INTERIM REPORT

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

June 1978

by

G. B. Mitchell, Yu-Shih Jeng
**Report Title:** Dike Stability Analysis, Basin F, Rocky Mountain Arsenal, Denver, Colorado

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- Yu-Shih Jeng

**Performing Organization:**
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180

**Funding Numbers:**
- 81266R44

**Abstract:**
This report presents the findings of the U.S. Army Engineer Waterways Experiment Station in compliance with the appropriate portions of Task 1.05.62. The work to be performed under Task 1.05.62 is defined as: Quantitative Feasibility Evaluation for Full Depth Containment of Basin F, and states, in part, that "Any hazards to the existing dikes due to age or construction should be identified" and "Assess the current physical condition of the Basin for determination of need for immediate structural repair."

**Subject Terms:**
- Treatment
- Disposal
- Liners

**Security Classification of Report:** Unclassified

**Security Classification of This Page:** Unclassified

**Limitation of Abstract:** UL

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DIKE STABILITY ANALYSIS, BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, CO

1. This analysis was performed during the period 9 November 1977 - 23 May 1978. The study was authorized by Intra-Army Order for Reimbursable Services (IAO) No. RM 56-78 dated 9 November 1977. A Work Statement attached to that IAO defines the work to be performed under Task 1.05.62, Quantitative Feasibility Evaluation for Full-Depth Containment of Basin F, and states, in part, that "Any hazards to the existing dikes due to age or construction should be identified" and "Assess the current physical condition of the Basin for determination of need for immediate structural repair." This report presents the findings of the U. S. Army Engineer Waterways Experiment Station (WES) in compliance with the appropriate portions of Task 1.05.62.

2. A visual on-site inspection was made of the dike, and four boring locations were selected. A plan view of Basin F, along with the boring locations, is shown in Figure 1. The initial borings were made by a WES drill crew operating a drill rig belonging to Rocky Mountain Arsenal (RMA). The rig was not equipped to obtain satisfactory undisturbed samples, and in order to expedite the investigation, the borings were made utilizing Standard Penetration Tests (SPT). Jar samples were obtained and tested in the WES Soil Testing Facility for moisture content, Atterberg limits, grain-size distribution, and specific gravity. The laboratory test results are presented in Figures 2-41. The graphic boring logs and results of the SPT tests are presented in Figures 42-45.

3. From the SPT and laboratory test results, shear strength and unit weight parameters were estimated. The soils were considered to be either cohesive (in which case no angle of internal friction was assigned) or cohesionless (in which case no cohesion was assigned).
These estimated values are presented in Figures 42-45. Stability analyses were performed by using the Wedge Method in the WES Computer Program SSW028.

4. It appeared from the calculated factors of safety (0.87 to 1.25) that a critical condition existed in the outside, or downstream, slope when the reservoir was at full pool (2 ft below the crest) and when a steady seepage state with an assumed phreatic line occurred through the dike. Since the reservoir has been at full pool and the dike has not failed, it was felt that either the estimated strength values were not valid or the asphaltic membrane liner on the upstream slope had been effective in preventing a steady seepage state from occurring and the conditions necessary to reduce strength to that for saturated drained conditions have not yet developed. (The laboratory tests indicate that the embankment zone below the assumed phreatic line is not saturated.) Since the possibility exists that the liner could become ineffective at some point at any time, and since the low factors of safety were calculated from estimated soil parameters, it was felt that additional borings to obtain undisturbed soil samples for more accurate laboratory testing were necessary.

5. Four additional borings were made within 5 ft of the initial borings by a WES drill crew using a WES drill rig. Undisturbed Shelby-tube samples, 5 in. in diameter, were obtained. Where the soil possessed sufficient cohesion, Q triaxial tests were performed; where the soil possessed low cohesion, S direct shear tests were performed. All test results are presented in Figures 46-79. A comparison of the initial estimated values and the measured laboratory values indicates that the estimated values were only slightly in error. Since several samples were tested from each zone, and since the values within a zone varied slightly, it was necessary to make statistical selections of values for use in the analyses. The selected soil parameters for respective zones are shown, along with the initial graphic borings logs and estimated values, in Figures 42-45. Stability analyses were performed
utilizing the selected values and the Modified Swedish Method in the CORPS Computer Program 10009. Only the downstream slope was evaluated. Again, pool level was assumed to be 2 ft below the crest. Analyses were also performed with a pseudo-seismic (earthquake) loading of 0.05 g. The analyses are presented in Figures 80-83.

6. The analyses revealed that the factors of safety are highly dependent upon the degree of cohesion. Figure 84 graphically depicts this sensitivity. Corps of Engineers (CE) criteria, however, dictate that the SS case be analyzed using the drained strength (S test), which in this case is without cohesion. On this basis, factors of safety of 0.79 to 1.11 were obtained. Because of the sensitivity of the factors of safety to cohesion, analyses were also performed using the undrained strength (Q test) which includes cohesion and represents the unsaturated "as is" condition of the dike. Factors of safety for this condition range from 4.43 to 9.80. A summary of all factors of safety is presented in Figure 85.

