Division

/11

attachments

8004170260

Responses to Comments by ACRS Consultant, Merit White

Question No. 1

"EDAC 117-217.10 Pool Heat Exchanger HE 102. The auxiliary seismic support is being designed to resist 1.0g with a safety factor 4. However, the maximum floor acceleration at that level is predicted to be about 1.3g while the spectral acceleration there is 8.75g (1% damping) and 5.5g (3% damping) over a considerable range of frequencies. Moreover, the support consists of a pair of cables wrapped around the unit which can give support only when in tension."

Response to Question No. 1

The original existing support system for Pool Heat Exchanger HE 102 was reviewed for its capacity to resist seismic motions and it was determined at that time that the original support system would be overstressed for the criterion earthquake. Since HE102 is not a primary safety-related component, the only criteria was to prevent it from falling onto adjacent primary piping systems and components. The original support system will be subjected to the corresponding spectral accelerations (computed at 1.67g horizontal and 0.90g vertical), but the added cable system will only be subjected to forces due to gravity should the original support system fail. The design philosophy is to use the cables and adjacent walls to control the fall of the heat exchanger away from any primary safety-related system.

Question No. 2

"EDAC 117 217.06 Fuel Flooding System. The dynamic response of the 50,000-gal water containers was made by means of Housner's method. The latter is intended for rigid tanks with open tops which are very different from flexible fabric bags which are under consideration here. It may well be that the predictions are conservative, or are conservative in most but not all respects. For example, is the equivalent water height of 8'3" for determining the earthquake loading on the end retaining walls (which have only 10% margin of safety - pp 2-2, 2-3) conservative? In addition, I do not understand the shape of the water bearing pressure diagram (Load Case 1) in Fig. 2-2. Should it not be a triangle?

Response to Question No. 2

The reservoir retaining wall design for earthquake loads is controlled by soil pressure behind the end wall, which is a maximum when the reservoir motion is away from the wall. An equivalent hydrostatic load of 45 pcf was assumed in the analysis for the soil pressure load. When the reservoir motion is toward the end wall, the water bearing pressure relieves the stresses in the wall caused by the soil pressure behind it. Therefore, this load case does not govern the retaining wall design even if the sloshing height is assumed to be at the top of the wall. The ten percent margin of safety referred to in EDAC report 217.08 is in regard to the working stress design of the walls for soil pressure only. Thus, the design of the retaining walls is conservative.

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Response to Question No. 2 - continued

The shape of the water bearing pressure diagram in Figure 2-2 of the EDAC report is an idealization of the Housner water sloshing model for which there are two types of loads -- a convective and an impulsive load. The convective-type load is assumed to have a triangular pressure distribution, while the impulsive-type load is assumed to have a uniform pressure distribution.

Question No. 3

Structural Mechanics Associates GETR 78-1. Fuel Storage Tanks

On page 23 and in Appendix B: What is justification of applying 2/3 of kinetic energy and inertia force as a loading on the outer container? I note that the same question was previously raised by the NRC Staff; the answer was hardly convincing.

Response to Question No. 3

The outer fuel storage tank wall was designed to absorb in an elastic mode 67% of the total energy produced by the rocking motion of the inner tanks. A realistic value of the actual kinetic energy that might be developed during seismic induced rocking of the inner tanks would be reduced by the substantial fluid inertia effects of the surrounding water. General Electric, and its consultants, conclude that the resultant kinetic energy would therefore be less than the 67% capability of the tank wall as indicated by the elastic analysis. Plastic deformation of the inner and outer tank walls was not taken into account and this mechanism of energy dissipation would increase the total capability of this system and the conservatism of the design.

Question No. 4

Structural Mechanics Associates GETR 78-1. Fuel Storage Tanks

Page 25 and Appendix A3-1 to 5: Analysis of rock bolts: For p_o = 3 ksi (maximum concrete bearing stress) the bolt force is calculated to be P_B = 30 k while the allowable value is 35 k. However, p_o = 3 ksi is very low for massive concrete which is sure to be stronger than test cylinders of the same material. Moreover, I do not check the numbers given. I find for p_o = 3 ksi at node 1, b_o = 4.9", giving P_B = 34 instead of 30. Using a more realistic p_o = 6 ksi gives b_o = 3.4" and P_B = 33 k.

Response to Question No. 4

Professor White's comments on the analysis of rock bolts are very perceptive. The estimated 4.5 in. value of b_o has been recalculated for a maximum concrete bearing stress of P_o = 3.0 ksi and P_o = 6.0 ksi, with the results b_o = 4.914 in. (at 3.0 ksi) and b_o = 3.412 inc. (at 6.0 ksi). Using these values to calculate

Response to Question No. 4 - continued

... the rock bolt loading, P_b; values of 34.0 k and 33.0 k are obtained. In both cases the rock bolt loadings remain below the allowable value of 35.0 k.

Question No. 5

25 July 1978 Responses to NRC questions on Phase 2 Report: Page 6, 2d full paragraph: It seems to me that the small difference between results of the 3-dimensional elastic mathematical model and the 2-dimensional non-linear model with linear elastic analysis more likely coincidence than proof of the negligible influence of the containment shell. The light weight of the shell is enough reason for its unimportance.

Response to Question No. 5

It is true that the influence of the steel containment shell on the response of the GETR Reactor Building is negligible mainly because of its very light weight in comparison to the total weight of the Reactor Building.

Question No. 6

Updated Response to NRC request for additional information: Response to Question 11 regarding fuel storage racks: (Also GE Report DSAR 78-4, June 1978) What is the basis for the friction coefficient (0.349) used here? Reference to a memo quoting Dr. Rabinowicz is not enough. Can a copy of Dr. R's report be supplied? (Ref. GE VPF V5455, 1-3-78)

Response 12 of above: Questioned was the conservatism of the rack sliding calculations. The response stated that the assumed input was conservative and this is not an adequate response. For the following reasons I question the validity of the response calculation briefly discussed in DSAR 78-4 (ref. above):

1. The equations of motion given are incorrect since $\ddot{u}$ must be identically zero part of the time (when there is no relative motion).
2. $m^1\ddot{u}_g$ is the driving mechanism. The very small value of m^1 (= M^1 in Table 2?) means that the input is weak. It is not obvious why m^1 is so small.
3. The extremely small predicted rack displacement - 0.16" - is hard to accept when one remembers that much weaker base motions have moved transformers and other objects by amounts of several inches.

Response to Question No. 6

1. The equations of motion given in DSAR 78-4 are applicable only when the rack slides. $m\ddot{U}$ is identically equal to zero when the rack does not slide.

