Engineering Analyses and Tests

MASTER

TEST REPORT

COEFFICIENT OF FRICTION BETWEEN
CARBON STEEL AND PERLITE CONCRETE SURFACES

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ENGINEERING ANALYSES & TESTS

TEST REPORT

COEFFICIENT OF FRICTION BETWEEN CARBON STEEL AND PERLITE CONCRETE SURFACES

FORWARD

The special study carried out in this document was conducted under Purchase Order No. 7557303 with Lawrence Livermore Laboratory, University of California. Mr. Robert C. Murray of the Structural Mechanics Group, LLL, served as the technical representative for monitoring the project. Mr. Raymond Perez represented Engineering Analysis and Test Co., Inc., as principal investigator.

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Abstract

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ABSTRACT

The results of coefficient of friction, μ , tests conducted on perlite blocks and carbon steel plates under various conditions are discussed. Variables included in the test entailed the use of lubricants (i.e. water and simulated radioactive waste solution) and abrasives (120 grit, 60 grit, 40 grit sand paper) applied to the surfaces of the perlite block and carbon steel plates.

1.0 Introduction

In the attempt to determine whether relative motion would exist between high level waste tank 8D-2 and its vault at the Nuclear Fuel Services (NFS) site, tests designed to determine the coefficient of static friction, μ , between the tank and vault under a variety of potential environments were undertaken.

In these tests the coefficient of static friction, μ , between ASTM A-515 grade 70 carbon steel, the new designation for ASTM A-201 grade A carbon steel, and perlite support blocks was determined. The perlite blocks act as both structural supports and thermal insulators for the waste tank which is maintained at 82°C (180°F).

The performance of these tests entailed the fabrication of perlite blocks and curing the blocks for 28 days per Chicago Bridge & Iron Specification for Perlite Concrete Insulating Foundations (1); compression testing of material samples per ASTM Designation C-39, and the performance of static friction measurements under a variety of environmental conditions including variations of normal force,

variations of surface texture and surface lubricants (i.e. water and simulated waste solution) and variations in temperature.

2.0 Summary and Conclusions

A series of coefficient of friction, μ , measurements utilizing a variety of test variables, were taken and found to be approximately .60 with a standard deviation between .02 and .08 for every condition tested. Normal forces of 10 to 100 psi were applied as were variations in temperature. The combined affect of these variables amounted to very little differences in the value of μ .

As can be seen in Table 4, μ is essentially a linear function with respect to increasing normal force. The coefficient of friction between perlite bricks and carbon steel was found to remain relatively constant irrespective of the normal force applied or alterations to the perlite brick or carbon steel surfaces due to abrasives or lubricants.

3.0 Preparation of Samples

Perlite concrete blocks 4"x4"x8" were prepared per Specification for Perlite Concrete Insulating Foundation as provided by Chicago Bridge & Iron Co., the Nuclear Fuel Service (NFS) vault system construction contractor. The fabrication of the blocks required mixing perlite aggregate obtained from the REDCO Perlite Company, Portland cement obtained locally, air entrainer from Central Solvents & Chemical Co., and water. Four different mixes were prepared as a means of evaluating μ as a function of mix proportions. The mixes prepared are included in Table 1.

The mix proportions were placed in a drum type mixer with water, air entrainer and cement added first to form a slurry prior to the addition of the aggregate. The batches were of three cubic feet in volume each. Each batch was mixed a total of 12 minutes. The blocks were then formed in wooden frames 4"x4"x8" while care was taken to minimize water content as specified in Table 1. The formed blocks were allowed to cure for 28 days under ambient conditions (i.e. $60^{\circ} < T < 80^{\circ} \text{F}$, $50\% < \text{R.H.} < 80\%$).

A sieve analysis was performed on the perlite aggregate per ASTM Specification C-332-54-T. The results of this analysis are indicated in Table 2.

4.0 Test Sequence

The coefficient of friction between the perlite bricks and carbon steel, μ , was obtained by incorporating the following variables:

- 1) Concrete mix proportions.
- 2) Normal force within the range of 10-100 psi was applied.
- 3) Surface texture for both carbon steel and perlite block.
- 4) Foreign material on the contact surface.
- 5) Temperature 21°C (70°F) and 93°C (200°F).

A solution of NaOH + NaNO₃, corresponding very closely to high level wastes collected in tank 8D-2, was used as one of the surface lubricants (see Table 3).