7. Because of the low factors of safety indicated for the SS case, further analyses were performed with the reservoir pool lowered by 2-ft increments to determine if a lower head would increase the factor of safety to 1.5 as required by CE criteria for the SS case. (We understand that the reservoir pool elevation is decreasing due to reduction and possible complete cessation of fluid discharge into the basin.) Boring 482 was selected as being representative and only this location was subjected to the additional analyses which were performed using both S and Q strengths and with and without earthquake loadings. The results are shown graphically in Figure 86. Increases in factors of safety were only slight.

8. A summary of all analyses indicates that in order to comply with current CE criteria of a factor of safety of 1.5 for the SS condition, the downstream dike slope must be altered from its present 1:1 to a flatter 1:2.5. It is estimated that the dike comprises approximately one-half of the total periphery of the basin; consequently,
approximately 3600 lin ft of dike must be altered. The alteration will require approximately 16,000 cu yd of soil. The operation should be fairly simple and can be accomplished by stripping soil from around the periphery with a bulldozer and shoving it up onto the existing slope. The absence of significant vegetation in the surrounding topsoil and on the dike slope should expedite the operation. The peripheral fence must be removed and replaced along the length of dike addressed.
BORING LOCATION MAP
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO
Sample No. 1
Elev or Depth 0-1.5
Classification SILTY SAND (SM) BROWN
Nat w % Gs = 2.70
LL 8.1 NP
PL
PI

Project ROCKY MOUNTAIN ARSENAL
Area F BASIN - DIKE
Boring No. 482
Date 28 DEC 77

GRADATION CURVES
Sample No. | Elev or Depth | Classification | Nat w % | LL | PL | Pi | Project | Area | Boring No. | Date
---|---|---|---|---|---|---|---|---|---|---
3 | 4.7-6.2 | SILTY SAND(SM) BROWN | 9.1 | NP | | | ROCKY MOUNTAIN ARSENAL | F BASIN - DIKE | 482 | 28 DEC 77
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<th>Sample No.</th>
<th>Elev. or Depth</th>
<th>Classification</th>
<th>Nat w. %</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
<th>Project</th>
<th>Area</th>
<th>Boring No.</th>
<th>Date</th>
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<tbody>
<tr>
<td>5</td>
<td>10.0-11.5</td>
<td>SILTY. CLAYEY SAND(SC)</td>
<td>13.4</td>
<td>25</td>
<td>18</td>
<td>7</td>
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<td>F. BASIN - DIKE</td>
<td>482</td>
<td>30 DEC 77</td>
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<tr>
<td></td>
<td></td>
<td>BROWN Gs= 2.70</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Sample No. | Elev. or Depth | Classification | Nat. w. % | LL | PL | PI | Project | Area | Boring No. | Date
--- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---
6 | 12.5-13.7 | SILTY SAND(SM) BROWN | 10.5 | NP | | | ROCKY MOUNTAIN ARSENAL | F BASIN - DIKE | 483 | 28 DEC 77

GS = 2.69
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<th>Nat w %</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
<th>Project</th>
<th>Area</th>
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<td>7</td>
<td>15.0-16.5</td>
<td>CLAYEY SAND(SC) BROWN</td>
<td>0.8</td>
<td>24</td>
<td>13</td>
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Gs = 2.71

GRADATION CURVES

ENG 1 MAY 93 2087
Sample No.: 8
Elev or Depth: 17.5-18.6
Classification: SANDY CLAY (CL) TAN
Nature %: 9.1
LL: 34
PL: 13
PI: 21

Project: ROCKY MOUNTAIN ARSENAL
Area: E. BASIN - DIKE
Boring No.: 493
Date: 28 DEC 77

GRADATION CURVES
Figure 22

GRADATION CURVES

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<th>Sample No.</th>
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<th>Classification</th>
<th>Net w %</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
<th>Project</th>
<th>Area</th>
<th>Boring No.</th>
<th>Date</th>
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<td>F. BASIN - DIKE</td>
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<td>29 DEC 77</td>
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Gs = 2.69
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<th>Nat w %</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
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<th>Area</th>
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<td>F. BASIN - DIKE</td>
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<td>29 DEC 77</td>
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<tr>
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<td>BROWN</td>
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</tbody>
</table>
Sample No. 4
Elev or Depth 7.5-8.9
Classification SILTY SAND (SM) BROWN
Gs= 2.70
Net w % 7.4
LL NP
PL
PI

Project ROCKY MOUNTAIN ARSENAL
Area F. BASIN - DIKE
Boring No. 484
Date 29 DEC 77
<table>
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<th>LL</th>
<th>PL</th>
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<td>COARSE</td>
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<td>ROCKY MOUNTAIN ARSENAL</td>
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<tr>
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<td>SANDY CLAY(CL) BROWN</td>
<td>14.2</td>
<td>28</td>
<td>14</td>
<td>14</td>
<td></td>
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<td></td>
<td>FINE</td>
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</table>