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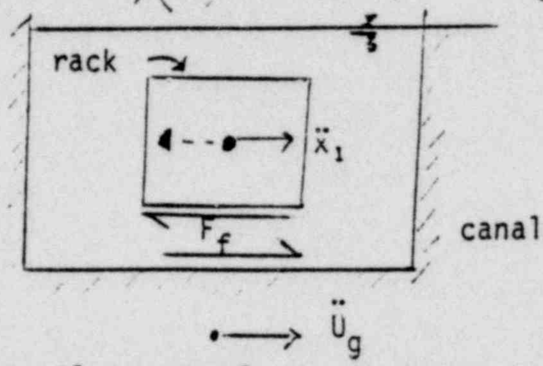
Response to Question No. 6 - continued

2. (a) m^1 is the same as M^1 in Table 2.

   (b) The equation of motion during the sliding can be derived as follows:

$$\left(\begin{bmatrix} M_1 & \\ & M_2 \end{bmatrix} + \begin{bmatrix} m_1 & -m_{12} \\ -m_{12} & m_2 \end{bmatrix} \right) \begin{Bmatrix} \ddot{x}_1 \\ \ddot{U}_g \end{Bmatrix} + \begin{Bmatrix} F_f \\ -F_f \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \end{Bmatrix} \quad \begin{matrix} (1) \\ (2) \end{matrix}$$



M_1, M_2 are structural masses of the storage rack and the canal, respectively. m_1, m_2 and m_{12} are hydrodynamic masses. $\ddot{X}_1$ and $\ddot{U}_g$ are respectively the accelerations of the rack and the canal. F_f is the friction force. Let $\ddot{x}_1 = \ddot{U}+\ddot{U}_g$, where $\ddot{U}$ is the relative acceleration between the rack and the canal. Equation (1) can be rewritten as follows:

$$(M_1+m_1)\ddot{U} = -(M_1+m_1-m_{12})\ddot{U}_g-F_f \qquad (3)$$

or, $$m\ddot{U} = -m^1\ddot{U}_g-F_f \qquad (4)$$

where

$$m=M_1+m_1, \qquad (5)$$

$$m^1=M_1+m_1-m_{12} \qquad (6)$$

$$F_f= \mu N \quad \text{when } \dot{U}> 0.$$

$$= -\mu N \quad \text{when } \dot{U}< 0.$$

where μ and N are respectively the friction coefficient and the normal force, which is just equal to the buoyant weight of the rack. Since the canal wall is very rigid, it can be shown by potential flow theory that m^1 is equal to $\frac{N}{g}$, where g is the acceleration due to gravity.

Response to Question No. 6 - continued

Thus, Equation 4 can be rewritten as follows:

$$m\ddot{U} = - N \frac{\ddot{U}_g}{g} \pm \mu N \tag{7}$$

When the $|\ddot{U}_g| \leqslant \mu g$, there is no sliding and $m\ddot{U}$ is identically equal to zero. Note that m^1 is small because it is equal to the buoyant weight of the rack divided by g which is less than the weight of the rack plus its contents in air.

3. The small predicted rack displacement compared with some observed sliding for other objects is due to the fact that the rack is relatively light, and the water tends to force the tank to move together with the canal.

A copy of Dr. Rabinowicz' report, VPF V5455, 1-3-78, is enclosed.

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ERNEST RABINOWICZ
14 EXMOOR ROAD
NEWTON, MASS. 02159

November 23, 1977

RECEIVED
NOV 28 1977
D. R. SPONSELLER

David R. Sponseller
Project Engineer
General Electric Company
175 Curtner Avenue - M/C 859
San Jose, CA 95125

Dear Mr. Sponseller:

I herewith am sending you two copies of my report, in which I have incorporated the changes recommended by your people and have added an appendix.

Sincerely,

Ernest Rabinowicz

Ernest Rabinowicz

Enclosure

3 D V5455 REV 0

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1/3/78

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REVISED BY COVER LETTER OF 11/23/77

G.E. P.O. 529-CC084X

September 26, 1977

RECEIVED
NOV 28 1977
D. R. SPONSELLER

Report to General Electric Nuclear Energy Programs Division

Attn: Mr. D. R. Sponseller

Friction coefficient value for a high density fuel storage system

Abstract

Friction coefficient values obtained earlier in a study of a 304 steel - 304 steel water lubricated sliding systems have been used to estimate friction coefficient values likely to be encountered in a high density fuel storage system currently being designed by the General Electric Company. The mean friction coefficient anticipated is .523, while the lowest friction coefficient likely to be encountered, (1.69 standard deviations below the mean) is .349.

Ernest Rabinowicz
Sept 26, 1977

Introduction

This study was undertaken to derive a realistic minimum friction coefficient value for a high density fuel storage system being designed at GE. In this system, it is desired to resist horizontal shear forces due to seismic action through friction to the spent fuel pool floor. The two sliding materials are 304 stainless steel, the 'lubricant' is demineralized water at 70-150°F (21 - 66°C), and the nominal interfacial pressure is 700 - 2000 psi (1).

Some months ago the writer undertook an experimental study of the friction to be anticipated in a high density fuel storage system being constructed by Boston Edison (2). Since the Boston Edison conditions closely resembled those of the GE application, it was decided to carry out no additional testing but to use the Boston Edison data; to apply correcting factors to make them applicable to the GE conditions; and then to use the recomputed friction values to estimate the lowest friction coefficient likely to be encountered by GE.

In the tests carried out for Boston Edison it was found that variables such as temperature and apparent pressure had little demonstrable effect on the friction coefficient. Surface roughness appeared to have some effect, in that very rough surfaces gave a slightly lower value for mean friction coefficient and a distinctly lower standard deviation, indicating that the lowest value of friction coefficient (i.e. the mean friction coefficient minus one or two standard deviations) was larger for rough surfaces than for smooth ones. All these results are in good agreement with what is known about the friction coefficient of very poorly lubricated metallic surfaces.

The only important systematic effect encountered in the Boston Edison tests was that the friction coefficient was a function of the sliding velocity, with the friction increasing as the velocity decreased (the typical negative characteristic, responsible for frictional oscillations). In the Boston Edison case, the tests were carried out at speeds of .04 and 4 in/sec, bracketing the sliding speeds believed to be of interest. In addition, a number of static friction coefficient values, after times of stick covering a rather wide range, were determined.

In the GE case considered here there are no sliding velocity requirements as such, but rather it is believed that the horizontal shear forces increase from zero to peak in a time interval which is in the range .09 to .18 seconds (3). This information must now be converted to equivalent sliding velocities. In a paper published some years ago (4), the writer suggested that the static friction coefficient f_s corresponding to a time of stick t_1, would be the same as the kinetic friction coefficient f_K at a sliding velocity v_1, provided that

$$v_1 = \frac{d}{t_1}$$

where d is the diameter of the junction formed between the two sliding surfaces.