Concrete blocks of the mix proportions indicated in Table 1 were tested. Variations in the normal force were obtained by using a hydraulic ram and anvil

in the test fixture (Figure 1). Variations in surface texture were obtained by lapping the block and steel plate with sand paper of grit sizes 120, 60 and 40.

4.1 Compression Test

The perlite concrete was subjected to compressive strength tests per ASTM Designation C39 which requires a minimum compressive strength of 125 psi after 28 days of curing. The compressive strength of samples from rows 1 and 2 (see Table 1) did not meet this requirement, the maximum strength measuring 76 psi. Insufficient water for adequate cohesion is believed to be the cause of this failure. The compressive strength of samples from rows 3 and 4 was found to be 239 psi. The test report from the laboratory where these tests were performed, American Standards Testing Laboratories, is attached.

5.0 Test Apparatus

The test fixture used is shown in Figure 1. As can be seen in the figure, an 8 ton capacity hydrojack was used to apply the normal force between a perlite block and the A-515 steel. A 3 ton hydrojack attached to a push bar was used to apply the tangential force. The test fixture incorporated the use of Enermac pneumatic diaphragm type pressure gauges and Hein-Werner hydrojacks, which were calibrated using a Baldwin Compression Tester at the UCLA Engineering Lab.

6.0 Test Results and Data

The coefficient of friction, μ , readings for each of the conditions tested are listed in Tables 4.1-4.4, as are the respective normal forces applied in the test sequence to obtain the μ readings.

Coefficient of friction measurements were not taken on the bricks from rows 1 & 2 because samples of these bricks failed the compression test, and therefore, they

are not believed to be representative of the
perlite bricks used at the NFS site.

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MADE BY M. PEREZ DATE _____

CHECKED BY _____ DATE _____

DESCRIPTION _____

CALCULATIONS FOR _____

Figure 1

Figure 2.1

Coefficient of Friction vs Normal Force
No Lubricant, $\mu(21^{\circ}\text{C})$ (70°F), Sample #3

Figure 2.2

Coefficient of Friction vs Normal Force
No Lubricant, $\nu(21^{\circ}\text{C})$ (70°F), Sample #4

Figure 3.1

Coefficient of Friction vs Surface Abrasion
No Lubricant, $\sim$ (21°C) (70°F), Sample #3

Figure 3.2
Coefficient of Friction vs Surface Abrasion
Water, $\gamma(21^{\circ}\text{C})$ (70°F), Sample #3

Figure 3.3

Coefficient of Friction vs Surface Abrasion
Simulated Waste Solution, $\sim(21^{\circ}\text{C})$ (70°F), Sample #3

Figure 3.4

Coefficient of Friction vs Surface Abrasion
No Lubricant, $\sim$ (93°C) (200°F), Sample #3

Figure 3.5

Coefficient of Friction vs Surface Abrasion
No Lubricant, $\sim(21^{\circ}\text{C})$ (70°F), Sample #4

Figure 3.6
Coefficient of Friction vs Surface Abrasion
Water, μ (21°C) (70°F), Sample #4

Figure 3.7

Coefficient of Friction vs Surface Abrasion
Simulated Waste Solution, $\sim(21^{\circ}\text{C})$ (70°F), Sample #4

Figure 3.8

Coefficient of Friction vs Surface Abrasion
No Lubricant, $\sim 93^{\circ}\text{C}$ (200°F), Sample #4

Table 1

	Perlite Aggregate (cu. ft.)	Portland Cement (lbs.)	Air Entrainment (cu. ft.)	Water (cu. ft.)
Row 1	2.005	31.0	0.008	0.568
Row 2	1.337	31.0	0.008	0.401
Row 3	2.005	31.0	0.008	0.802
Row 4	1.337	31.0	0.008	0.668

Table 2
Perlite Aggregate Sieve Analysis

Sieve Size	% by Weight	Cummulative	Minimum Allowed*	Maximum Allowed*
8	3.8	3.8	0	15
16	38.5	42.3	15	60
30	40.1	82.4	40	80
50	10.3	92.7	75	95
100	3.5	96.2	90	100

* weight percent

Table 3

	<u>Neutralized Waste, M</u>		<u>Simulated Waste, M</u>
	<u>Supernate</u>	<u>Sludge</u> ^(a)	
Al	0.01	0.09 (1.8)	NA
Cl	0.01	NA	NA
Cr + Ni	NA	0.04 (0.8)	NA
C ₂ O ₄	0.08	NA	NA
F	0.01	NA	NA
Fe	NA	0.29 (5.8)	NA
HNO ₃	NA	NA	NA
Mo	0.01	NA	NA
Na + K	6.78	NA	6.78
OH (Excess)	0.17	NA	0.17
P	0.08	NA	NA
SO ₄	0.28	NA	NA
Th	NA	NA	NA