**GRAIN SIZE IN MILLIMETERS**

**PERCENT FINE BY WEIGHT**

**PERCENT COARSER BY WEIGHT**

**U.S. STANDARD SIEVE OPENING IN INCHES**

**U.S. STANDARD SIEVE NUMBERS**

**HYDROMETER**

**GRADATION CURVES**

**Project:** ROCKY MOUNTAIN ARSENAL

**Classification:** SANDY CLAY(CL) BROWN

**Nat w %:** 14.2

**LL:** 28

**PL:** 14

**PI:** 14

**Area:** F BASIN - DIKE

**Boring No.:** 484

**Date:** 29 DEC 77

**ENG FORM 1 MAY 62 2087**
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Elev or Depth</th>
<th>Classification</th>
<th>Net w %</th>
<th>LL</th>
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<th>PI</th>
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<tr>
<td>2</td>
<td>2.5-3.0</td>
<td>SILTY SAND(SM) BROWN</td>
<td>10.1</td>
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<tr>
<td></td>
<td></td>
<td>Gs= 2.70</td>
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**Project**: ROCKY MOUNTAIN ARSENAL

**Area**: F BASIN - DIKE

**Boring No.**: 485

**Date**: 29 DEC 77
### Sample No. 5

**Location:** 10.0-11.5

**Classification:** Silty Sand (SM) Brown

**Net w%:** 6.9

**LL:** NP

**Project:** Rocky Mountain Arsenal

**Area:** F Basin - Dike

**Boring No.:** 485

**Date:** 29 Dec 77

---

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Elev or Depth</th>
<th>Classification</th>
<th>Net w%</th>
<th>LL</th>
<th>PL</th>
<th>PI</th>
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<tbody>
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<td>10.0-11.5</td>
<td>Silty Sand (SM) Brown</td>
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<td>NP</td>
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<td>Gs = 2.70</td>
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---

**Grading Curves**

- **Percent Finer by Weight**
- **Percent Coarser by Weight**

**U.S. Standard Sieve Opening in Inches**

- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 5
- 2
- 1
- 0.5
- 0.25
- 0.1
- 0.05
- 0.01
- 0.005
- 0.001

**U.S. Standard Sieve Numbers**

- 6
- 4
- 3
- 2
- 1
- 0.5
- 0.25
- 0.1
- 0.05
- 0.01
- 0.005
- 0.001

**Grain Size in Millimeters**

- 500
- 100
- 50
- 20
- 10
- 5
- 2
- 1
- 0.5
- 0.25
- 0.1
- 0.05
- 0.01
- 0.005
- 0.001

---

**COBBLES**

- Coarse
- Fine

**GRAVEL**

- Coarse
- Fine

**SAND**

- Coarse
- Medium
- Fine

**SILT OR CLAY**

- Coarse
- Fine

---

**Legend:**

- COARSE
- FINE

---

**Note:**

- The graph shows the gradation curve for the sample in question.
- The sample is identified as Silty Sand (SM) with a net w% of 6.9 and a Gs of 2.70.
- The area of interest is F Basin - Dike.

---

**Date:** 29 Dec 77

---

**Form:** ENG 1 MAY 03 2087
<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Elev or Depth</th>
<th>Classification</th>
<th>Nat w %</th>
<th>LL</th>
<th>PL</th>
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<th>Date</th>
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<tr>
<td>9</td>
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<td>26.7</td>
<td>45</td>
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<td>ROCKY MOUNTAIN ARSENAL</td>
<td>F. BASIN - DIKE</td>
<td>485</td>
<td>29 DEC 77</td>
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\[ G_s = 2.74 \]
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<th>S TEST</th>
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<tr>
<td>127, 36, 0</td>
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<tr>
<td>134, 32, 0</td>
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<td>137, 0, 4350</td>
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<td>138, 0, 9930</td>
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**SELECTED LABORATORY VALUES**

- **SOIL 1**
  - 132, 32, 900, 34, 0

- **SOIL 2**
  - 115, 15, 840, 32, 0

---

**GRAPHIC BORING LOGS & STRENGTH VALUES**

**DIKE STABILITY ANALYSIS**

**BASIN P**

**ROCKY MOUNTAIN ARSENAL**

**DENVER, COLORADO**
INITIAL INVESTIGATION

<table>
<thead>
<tr>
<th>BLOWS PER FOOT</th>
<th>WATER CONTENT</th>
<th>ESTIMATED VALUES</th>
<th>x_w, PCF</th>
<th>Q, DEG. C</th>
<th>C, PSF</th>
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<tr>
<td>20 40 60 80 100</td>
<td>0 10 20 30 40</td>
<td>135 34 0</td>
<td>132 41 0</td>
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### ESTIMATED VALUES

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<th>$\varphi$, DEG.</th>
<th>$c$, PSF</th>
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### SELECTED LABORATORY VALUES

<table>
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<th>Depth, ft</th>
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**SOIL #1**

**SOIL #2**

---

**GRAPHIC BORING LOGS & STRENGTH VALUES**

**DIKE STABILITY ANALYSIS**

**BASIN F**

**ROCKY MOUNTAIN ARSENAL**

**DENVER, COLORADO**
### Initial Investigation

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- Natural Water Content
- Liquid Limit
- Plastic Limit

\[ \gamma_w, \text{pcf} \]

\[ \gamma_u, \text{pcf} \]
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<tr>
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<th>$\phi$, DEG.</th>
<th>$C$, PSF</th>
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<th>SELECTED LABORATORY VALUES</th>
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<th>$S$ TEST</th>
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<td>$\gamma_w$, PCF</td>
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SOIL #1