Later work (5) has shown that d is given by the relationship

$$d = \frac{60{,}000\ W_{ab}}{p}$$

where W_{ab} is the surface energy of adhesion of the contacting materials (in this case a value of twice the intrinsic surface energy or 3400 erg/cm^2 seems reasonable), while p is the penetration hardness of the 304 stainless steel (in this case about 2.5×10^{10} dyne/cm^2). This yields a value for d of 8.2×10^{-3} cm, or 3.2×10^{-3} inches. The writer estimates that an error of $\pm$ a factor of two is associated with this calculation, so that junction diameters of anywhere in the range 1.6×10^{-3} inches to 6.4×10^{-3} inches are possible. A detailed discussion of this calculation is contained in Appendix I.

In the GE case, the highest sliding velocity (and hence the lowest friction coefficient) would be encountered when surfaces with junctions of the largest possible size (6.4×10^{-3} inches) meet shear forces which increase in the lowest possible time (.09 seconds); the equivalent sliding velocity v_1 would be 7.1×10^{-2} in/sec. The Boston Edison friction test data must therefore be converted to this sliding velocity.

In the Boston Edison tests, for the first eight series of tests, half were carried out at the higher speed of 4 in/sec, and half at the lower speed, of .04 in/sec. The mean friction coefficient was found to be .37 at 4 in/sec, and .55 at .04 in/sec. The ratio of friction coefficients is 1.49. These experimental data agree quite closely with results obtained by the writer many years ago using an unlubricated plain steel on plain steel sliding system (figure 1). This earlier series of tests suggests that the plot of friction coefficient against log sliding velocity tends to be a straight line; it has therefore been assumed that it is precisely a straight line.

Figure 2 represents the friction coefficient values for the two applications. It will be seen that the friction at .071 in/sec is a factor of 1.42 greater than at 4 in/sec, while being a factor of 1.05 smaller than at .04 in/sec. Accordingly, to convert the friction values of the Boston Edison tests to the GE case, multiply the high speed and low speed friction coefficient values by the corresponding correction factor.

This takes care of the one hundred kinetic friction coefficient values, and leaves the question of what to do about the remaining 99 static friction values. They cover a variety of times of stick, geometries, roughness and rates of application of the shear force, and it is suspected that the GE fuel storage system may also encounter a variety of these variables since it is not a

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closely controlled laboratory situation. Secondly, the static and kinetic values have very similar means and standard deviations. It has therefore been decided simply to leave these values as they are.

Experimental friction values adjusted for GE case

Test 1. 304 steel on 304 steel. Room temperature. Hemispherically ended slider. Roughness 29 microinches rms. Distilled water lubricant. Sliding speed = 4 in/sec. Friction coefficients have been multiplied by 1.42.
f values:- 0.54, 0.64, 0.58, 0.50, 0.50, 0.53, 0.53, 0.48, 0.47, 0.47

Mean friction coefficient = 0.52.

Test 2. 304 steel on 304 steel. Room temperature. Hemispherically ended slider. Roughness 29 microinches rms. Distilled water lubricant. Sliding speed = 0.04 in/sec. Friction coefficients have been divided by 1.05
f values :- 0.35, 0.44, 0.59, 0.62, 0.61, 0.61, 0.61, 0.58, 0.63, 0.59

Mean friction coefficient = 0.56.

Static f:- 0.62, 0.58, 0.57, 0.63, 0.74, mean = 0.62

Test 3. 304 steel on 304 steel. 73C - 74C. Hemispherically ended slider. Roughness 29 microinches rms. Distilled water lubricated. Sliding speed 4 in/sec. Friction coefficient values have been multiplied by 1.42 .
f values:- 0.50, 0.60, 0.62, 0.55, 0.65, 0.71, 0.70, 0.70, 0.58, 0.55

Mean friction coefficient = 0.62

Test 4. 304 steel on 304 steel. 72-76C. Hemispherically ended slider. Roughness 29 microinches rms. Distilled water lubricated. Sliding speed = 0.04 in/sec. Friction coefficient values have been divided by 1.05.
f values:- 0.44, 0.50, 0.49, 0.61, 0.62, 0.68, 0.72, 0.57, 0.64, 0.78

Mean friction coefficient = 0.60

Static f:- 0.64, 0.46, 0.57, 0.56, 0.74 mean = 0.59

<u>Test 5</u>. 304 steel on 304 steel. Room temperature. Slider end diameter 0.09". Roughness 27 microinches rms. Distilled water lubricant. Sliding speed 3.9"/sec. Friction coefficient values have been multiplied by 1.42.

f values:- 0.51, 0.38, 0.45, 0.30, 0.36, 0.30, 0.44, 0.38, 0.47, 0.54

Mean friction coefficient = <u>0.41</u>.

<u>Test 6</u>. 304 steel on 304 steel. Room temperature. Sliding speed = 4.3×10^{-2}"/sec. Slider end diameter 0.09", distilled water, roughness 27 μ" rms. Friction coefficient values have been divided by 1.05

f values:- 0.39, 0.41, 0.47, 0.48, 0.43, 0.45, 0.48, 0.50, 0.50, 0.47

Mean friction coefficient = <u>0.46</u>.

Static f:- 0.51, 0.49, 0.52, 0.47, 0.49, mean = 0.50

<u>Test 7</u>. 304 steel on 304 steel. 71-79C. Slider end diameter 0.09". Roughness 27 microinches rms. Distilled water lubricant. Sliding speed 3.8"/sec. Friction coefficient values have been multiplied by 1.42.

f values:- 0.72, 0.72, 0.55, 0.57, 0.57, 0.58, 0.51, 0.38, 0.43, 0.54

Mean friction coefficient = <u>0.56</u>

<u>Test 8</u>. 304 steel on 304 steel. 72-76 C. Slider end diameter 0.09". Roughness 27 microinches rms. Distilled water lubricant. Sliding speed 4.1×10^{-2}"/sec. Friction coefficient values have been divided by 1.05

f values:- 0.40, 0.36, 0.50, 0.42, 0.44, 0.42, 0.57, 0.45, 0.65, 0.41

Mean friction coefficient = <u>0.46</u>

Static f:- 0.36, 0.36, 0.45, 0.70, 0.55, mean = 0.48

<u>Test 9</u>. 304 steel on 304 steel. Room temperature. Slider end diameter 0.09". Roughness 27 microinches rms. Distilled water lubricant with fine iron oxide particles to a depth of .005". Sliding speed 4.2×10^{-2} in/sec. Friction coefficient values have been divided by 1.05.

f values:- 0.44, 0.50, 0.49, 0.50, 0.50, 0.47, 0.53, 0.54, 0.58, 0.51

Mean friction coefficient = <u>0.51</u>

<u>Test 10</u>. Same as test 9 but iron oxide particles to a depth of 0.25". Friction coefficient values have been divided by 1.05

f values:- 0.58, 0.55, 0.54, 0.60, 0.51, 0.50, 0.51, 0.54, 0.53, 0.55

Mean friction coefficient = <u>0.54</u>.