(a) numbers in parentheses are based on wet sludge volume

NA - not applicable

Table 4.1
Coefficient of Friction Measurements (μ)
40 Grit Abrasion

Normal Force	Water		NaOH + NaNO ₃		No Lubrication		~93°C (200°F)	
	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4
477	.7321	.6711	.2440	.6101	.6711	-----	.6102	.6102
715	.7727	.6101	.4881	.5694	.7727	.6514	.5695	.6915
954	.7016	.6406	.4575	.5491	.7321	.7016	.6102	.6712
1192	.7565	.6467	.4636	.5613	.6711	.6507	.5857	.6834
1431	.6914	.6101	.6101	.5491	.6507	.6623	.5796	.6508
1669	.6362	.5926	.5926	.5403	.5926	.6449	.5666	.6276
1908	.6101	.5872	.6253	.5016	.5948	.6253	.5644	.6254
2146	.5829	.5694	.6101	.5003	.5558	.6236	.5288	.6102
2385	.5613	.5857	.5735	.4770	.5369	.6162	.5747	.5980
2623	.5324	.5768	-----	-----	-----	.6156	.4828	.5975
2862	-----	-----	-----	-----	-----	-----	-----	-----
	$m = .6577$ $s = .0849$	$m = .6090$ $s = .0336$	$m = .5526$ $s = .0707$	$m = .5398$ $s = .0410$	$m = .6420$ $s = .0793$	$m = .6503$ $s = .0338$	$m = .5623$ $s = .0399$	$m = .6364$ $s = .0357$

m = mean

s = standard deviation

Table 4.2
Coefficient of Friction Measurements (μ)
60 Grit Abrasion

Normal Force	Water		NaOH + NaNO ₃		No Lubrication		93°C (200°F)	
	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4
477	.6711	.6711	-----	.6711	.6712	.6102	.5491	.4881
715	.7321	.7321	.7626	.6914	.6102	.6102	.6102	.7322
954	.7016	.7016	.7321	.6406	.5186	.6590	.6102	.7322
1192	.6589	.6345	.7117	.6589	.6990	.6712	.5857	.7322
1431	.6101	.6304	.6449	.6507	.6305	.6625	.5695	.7322
1669	.5926	.6101	.6253	.6445	.6625	.6664	.5404	.6573
1908	.5796	.5948	.5597	.6558	.6254	.6644	.5339	.6864
2146	.5694	.5965	.5735	.7168	.5566	.6590	.5288	.6780
2385	.5613	.5857	-----	.6372	.5613	.6545	.5125	.6590
2623	.5546	.5879	-----	.6406	.5325	-----	.5046	.6212
2862	-----	-----	-----	.6544	.5085	-----	-----	-----
	$m = .6231$ $s = .0633$	$m = .6345$ $s = .0512$	$m = .6638$ $s = .0722$	$m = .6606$ $s = .0246$	$m = .5978$ $s = .0593$	$m = .6530$ $s = .0260$	$m = .6142$ $s = .0710$	$m = .6719$ $s = .0757$

m = mean

s = standard deviation

Table 4.3
Coefficient of Friction Measurements (μ)
120 Grit Abrasion

Normal Force	Water		NaOH + NaNO ₃		No Lubrication		$\sim 93^{\circ}\text{C}$ (200°F)	
	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4
477	.5491	-----	-----	.6712	.6712	.6712	.6712	.7322
715	.6101	-----	.6102	-----	.6508	.6915	.7729	.7116
954	.6101	-----	.6102	.7017	.6102	.6407	.7627	.7017
1192	.6345	-----	.6102	.6590	.5613	.5580	.7322	.6956
1431	.6101	-----	.5898	.6508	.6305	.5898	.7017	.6712
1669	.5926	-----	.5840	.6625	.5927	.5753	.6712	.6712
1908	.5948	-----	.5873	.6559	.5491	.5644	.6330	.6559
2146	.5694	-----	.5695	.6373	.5288	.5559	.5896	.6441
2385	.5491	-----	.5735	.6102	.5247	.5491	.5369	.6346
2623	.5324	-----	-----	-----	.4992	.5436	.5159	.6212
2862	-----	-----	-----	-----	.4780	.5390	-----	-----
	$m = .5852$ $s = .0335$	----- -----	$m = .5918$ $s = .0166$	$m = .6561$ $s = .0263$	$m = .5724$ $s = .0634$	$m = .5926$ $s = .0528$	$m = .6587$ $s = .0895$	$m = .6736$ $s = .0359$