SOIL #2
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<td>( \gamma_w, \text{pcf} )</td>
<td>( \phi )</td>
</tr>
<tr>
<td>136</td>
<td>39</td>
</tr>
<tr>
<td>129</td>
<td>35</td>
</tr>
<tr>
<td>140</td>
<td>31</td>
</tr>
<tr>
<td>116</td>
<td>0</td>
</tr>
</tbody>
</table>

SOIL #1

SOIL #2

GRAPHIC BORING LOSS & STRENGTH VALUES
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Figure 10
Figure 46

**CONTROLLED-STRAIN TEST**

**DESCRIPTION OF SPECIMENS:** SILTY SAND (SM), TAN;

CEMENTED SLIGHTLY

**REMARKS:** PROJECT DIKE STABILITY

**SHEAR STRESS, T/SQ FT**

**NORMAL STRESS, T/SQ FT**

**DEViator STRESS, T/SQ FT**

**AXIAL STRAIN, %**

**SPECIMEN NO.**  

<table>
<thead>
<tr>
<th></th>
<th>Δ1</th>
<th>Y2</th>
<th>X3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT, %</td>
<td>7.8</td>
<td>8.1</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>DRY DENSITY, PCF</td>
<td>115.1</td>
<td>120.4</td>
<td>115.7</td>
<td></td>
</tr>
<tr>
<td>SATURATION, %</td>
<td>45.4</td>
<td>54.7</td>
<td>46.7</td>
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</tr>
<tr>
<td>VOID RATIO</td>
<td>0.464</td>
<td>0.400</td>
<td>0.457</td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRY DENSITY, PCF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOID RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BACK PRESS., TSF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN PRIN. STRESS, TSF</td>
<td>0.5</td>
<td>1.5</td>
<td>3.0</td>
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</tr>
<tr>
<td>MAX. DEV. STRESS, TSF</td>
<td>3.60</td>
<td>6.65</td>
<td>11.97</td>
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</tr>
<tr>
<td>TIME TO FAILURE, MIN.</td>
<td>19</td>
<td>23</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>RATE OF STRAIN INCR., %</td>
<td>5</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INITIAL DIAMETER, IN.</td>
<td>1.40</td>
<td>1.40</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>INITIAL HEIGHT, IN.</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td></td>
</tr>
</tbody>
</table>

UNDISTURBED SPECIMEN

O TEST

**PROJECT DIKE STABILITY**

**ROCKY MOUNTAIN ARSENAL**

**BORING NO. 482-U**

**SAMPLE NO. 1**

**DEPTH/ELEV 0.5-1.9**

**TECH. JAL**

**LABORATORY USAE WES**

**DATE 26 MAR 78**

**TRIAxIAL COMPRESSION TEST REPORT**


**SPECIMEN NO.**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ1</td>
<td>11.7</td>
<td>12.1</td>
<td>12.7</td>
<td></td>
</tr>
<tr>
<td>Y2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X3</td>
<td></td>
<td></td>
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<td></td>
</tr>
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</table>

**WATER CONTENT, %**

<table>
<thead>
<tr>
<th></th>
<th>11.7</th>
<th>12.1</th>
<th>12.7</th>
</tr>
</thead>
</table>

**DRY DENSITY, PCF**

<table>
<thead>
<tr>
<th></th>
<th>111.0</th>
<th>114.2</th>
<th>112.1</th>
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</thead>
</table>

**SATURATION, %**

<table>
<thead>
<tr>
<th></th>
<th>60.9</th>
<th>68.7</th>
<th>69.1</th>
</tr>
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</table>

**VOID RATIO**

<table>
<thead>
<tr>
<th></th>
<th>0.518</th>
<th>0.476</th>
<th>0.504</th>
</tr>
</thead>
</table>

**BEFORE SHEAR**

**INITIAL**

**WATER CONTENT, %**

**DRY DENSITY, PCF**

**SATURATION, %**

**VOID RATIO**

**BACK PRESS., TSF**

<table>
<thead>
<tr>
<th></th>
<th>0.5</th>
<th>1.5</th>
<th>3.0</th>
</tr>
</thead>
</table>

**MIN PRIN. STRESS, TSF**

<table>
<thead>
<tr>
<th></th>
<th>2.08</th>
<th>4.44</th>
<th>6.54</th>
</tr>
</thead>
</table>

**MAX. DEV. STRESS, TSF**

<table>
<thead>
<tr>
<th></th>
<th>29</th>
<th>28</th>
<th>26</th>
</tr>
</thead>
</table>

**TIME TO FAILURE, MIN.**

<table>
<thead>
<tr>
<th></th>
<th>1.39</th>
<th>1.40</th>
<th>1.41</th>
</tr>
</thead>
</table>

**RATE OF STRAIN INCR., %**

<table>
<thead>
<tr>
<th></th>
<th>3.00</th>
<th>3.00</th>
<th>3.00</th>
</tr>
</thead>
</table>