<u>Static friction test I.</u> 304 steel on 304 steel. Room temperature. Slider end diameter 0.09". Roughness 27 microinches rms. Distilled water lubricant. Initiating sliding speed = 6×10^{-4} in/sec.

Time of stick	Friction coefficient values	
1-sec	.23, .33, .44, .23, .70	.62, .56, .61, .68, .68, .64
10	.39, .39, .42, .32, .50	.61, .54, .61, .68, .66, .67
100	.36, .51, .37, .47, .50	.59, .54, .62, .67, .69, .68
1,000	.33 .46, .35, .48, .60	.61, .63, .69, .60
10,000	.29	.58, .72
50,000	.59	

<u>Static friction test II.</u> Same as static friction test I, but surface roughness is 310 microinches rms.

Time of stick	Friction coefficient values
1 sec	.44, .46, .48, .45, .49, .49, .54, .49
10	.52 .46 .49 .48 .51 .53 .52 .60
100	.45 .45 .43 .49 .50 .51 .45 .60
1,000	.43 .49 .52 .51
10,000	.50 .49 .46 .54
50,000	.43

All the adjusted friction coefficient values obtained are tabulated in Table 1, and a histogram and normal distribution which matches the distribution are given in figure 3. The χ^2 value between the histogram and the curve (for 9 degrees of freedom) is 10.3 giving a P value of .25, which suggests that the data are consistent with a normal distribution, and thus it is appropriate to use th properties of the normal distribution (e.g. the proportion of the curve lyi. outside $\bar{f} \pm 1.69\sigma$) in analysing the data.

Discussion

The question in the GE case is that of arriving at a realistic value for the least static coefficient of friction which might be encountered. Normally, this would be represented by the mean friction coefficient minus three or four standard deviations. As stated in the writer's Boston Edison report, there was a tremendous amount of averaging in the actual application as opposed to the experimental test conditions, since the total normal load and the total area of contact was of the order of 1000 times greater. Because the low experimental friction valuesall seemed attributable to very small patches on the 304 steel surfaces, a mean friction coefficient minus two standard deviations seemed quite adequate. However, in the Boston Edison situation, both maximum and minimum friction coefficients were of interest, and the $(\bar{f} \pm 2\sigma)$ criteria gave 95.5% assurance of identifying these values, as against a 4.5% probability of failing to do so. In the GE case, only the lower tail of the normal distribution is of interest, and to impose the same requirement of a 95.5% assurance of having identified the minimum value, the $(\bar{f} - 1.69\ \sigma)$ point must be found. In this case, this gives a minimum friction value of .349.

It should be mentioned that in this analysis all the friction data were cmobined into one population, whereas in the Boston Edison study the high and low friction values were considered separately. This was done because the earlier study contained two essentially dissimilar sets of friction coefficients, obtained at two widely different sliding speeds, whereas in the present study the results have been adjusted to the same sliding speed.

How reliable is the friction coefficient value we have derived? It should be clear that essentially random errors of about .005 or .010 produced by instrumental factors like recorder reading error and zero drift uncertainties produce negligible effect when combined with the statistical fluctuation of more than ten times the magnitude. Systematic errors due to having measured or computed the wrong quantities have all been chosen so as to give a conservative result. For example, an exceptionally large value of sliding velocity v was used in the calculations, since the maximum possible junction size and the minimum possible time of application of the shear force was considered. If a value of v smaller by a factor of two had been used, kinetic friction coefficient values larger by about .04 would have resulted, which would in the end have led to overall ($\overline{f}$ - 1.69 σ) values larger by about .02.

In the case of the static friction coefficient values, if there is a systematic error it is that the friction coefficient was measured after short periods of sticking (16 hours, or less), whereas in the application the times are likely to be in the months range. Although it is hard to estimate the effect of this, the writer's opinion is that this factor also will increase the overall ($\overline{f}$ - 1.69 σ) value by about .01 or .02. As indicated in the Boston Edison report, this may by now be a minority view. The majority would argue that no substantial correction because of the difference in the times of stick is warranted.

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The only possible source of error that remains is that due to contamination. Depending on how the 304 surfaces were made there may be some contaminants left on the surfaces which will give initially low friction coefficient values, perhaps as low as .05 below those given in the tests. (For example, when running the tests for Boston Edison the author carried out some preliminary runs using 304 steel specimensjust as they were found in the laboratory, without any preliminary cleaning, and this gave friction coefficient values up to a value of .05 lower than the values obtained later after the specimens were cleaned by abrasion.) However, this is a situation which improves with time, i.e. at the high temperatures, the contaminants will tend to move to the water-air interface at the top of the fuel storage system.

In any case, this source of error can be greatly reduced if care is taken that the 304 steel pads of the fuel storage racks are thoroughly cleaned, preferably using coarse, clean abrasive paper, before they are introduced into the fuel storage system. (The advantage of using rough surfaces is that the lowest value of friction coefficient is increased even though the mean value is somewhat reduced. Refer to static friction tests 1 and 2. In test 1, using a smooth surface, the mean friction is .53, but the lowest friction is .23. In test 2 using a rough surface, the mean friction is .49 and the lowest friction is .43).

Conclusions

The recommended minimum coefficient of friction to be used for design in the GE application is 0.349.

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Acknowledgements

I wish to thank Mr. David R. Sponseller and Mr. Wallace Wheadon of GE, as well as Dr. John Reed of EDAC, for helpful inputs. Dr. Mukti Das of the Boston Edison Company provided much useful information with regards to the experimental work.

Table I. The friction coefficient values

	20	30	40	50	60	70
0		2	1	15	6	4
1			2	10	8	1
2		1	3	4	6	4
3	2	2	6	5	3	
4			6	10	4	2
5		2	8	6	2	
6		5	5	2	1	
7		1	8	6	2	
8		3	6	8	5	1
9	1	3	11	4	2	

Note: This table indicated that there were 11 friction coefficient values of .49 (the intersection of the 9 row and the 40 column), as well as 15 values of .50 (the intersection of the 0 row and the 50 column).

References

(1) Telex, D. R. Sponseller of GE to Dr. Ernest Rabinowicz, 8/8/77.

(2) E. Rabinowicz, "Friction coefficients of water-lubricated stainless steels for a spent fuel rack assembly," unpublished report to the Boston Edison Company dated Nov. 5, 1976.