$m = \text{mean}$

$s = \text{standard deviation}$

Table 4.4
Coefficient of Friction Measurements (μ)
No Abrasions

Normal Force	Water		NaOH + NaNO ₃		$\sim 93^{\circ}\text{C}$ (200°F)		Air			
	Row 3	Row 4	Row 3	Row 4	Row 3	Row 4	Row 1	Row 2	Row 3	Row 4
477	.6712	.6712	.5491	.7931	.4270	.4881	.4881	.6102	.6712	.8054
715	-----	.6915	.5695	.8134	.4474	.4474	.4474	.5695	.6407	-----
954	.6712	.6712	.6407	.7626	.4270	.5796	-----	.6407	.5857	.8949
1192	.6346	.6346	.6590	.7077	.4148	.5613	-----	.5857	.5898	.7566
1431	.6102	.6508	.6305	.6914	.4474	.5287	-----	.5695	.4881	.7671
1669	.6102	.6625	.6276	.6798	.4706	.5229	-----	.5753	.4746	.7474
1908	.6254	.6559	.6254	.6634	.4875	.5109	-----	.5644	.4881	.7078
2146	.6102	.6780	.6120	.6372	.4745	.4881	-----	.5966	.4474	.6407
2385	.5857	.6590	.5857	.6345	.5003	.4758	-----	-----	-----	.5695
2623	.5286	.6656	-----	.6322	.4499	.4714	-----	-----	-----	-----
2862	.5163	-----	-----	.6202	-----	-----	-----	-----	-----	-----
	$m = .6063$ $s = .0496$	$m = .6640$ $s = .0156$	$m = .6109$ $s = .0358$	$m = .6941$ $s = .0679$	$m = .4566$ $s = .0296$	$m = .5074$ $s = .0414$	$m = .4678$	$m = .5890$ $s = .0260$	$m = .5482$ $s = .0842$	$m = .7362$ $s = .0994$

m = mean
 s = standard deviation

American Standards Testing Laboratories

2130 SEPULVEDA BOULEVARD • LOS ANGELES, CALIFORNIA 90025 • TELEPHONE: 213/477-6593

COMPRESSION TEST REPORT

Test made for . EA&T COMPANY, INC.

Job Identification BLOCKS OF PERLITE CONCRETE

Location in Structure	TEST MIX
Top of Deck	1
Bottom of Deck	2
Top of Subgrade	3
Bottom of Subgrade	4
Top of Base	5
Bottom of Base	6
Top of Subgrade	7
Bottom of Subgrade	8
Top of Base	9
Bottom of Base	10
Top of Subgrade	11
Bottom of Subgrade	12
Top of Base	13
Bottom of Base	14
Top of Subgrade	15
Bottom of Subgrade	16
Top of Base	17
Bottom of Base	18
Top of Subgrade	19
Bottom of Subgrade	20
Top of Base	21
Bottom of Base	22
Top of Subgrade	23
Bottom of Subgrade	24
Top of Base	25
Bottom of Base	26
Top of Subgrade	27
Bottom of Subgrade	28
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Bottom of Base	86
Top of Subgrade	87
Bottom of Subgrade	88
Top of Base	89
Bottom of Base	90
Top of Subgrade	91
Bottom of Subgrade	92
Top of Base	93
Bottom of Base	94
Top of Subgrade	95
Bottom of Subgrade	96
Top of Base	97
Bottom of Base	98
Top of Subgrade	99
Bottom of Subgrade	100

LABORATORY DATA PERLITE CONCRETE

Date Cast: 11/7/77

[illegible]

FIELD DATA

Mix Designation FERLITE 6 cu.ft.perlite
Cement Brand 1 bag portland, 9gal. water
 GALLO PORTLAND

Slump
Admixture R. AIR

Specified Strength @ 28 Days 125 PSI MIN.

Ready Mix Plant JOB MIXED

Cylinders Made By **F&T**

Date Cylinders Delivered 12/5/77 by CLIENT

DISTR:

EA&T COMPANY INC.

Respectfully submitted,

American Standards Testing Laboratories

1 D = Rows 3 & 4

1 W = Rows 1 & 2

By