**INITIAL DIAMETER, IN.**

**INITIAL HEIGHT, IN.**

**DESCRIPTION OF SPECIMENS:** Silty Sand (SM), Tan

**CONTRIBUTED-STRAIN TEST**

**PROJECT DIKE STABILITY**

**ROCKY MOUNTAIN ARSENAL**

**BORING NO. 482-U**

**SAMPLE NO. 2**

**DEPHE/ELEV 5.5-6.55**

**TECH. JAL**

**LABORATORY USE WES**

**DATE 27 MAR 78**

**TRIAxIAL COMPRESSION TEST REPORT**

Figure 47
<table>
<thead>
<tr>
<th>SPECIMEN NO.</th>
<th>Δ1</th>
<th>Y2</th>
<th>X3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT. %</td>
<td>13.1</td>
<td>12.4</td>
<td>12.2</td>
<td></td>
</tr>
<tr>
<td>DRY DENSITY. PCF</td>
<td>117.2</td>
<td>116.0</td>
<td>119.9</td>
<td></td>
</tr>
<tr>
<td>SATURATION. %</td>
<td>80.6</td>
<td>73.9</td>
<td>81.2</td>
<td></td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>0.439</td>
<td>0.453</td>
<td>0.406</td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRY DENSITY. PCF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VOID RATIO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BACK PRESS. TSF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MIN PR/N. STRESS. TSF</td>
<td>0.5</td>
<td>1.5</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>MAX. DEV. STRESS. TSF</td>
<td>1.20</td>
<td>6.50</td>
<td>10.57</td>
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</tr>
<tr>
<td>TIME TO FAILURE. MIN.</td>
<td>13</td>
<td>169</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>RATE OF STRAIN INCR. %</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INITIAL DIAMETER. IN.</td>
<td>1.40</td>
<td>1.40</td>
<td>1.39</td>
<td></td>
</tr>
<tr>
<td>INITIAL HEIGHT. IN.</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td></td>
</tr>
</tbody>
</table>

DESCRIPTION OF SPECIMENS: CLAYEY SAND (SC)

DARK BROWN: FRIABLE

LL 28 PL 13 PI 15 GS 2.70 UNDISTURBED SPECIMEN Q TEST

REMARKS:
PROJECT DIKE STABILITY
ROCKY MOUNTAIN ARSENAL
BORING NO. 482-U SAMPLE NO. 3
DEPTH/ELEV 10.0-11.1 TECH. CR
LABORATORY USAE WES DATE 27 MAR 78

TRIAXIAL COMPRESSION TEST REPORT

Figure 48
### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content, $w_i$</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Void Ratio, $e_i$</td>
<td>0.761</td>
<td>0.750</td>
<td>0.769</td>
</tr>
<tr>
<td>Saturation, $S_i$</td>
<td>15.6%</td>
<td>15.8%</td>
<td>16.1%</td>
</tr>
<tr>
<td>Initial Drying Density, $\gamma_{d, i}$</td>
<td>95.7</td>
<td>96.3</td>
<td>95.3</td>
</tr>
<tr>
<td>Void Ratio After Consolidation, $e_f$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50% Consolidation, Min, $t_{50}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content, $w_f$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Void Ratio, $e_f$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation, $S_f$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Stress, T/SQ FT, $\sigma$</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/SQ FT, $\tau_{max}$</td>
<td>0.64</td>
<td>1.35</td>
<td>1.85</td>
</tr>
<tr>
<td>Actual Time to Failure, Min, $t_f$</td>
<td>660</td>
<td>930</td>
<td>990</td>
</tr>
<tr>
<td>Rate of Strain, In./Min</td>
<td>0.0037</td>
<td>0.0037</td>
<td>0.0037</td>
</tr>
<tr>
<td>Ultimate Shear Stress, T/SQ FT, $\tau_{ult}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Specimen Details
- **Type of Specimen:** UNDISTURBED
- **Classification:** SILTY SAND (SM), TAN
- **LL:** NP
- **PL:** NP
- **PL:** NP
- **Pi:** NP
- **G:** 2.70
- **Project:** DIKE STABILITY
- **Area:** ROCKY MOUNTAIN ARSENAL
- **Boring No.:** 482-U
- **Sample No.:** 4
- **Date:** 30 MAR 78

### Direct Shear Test Report

**Figure 49**
<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT</td>
<td>( \omega_0 )</td>
<td>7.0%</td>
<td>6.8%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>( \epsilon_0 )</td>
<td>0.664</td>
<td>0.654</td>
</tr>
<tr>
<td>SATURATION</td>
<td>( S_0 )</td>
<td>28.5%</td>
<td>28.1%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>( \gamma_d )</td>
<td>101.3</td>
<td>101.9</td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION</td>
<td>( \epsilon_c )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>( t_{50} )</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>WATER CONTENT</td>
<td>( \omega_f )</td>
<td>14.9%</td>
<td>15.8%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>( \epsilon_f )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION</td>
<td>( S_f )</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>( \sigma )</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{\max} )</td>
<td>0.61</td>
<td>1.30</td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>( t_f )</td>
<td>750</td>
<td>960</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td>0.00033</td>
<td>0.00033</td>
<td>0.00033</td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{ult} )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **TYPE OF SPECIMEN**: UNDISTURBED
- **CLASSIFICATION**: CLAYEY SILTY SAND (SC-SM)
- **PROJECT**: DIKE STABILITY
- **ROCKY MOUNTAIN ARSENAL**
- **AREA**
- **BORING NO.**: 482-U
- **SAMPLE NO.**: 5
- **DEPTH**: 16.1-17.2
- **DATE**: 31 MAR 78
- **INCH**: 3.00 IN. SQUARE 0.547 IN. THICK