(3) Letter, Subject "G.E. P.O. 529-CC084X," D. R. Sponseller of G.E. to Dr. Ernest Rabinowicz, 8/12/77, with attached preliminary drawing, C5442E-103, dated 8/18/77.

(4) E. Rabinowicz, "The intrinsic variables affecting the stick-slip process," Proc. Phys. Soc., 71, 668-675, 1958.

(5) E. Rabinowicz, "Friction and Wear of Materials," John Wiley & Sons, N.Y., 1965, pp 151-158.

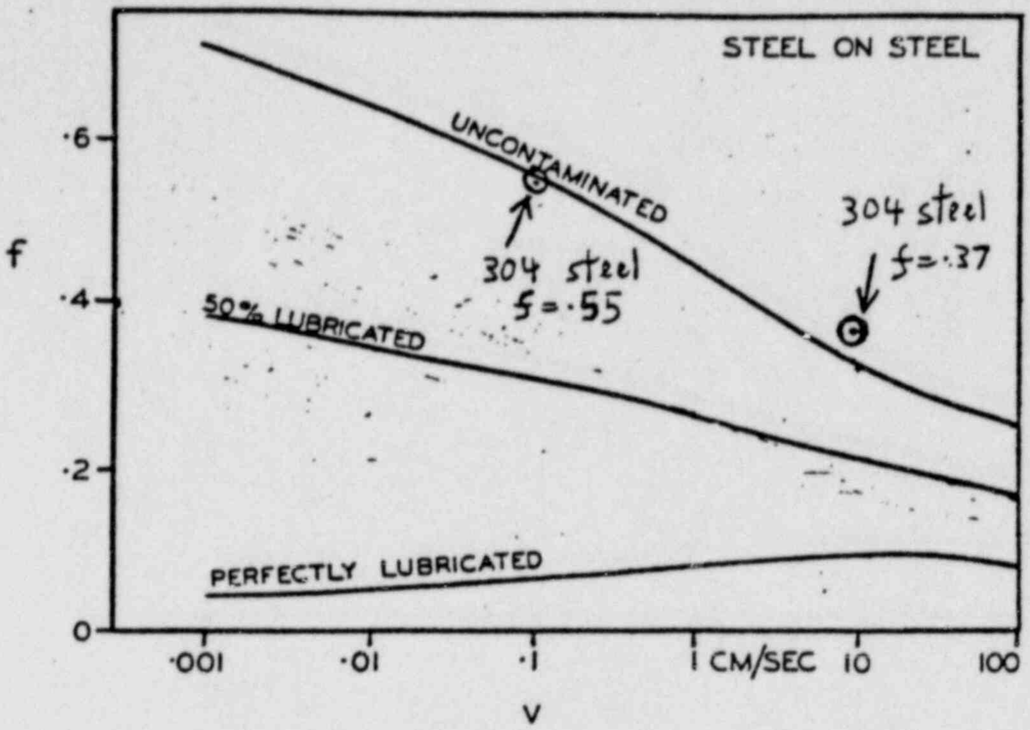

Figure 1. Plot dating to 1958 (reference 4) showing the friction-velocity function for 1020 steel sliding on 1020 steel at various stages of lubrication. The data obtained with water-lubricated 304 steel fits the line denoting unlubricated sliding very well.

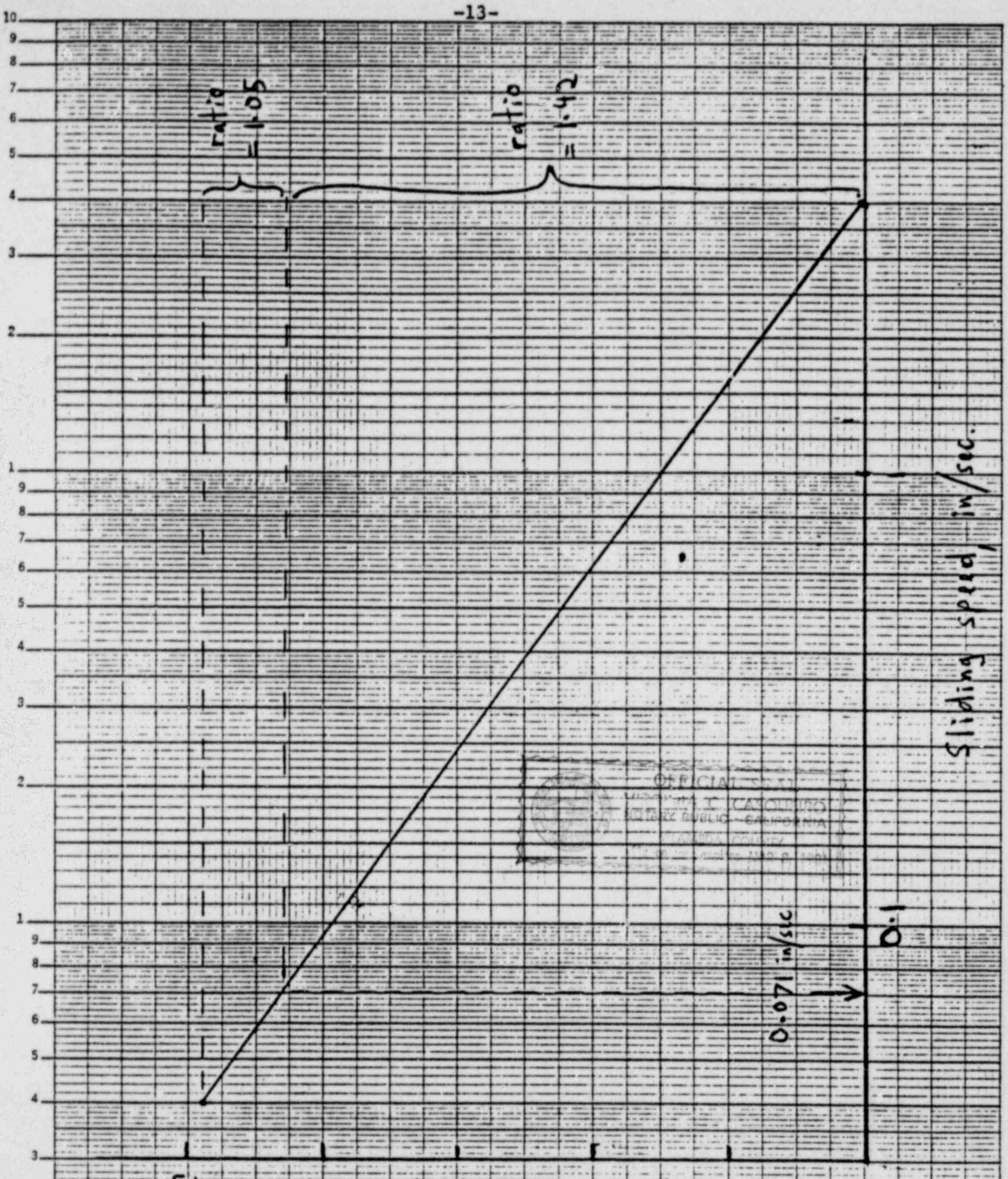

Figure 2. Schematic illustration of the friction-velocity relationships for stainless steel, water-lubricated surfaces.