**DIRECT SHEAR TEST REPORT**

---

**Figure 50**
**DIRECT SHEAR TEST REPORT**

**TEST NO.**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT</td>
<td>$W_o$</td>
<td>$14.1%$</td>
<td>$15.2%$</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>$e_o$</td>
<td>$0.991$</td>
<td>$0.993$</td>
</tr>
<tr>
<td>SATURATION</td>
<td>$S_o$</td>
<td>$38.7%$</td>
<td>$41.6%$</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>$\gamma_s$</td>
<td>$85.3$</td>
<td>$85.2$</td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION</td>
<td>$e_r$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>$t_{50}$</td>
<td>$3$</td>
<td>$&lt;1$</td>
</tr>
<tr>
<td>WATER CONTENT</td>
<td>$W_f$</td>
<td>$26.0%$</td>
<td>$24.9%$</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>$e_f$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION</td>
<td>$S_f$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>$\sigma$</td>
<td>$1.0$</td>
<td>$2.0$</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>$\tau_{max}$</td>
<td>$0.67$</td>
<td>$1.35$</td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>$t_f$</td>
<td>$900$</td>
<td>$690$</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td></td>
<td>$0.0038$</td>
<td>$0.0038$</td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>$\tau_{ult}$</td>
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</tr>
</tbody>
</table>

**TYPE OF SPECIMEN**

UNDISTURBED

**CLASSIFICATION**

SANDY CLAY (CL), LIGHT BROWN

**LL**

$39$

**PL**

$15$

**PI**

$24$

**$G_s$**

$2.72$

**PROJECT**

DIKE STABILITY

**AREA**

ROCKY MOUNTAIN ARSENAL

**BORING NO.**

$482-U$

**SAMPLE NO.**

$6$

**DEPTH EL**

$20.0-21.1$

**DATE**

$01$ APR $78$

**RCH**

Figure 51
Figure 52
**controlled-strain test**

**description of specimens:** clayey sand (SC).

**TAN:** friable

<table>
<thead>
<tr>
<th>specimen no.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>water content, %</td>
<td>12.3</td>
<td>12.7</td>
<td>12.1</td>
<td></td>
</tr>
<tr>
<td>dry density, PCF</td>
<td>118.8</td>
<td>119.5</td>
<td>119.1</td>
<td></td>
</tr>
<tr>
<td>saturation, %</td>
<td>79.2</td>
<td>83.5</td>
<td>78.6</td>
<td></td>
</tr>
<tr>
<td>void ratio</td>
<td>0.419</td>
<td>0.411</td>
<td>0.416</td>
<td></td>
</tr>
<tr>
<td>water content, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dry density, PCF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>saturation, %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>void ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>back press., TSF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>min pr:n. stress, TSF</td>
<td>0.5</td>
<td>1.5</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>max. dev. stress, TSF</td>
<td>4.04</td>
<td>5.42</td>
<td>5.28</td>
<td></td>
</tr>
<tr>
<td>time to failure, min.</td>
<td>11</td>
<td>19</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>rate of strain incr. %</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>initial diameter, in.</td>
<td>1.39</td>
<td>1.39</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>initial height, in.</td>
<td>3.00</td>
<td>3.00</td>
<td>3.00</td>
<td></td>
</tr>
</tbody>
</table>

**Project dike stability**

**rocky mountain arsenal**

**borong no:** 483-U

**sample no:** 4

**Depth/elev:** 11.0-12.3

**tech. cr.**

**Laboratory use:** WES

**Date:** Mar 78

**Triaxial compression test report**

Figure 54
SPECIMEN NO. | Δι | γ2 | χ3 | 4
---|---|---|---|---
WATER CONTENT, % | 8.5 | 8.8 | 8.8
DRY DENSITY, PCF | 104.8 | 103.7 | 106.1
SATURATION, % | 39.0 | 39.2 | 40.5
VOID RATIO | 0.602 | 0.620 | 0.593
WATER CONTENT, %
DRY DENSITY, PCF
SATURATION, %
VOID RATIO
BACK PRESS., TSF
MIN PRIN. STRESS, TSF | 0.5 | 1.5 | 3.6
MAX. DEV. STRESS, TSF | 2.00 | 4.01 | 7.74
TIME TO FAILURE, MIN. | 23 | 29 | 24
RATE OF STRAIN INCR.% | 5
INITIAL DIAMETER, IN. | 1.41 | 1.40 | 1.40
INITIAL HEIGHT, IN. | 3.00 | 3.00 | 3.00