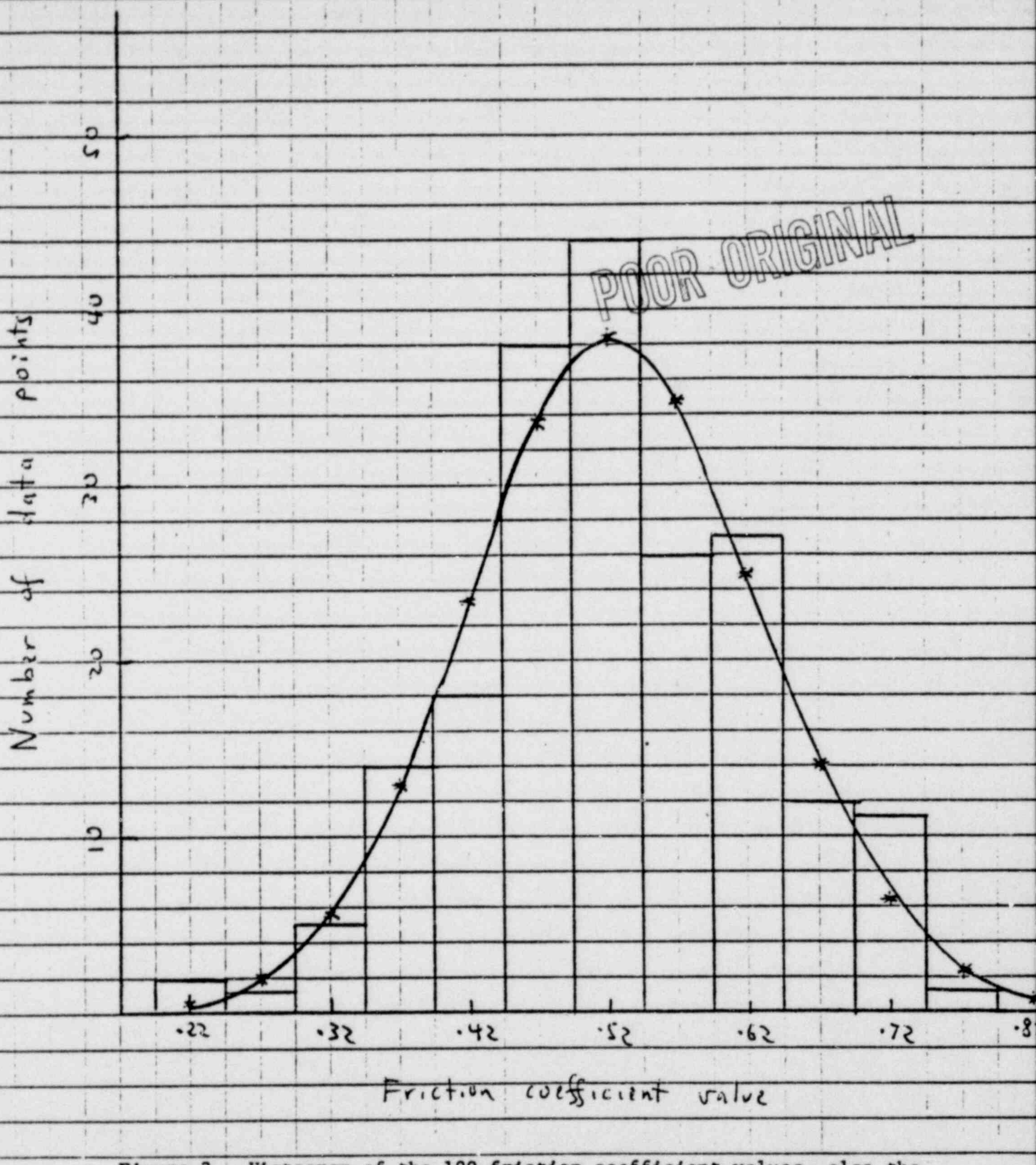

Figure 3. Histogram of the 199 friction coefficient values, also the corresponding normal distribution. The mean friction coefficient is .523, while the standard deviation is .103.

Appendix I. The size of junctions

On page 3 of the report, a value of 6.4×10^{-3} inches is adopted for the size of junctions to be anticipated in the HDSS. In this appendix a more extensive discussion of the reason for adopting this particular value is given.

Methods for determining the diameters of junctions were first developed in the 1950's. A summary is contained in Table 3.1 of reference 5, reproduced below.

Table 3.1 Estimates of Junction Diameter

Combination	Load	Lubricant	Method	Junction Diameter	Reference
Copper on steel	1 kg	None	f_s − distance	7μ	Rabinowicz, 1951
Steel on copper	1 kg	None	f_s − distance	6μ	Rabinowicz, 1951
Copper on copper	1 kg	Cetane	f_s − distance	8μ	Rabinowicz, 1951
Copper on steel	2 kg	None	Particle size	31μ	Rabinowicz, 1953
Copper on copper	0.1 kg	None	f_k autocorrelation	10μ	Rabinowicz, 1956
Copper on copper	0.1 kg	None	f_k fluctuations	5μ	Rabinowicz, 1956
Steel on steel	50 kg	Contaminated	$f_s - t$ vs. $f_k - v$	10μ	Rabinowicz, 1958
Copper on copper	Any	None	$24000\ \gamma/p$	26μ	Eq. 3.15
Steel on steel	Any	None	$24000\ \gamma/p$	13μ	Eq. 3.15

It will be seen that the values shown range from 0.2×10^{-3} inches to 1.2×10^{-3} inches.

A little later, the surface energy theory of wear particle formation was developed. According to this theory, during sliding at moderate loads, (1 kg or less), junctions are formed, at some of them adherent wear particles are generated with diameters equal to the junction diameter, then these adherent wear particles tend to grow in size, until their diameter reaches a value given by the equation

$$\text{diameter} = 60{,}000\, W_{ab}/p \qquad \text{A1}$$

At this point the particle leaves the sliding surface.

The current status of the adhesive wear theory in general is discussed in a recent paper (A1).

Unfortunately, this theory has not yet given good values for the sizes of adherent particles and hence of junctions. But empirical data suggests that the adherent particles, and hence the junctions, have about 1/3 the diameter of loose wear particles. Accordingly, an appropriate value for the junction diameter d_j is given by the equation

$$d_j = 20{,}000\, W_{ab}/p \qquad \text{A2}$$

This equation is given on p 4.11 of reference A2.

Now W_{ab}, the energy of adhesion, may be written in the form

$$W_{ab} = \gamma_a + \gamma_b - \gamma_{ab} \qquad A_3$$

where γ_a and γ_b are the surface energies of the two sliding metals a and b respectively, and γ_{ab} is the interfacial energy. In this case, a and b are both stainless steel, and hence γ_{ab} is equal to zero, and γ_a as well as γ_b may be taken to have the same surface energy as iron, the main consticuent of stainless steel, namely 1700 erg/cm^2 (see Table 2.1 on p 2.3 of reference A2). If p is made equal to 250 kg/mm^2, (and this value is based on experimental hardness measurements of various samples of 304-grade stainless steel in the Surface Laboratory at MIT) then by substitution in eqn. A2 it is found that d_j is 3.2×10^{-3} inches.

Now this value of d_j applies primarily to lightly loaded surfaces, typically with apparent pressures of about 100 psi or less, and total loads of but a few pounds. When the pressures are higher, and especially when a large total load is used, then the junction size is subject to change. According to one school of thought the average junction size increases proportionately to the tenth root of the apparent pressure (ref. A3), while according to another view there is no change in average junction size, at any rate until pressures exceeding 10,000 psi are reached (ref. A4). This second view, based on more recent and sophisticated experiments, is more likely to be correct.

In this case, it seems safest to allow for an increase in junction size by a factor of two over and above the value given by equation A3, which brings it up to a value of 6.4×10^{-3} inches. All in all, this seems to be a realistic value, and at the same time it is, to the extent that it is in error, likely to be an overestimate. In the present situation that makes it a conservative assumption.

Note that the other possible source of error in the calculation for junction diameter lies in the fact that the influence of the water has been ignored. This might reduce the surface energy of the steel by as much as a factor of two from the value of 1700 erg/cm^2, thus reducing the junction size by a factor of two. Considering both this factor and the influence of pressure considered above, the possible junction size values may vary by as much as a function of two about the value of 3.2×10^{-3} inches computed above by the use of eqn. A2, as is pointed out on page 2 of the main report.

References to Appendix I

A1) E. Rabinowicz, "The dependence of the adhesive wear coefficient on the surface energy of adhesion," pp 36-40 of "Wear of Materials - 1977" ASME, N.Y., 1977.

A2) E. Rabinowicz, "Study Guide to Friction, Wear and Lubrication, a Self-Study Subject," Center for Advanced Engineering Study, M.I.T., Cambridge, Massachusetts, 1974.

A3) E. Rabinowicz, "A quantitative study of the wear process," Proc. Phys. Soc. (London), 66B, 929-936, 1953.

A4) J.B.P. Williamson, "Topography of solid surfaces," pp 85-113 of "Inter-disciplinary Approach to Friction and Wear," NASA SP-181, Washington, D.C., 1968.

Appendix II

Technical Biography of Ernest Rabinowicz

Education

Cambridge University, England	1944-1947	B.A. in Physics
Cambridge University, England	1947-1950	Ph.D. in Physical Chemistry

Thesis title "Autoradiographic study of frictional damage"

Positions

1950-1954	Research staff member, M.I.T.
1954-1961	Assistant Professor of Mechanical Engineering, M.I.T.
1961-1967	Associate Professor of Mechanical Engineering, M.I.T.
1967-	Professor of Mechanical Engineering, M.I.T.
1961 Summer	Consultant, IBM
1969 Spring	Visiting Professor, Haifa Technion
1970 Summer	Consultant, IBM

Professional Organizations

Member, American Physical Society
Member, American Society of Lubrication Engineers
Member, American Society of Mechanical Engineers
Fellow, Physical Society of London
Group Subscriber, Institution of Mechanical Engineers, London
Registered Professional Engineer, Commonwealth of Massachusetts

Awards

Hodson Award of the American Society of Lubrication Engineers for 1957.

Research Experience

His research has been in the fields of friction and wear, mechanical reliability, electric contacts, the mechanisms of polishing and comminution, and the use of radioisotopes.

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Teaching Experience

Courses taught have been in the fields of Friction and Wear, Applied Mechanics, Materials, Experimentation, Electroplating, and Materials Processing.

Publications

Books

'Friction and Wear of Materials,' Wiley, New York, 1965.

'An Introduction to Experimentation,' Addison-Wesley, Reading, Mass., 1970.

(with N. H. Cook) 'Physical Measurement and Analysis,' Addison-Wesley, Reading, Mass., 1963.

(edited) 'Friction - Selected Reprints,' Amer. Inst. Phys., New York, 1964.

(with six other authors) 'Mechanical Behavior of Materials,' ed. F. A. McClintock and A. S. Argon, Addison-Wesley, Reading, Mass., 1966.

(with six other authors) 'An Introduction to the Mechanics of Solids,' ed. S. H. Crandall and N. C. Dahl, McGraw Hill, N.Y., 1959.

Videotape Lecture Series

"An Introduction to Experimentation, A Self-Study Subject," Center for Advanced Engineering Study, M.I.T., Cambridge, Mass., 1972.

"Friction, Lubrication, and Wear, A Self-Study Subject," Center for Advanced Engineering Study, M.I.T., Cambridge, Mass., 1974.

Other technical writing

One patent and eighty articles, including

- 'Wear,' Encyclopaedia Brittanica
- 'Friction,' Encyclopedia Americana
- 'Tribological Phenomena,' Encyclopaedia Brittanica
- 'Friction' and 'Wear,' McGraw-Hill Encyclopedia of Science and Technology

Reference Work Listings

Who's Who in America

American Men and Women in Science

Response to Recommendations by ACRS Consultant, Shailer S. Philbrick

The recommendations of Shailer S. Philbrick have been evaluated by Earth Sciences Associates and the following response made:

GE and its consultants agree with Dr. Philbrick on the desirability of knowing whether shears are present beneath the GETR and at what depth. The configuration of the shears in plan view, both uphill and downhill from the GETR is known from trench explorations and is shown on Figure 5 of the Geologic Investigation, Phase II report, February 1979, by Earth Sciences Associates. However, the configuration of the shears in profile, at depth, is known only by projecting from trench exposures, although these projections are confined within rather narrow limits by the requirement that they fit reasonably what is known about the structural geologic setting.

The configuration of the shears at depth may vary also depending on whether one assumes a tectonic or a landslide model for their origin. The shallowest configuration results from the assumption that the shears originated as landslide failure surface. Figure 8 in the Phase II report shows the configuration of the shears in profile based on a landslide model. The configuration of the failure surfaces on this profile represents the best fit selected by a computerized stability analysis using reasonable values for the strength of the materials and what is known about slope configuration, groundwater conditions, and the locations of the shears at the surface.