DESCRIPTION OF SPECIMENS: CLAYEY SAND (SC), BROWN

LL 30 | PL 16 | PI 14 | GS 2.69
UNDISTURBED SPECIMEN | Q TEST
REMARKS: PROJECT GENE STABILITY

ROCKY MOUNTAIN ARSENAL
BORING NO. 483-U | SAMPLE NO. 5
DEPTH/ELEV 12.3-13.3 | TECH. JAL
LABORATORY USE WES | DATE 28 MAR 78
TRIAXIAL COMPRESSION TEST REPORT

Figure 55
Figure 56
<table>
<thead>
<tr>
<th>TYPE OF SPECIMEN</th>
<th>UNDISTURBED</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CLASSIFICATION</td>
<td>SANDY CLAY (CL), LIGHT BROWN</td>
<td></td>
</tr>
<tr>
<td>LL</td>
<td>29</td>
<td>PL</td>
</tr>
<tr>
<td>PI</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Gs</td>
<td>2.71</td>
<td></td>
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<tr>
<td>PROJECT</td>
<td>DIKE STABILITY</td>
<td></td>
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<tr>
<td>AREA</td>
<td>ROCKY MOUNTAIN ARSENAL</td>
<td></td>
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<td>BORING NO.</td>
<td>483-U</td>
<td></td>
</tr>
<tr>
<td>SAMPLE NO.</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>DEPTH</td>
<td>16.1-17.1</td>
<td></td>
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<tr>
<td>DATE</td>
<td>02 APR 78</td>
<td></td>
</tr>
</tbody>
</table>

**SHEAR STRENGTH PARAMETERS**

- \( \phi' = \) ____________
- \( \tan \phi' = \) ____________
- \( \sigma' = \) ____________ T/SQ FT

**TEST NO.**

<table>
<thead>
<tr>
<th>WATER CONTENT</th>
<th>Ws</th>
<th>15.5%</th>
<th>15.1%</th>
<th>15.0%</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOID RATIO</td>
<td>es</td>
<td>0.695</td>
<td>0.752</td>
<td>0.730</td>
<td></td>
</tr>
<tr>
<td>SATURATION</td>
<td>Sr</td>
<td>28.9%</td>
<td>29.5%</td>
<td>31.3%</td>
<td>%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>( \gamma_d )</td>
<td>99.8</td>
<td>98.1</td>
<td>97.8</td>
<td></td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION</td>
<td>ez</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>( \tau_{50} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT</td>
<td>Wf</td>
<td>15.5%</td>
<td>15.1%</td>
<td>15.0%</td>
<td>%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>ef</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION</td>
<td>Sr</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>( \sigma )</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{max} )</td>
<td>0.67</td>
<td>1.35</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>( \tau_{f} )</td>
<td>1200</td>
<td>1260</td>
<td>1530</td>
<td></td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td>0.0032</td>
<td>0.0032</td>
<td>0.0032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{ult} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**DIRECT SHEAR TEST REPORT**

ENG FORM 2092 (EM 1110-2-1906) PREVIOUS EDITIONS ARE OBSOLETE

*Figure 57*
HORIZ. DEFORMATION, IN.

Shear Strength Parameters

\[ \phi' = \quad \tan \phi' = \quad \phi' = \ldots \quad \text{T/SQ FT} \]

CONTROLLED STRESS

CONTROLLED STRAIN

Type of Specimen: UNDISTURBED

Classification: Sandy Clay (CL), Brown

LL 40 PL 15 PI 25 G 2.73

Remarks

Project: DIKE STABILITY

Area: ROCKY MOUNTAIN ARSENAL

Boring No. 483-U Sample No. 8

Depth: 20.0-21.2 Date: 04 APR 78

RCH

DIRECT SHEAR TEST REPORT

Figure 58
### Test No.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>(W_o)</td>
<td>8.3%</td>
<td>8.2%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>(e_o)</td>
<td>0.867</td>
<td>0.856</td>
</tr>
<tr>
<td>Saturation</td>
<td>(S_o)</td>
<td>26.1%</td>
<td>26.3%</td>
</tr>
<tr>
<td>Dry Density, LB/CU FT</td>
<td>(Y_d)</td>
<td>91.3</td>
<td>91.8</td>
</tr>
<tr>
<td>Void Ratio After Consolidation</td>
<td>(e_r)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, MIN</td>
<td>(t_{50})</td>
<td>3</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Water Content</td>
<td>(W_f)</td>
<td>21.6%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>(e_f)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation</td>
<td>(S_f)</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Normal Stress, T/SQ FT</td>
<td>(\sigma)</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/SQ FT</td>
<td>(\tau_{max})</td>
<td>0.59</td>
<td>1.22</td>
</tr>
<tr>
<td>Actual Time to Failure, MIN</td>
<td>(t_f)</td>
<td>645</td>
<td>960</td>
</tr>
<tr>
<td>Rate of Strain, IN./MIN</td>
<td></td>
<td>0.0033</td>
<td>0.0033</td>
</tr>
<tr>
<td>Ultimate Shear Stress, T/SQ FT</td>
<td>(\tau_{ult})</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Type of Specimen
- **UNDISTURBED**