From Figure 8, it can be seen that the shear beneath the GETR is at a depth of 250 to 300 feet. Although large diameter borings were used successfully to locate shears immediately uphill from their exposure in Trench T-1 (see Figure 2, Phase II report), the effective depth limit of the equipment used to drill these large diameter borings is about 100 feet. During the course of the Phase II Investigation, drilling a line of deep holes to intercept the shears at depth, using rotary wash or core boring rigs, was considered. However, because of the gravelly nature of the Livermore Gravels, it was concluded that core recovery would not be sufficient to provide reasonable assurance of detecting a very thin shear surface at a depth of 200 or 300 feet and this approach was abandoned.

Questions By ACRS Consultant, Paul Pomeroy

Question No. 1f

Is the Calaveras fault the postulated source of the largest acceleration the site might experience?

Response to Question No. 1f

Yes

Question No. 1g

If so, what is the maximum magnitude of the design earthquake? Basis for this?

Response to Question 1g

The maximum magnitude of the design earthquake (which is on the Calaveras fault) is M7.0 - 7.5. The basis for this is a study by C. Richter (Lindvall, Richter & Associates) "Potential Earthquakes on the Calaveras Fault", December 9, 1977 (Reference 1). Dr. Charles F. Richter was requested to make an independent review of the potential effects of the Calaveras fault. In his report (Reference 1) Dr. Richter postulates a maximum credible earthquake on the Calaveras fault of M7.5 with a peak horizontal ground acceleration of 0.7g. A mean effective acceleration for engineering design purposes of 0.5g for the maximum credible earthquake is specified for the site. Magnitude values stated in the NRC "GETR Safety Evaluation Report Input" (September 27, 1979) are consistent with these values.

Richter noted (November 9, 1979) in information prepared for the November 14, 1979 ACRS GETR subcommittee meeting and forwarded subsequently to the ACRS the following:

> Evaluation of the capability of the Calaveras fault has now to consider the earthquake of August 6, 1979, in the Gilroy-Hollister part of the fault, with magnitude near 5.7. This is an additional instance like those known from the past, all of which have been limited in extent. The earliest of these, that of 1861, was reported from near the present site of Livermore. Other earthquakes have affected the vicinities of Walnut Creek and of Danville; perhaps the Mare Island earthquake of 1898 should be included.
>
> This evidence appears to document the Calaveras fault as habitually active only in relatively short segments, not in an extended fault rupture -- which would, in our judgement, support magnitude of 7 rather than of 7½.

Question No. 1h

What acceleration vs. distance data is used to determine the acceleration on site?

Response to Question No. 1h

Several approaches including a review of California Division of Mines and Geology data, and an independent review by Dr. Charles Richter were used to determine the peak ground acceleration at the GETR site. An analysis using the NOAA Earthquake Data File (Reference 2) which lists earthquakes by time, epicentral location and Modified Mercalli Intensity between 1906 and 1971 was made to determine the peak ground acceleration at the site. The Howell and Schultz San Andreas attentuation equation (Reference 3) was used:

$$I = I_0 \exp(-0.0037\Delta)$$

where

I = intensity at site

I_0 = intensity at fault

Δ = distance from fault to site in km.

The second approach was based on the University of California Seismological Laboratory data (Reference 4) which are in the form of time, epicentral location, magnitude, and a brief description of observed damage for earthquakes from 1910 to 1972. The Schnabel-Seed attenuation relationship (Reference 5) which relates magnitude and distance from epicenter to site, to peak ground acceleration at the site was used.

The site was also reviewed using data published by the California Division of Mines and Geology (Reference 6). The CDMG data includes a map by Greensfelder showing maximum credible rock accelerations from earthquakes in California. For the GETR site the maximum credible rock acceleration (which is analogous to maximum effective peak ground acceleration) is shown as 0.5g.

Dr. Richter's study (Reference 1) postulated a maximum credible earthquake of M7.5 in the Calaveras with a corresponding mean effective acceleration for design purposes of 0.5g.

Response to Question No. 1h - continued

The USNRC Order to Show Cause, dated 24 October 1977, stated that ground motions in excess of 0.75g should be considered possible at the GETR site. In order to show that the GETR is safe and does not pose a risk to the public, to eliminate any concern regarding the level of conservatism associated with the analysis, and to expedite NRC review, General Electric Company (GE) performed additional reanalyses of the structures and systems important to safety, using revised earthquake criteria (Reference 7) which complied with the intent of the Order to Show Cause, although GE and its consultants felt the revised criteria are overly conservative. The revised criteria are:

> 0.8g peak ground acceleration in two orthogonal horizontal directions anchored to USNRC Regulatory Guide 1.60 response spectra shapes and with two-thirds of the horizontal value for vertical motion.

In order to expedite the review process GE proceeded with the reanalysis using 0.8g effective peak ground accelerations (EPGA) as a bounding situation.

Question No. 1i

What modification, if any, is made for possible near field effects?

Response to Question No. 1i

The near field effects and their relationship to magnitude, including data from the Imperial Valley (October 15, 1979) and Coyote Lake (August 6, 1979) earthquakes are being studied and assessed. Results will be forwarded when the studies are completed.

References

1. Richter, Charles F., "Potential Earthquakes on the Calaveras Fault," Lindvall, Richter & Associates Report, 9 December 1977.

2. National Oceanographic and Atmospheric Administration Earthquake Data File, 1906 to present, December 1975.

3. Howell, B. F., Jr., and T. R. Schultz, "Attenuation of Modified Mercalli Intensity with Distance from Epicenter", Bulletin of Seismological Society of America, p. 651, June 1975.

4. Bolt, Bruce A, and Roy D. Miller, "Catalogue of Earthquakes in Northern California and Adjoining Areas, 1 January 1910 to 31 December 1972, Seismologic Stations," University of California, Berkeley, California, 1975.

5. Schnabel, Per B., and H. Bolton Seed, "Accelerations in Rock for Earthquakes in the Western United States," Earthquake Engineering Research Center, University of California, Berkeley, California, EERC-72-2, July 1972.

6. Greensfelder, Roger W., "Maximum Credible Rock Accelerations from Earthquakes in California - Map Sheet 23," California Division of Mines and Geology, 1972, revised August 1974.

7. Engineering Decision Analysis Company, Inc., "Seismic Analysis of Reactor Building, General Electric Test Reactor, Phase 2," prepared for General Electric Company (GETR), Pleasanton, California EDAC 117-217.03, 1 June 1978.

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VIRGINIA C. CASQUEIRO
NOTARY PUBLIC - CALIFORNIA
ALAMEDA COUNTY
My comm. expires MAR 8, 1981