### Classification
- **SANDY CLAY (CL), LIGHT BROWN**

### Designation
- **3.00 IN. SQUARE**
- **0.547 IN. THICK**

### Soil Parameters
- LL: 39
- PL: 17
- PI: 22
- Gs: 2.73

### Project
- **DIKE STABILITY**
- **ROCKY MOUNTAIN ARSENAL**

### Boring Details
- Boring No.: 483-U
- Sample No.: 9
- Depth: 21.2-22.0
- Date: 05 APR 76

### Figure 59
### Shear Strength Parameters

- \( \phi' = \) [value] 
- \( \tan \phi' = \) [value] 
- \( \epsilon' = \) [value] T/SQ FT

### Test Table

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content ( w_w )</td>
<td>6.5%</td>
<td>6.5%</td>
<td>6.6%</td>
</tr>
<tr>
<td>Void Ratio ( e_0 )</td>
<td>0.740</td>
<td>0.744</td>
<td>0.758</td>
</tr>
<tr>
<td>Saturation ( S_s )</td>
<td>24.1%</td>
<td>23.9%</td>
<td>23.9%</td>
</tr>
<tr>
<td>Dry Density, LB/CU FT ( \gamma_d )</td>
<td>98.3</td>
<td>98.1</td>
<td>97.3</td>
</tr>
<tr>
<td>Void Ratio After Consolidation ( e_c )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, Min ( t_{50} )</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Water Content ( w_f )</td>
<td>19.2%</td>
<td>16.5%</td>
<td>15.1%</td>
</tr>
<tr>
<td>Void Ratio ( e_f )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation ( S_f )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Normal Stress, T/SQ FT \( \sigma \)
- 1.0
- 2.0
- 3.0

### Maximum Shear Stress, T/SQ FT \( \tau_{max} \)
- 0.58
- 1.22
- 1.95

### Actual Time to Failure, Min \( t_f \)
- 660
- 720
- 990

### Rate of Strain, IN./MIN
- 0.0024
- 0.0024
- 0.0024

### Ultimate Shear Stress, T/SQ FT \( \tau_{ult} \)
-   |

### Type of Specimen
- Undisturbed

### Classification
- Sandy Clay (CL), Brown

### LL
- 28

### PL
- 16

### PI
- 12

### G
- 2.74

### Remarks
- [Blank]

### Project
- Dike Stability
- Rocky Mountain Arsenal

### Area
- [Blank]

### Boring No.
- 483-U

### Sample No.
- 10

### Depth
- 25.0-26.3

### Date
- 05 APR 78

### Direct Shear Test Report
Figure 61
CONTROLED-STRAIN TEST

DESCRIPTION OF SPECIMENS: CLAYEY SAND (SC), TAN

<table>
<thead>
<tr>
<th>SPECIMEN NO.</th>
<th>∆1</th>
<th>∆2</th>
<th>∆3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT, %</td>
<td>11.7</td>
<td>11.1</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>DRY DENSITY, PCF</td>
<td>115.5</td>
<td>114.2</td>
<td>115.8</td>
<td></td>
</tr>
<tr>
<td>SATURATION, %</td>
<td>68.8</td>
<td>63.0</td>
<td>64.0</td>
<td></td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>0.459</td>
<td>0.476</td>
<td>0.456</td>
<td></td>
</tr>
</tbody>
</table>

INITIAL

BEFORE SHEAR

MIN PRIN. STRESS, TSF | 0.5 | 1.5 | 3.0
MAX. DEV. STRESS, TSF | 3.35 | 5.00 | 9.02
TIME TO FAILURE, MIN. | 28 | 19 | 25
RATE OF STRAIN INCR.% | 1.40 | 1.40 | 1.41
INITIAL DIAMETER, IN. | 3.00 | 3.00 | 3.00
INITIAL HEIGHT, IN. | 3.00 | 3.00 | 3.00

REMARKS:
PROJECT DIKE STABILITY
ROCKY MOUNTAIN ARSENAL
BORING NO. 484-U
SAMPLE NO. 2
DEPHT/ELEV 1.1-2.2
TECH. JAL
LABORATORY USE S/WES
DATE 29 MAR 78
TRIAXIAL COMPRESSION TEST REPORT

Figure 62
Figure 63
**Table:**

<table>
<thead>
<tr>
<th>SPECIMEN NO.</th>
<th>Δ1</th>
<th>Y2</th>
<th>X3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT, %</td>
<td>7.4</td>
<td>7.0</td>
<td>7.0</td>
<td>7.0</td>
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<tr>
<td>DRY DENSITY, PCF</td>
<td>102.4</td>
<td>101.8</td>
<td>101.8</td>
<td>101.8</td>
</tr>
<tr>
<td>SATURATION, %</td>
<td>30.9</td>
<td>28.8</td>
<td>28.8</td>
<td>28.8</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>0.646</td>
<td>0.655</td>
<td>0.655</td>
<td>0.655</td>
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</tbody>
</table>

**Controlled-Strain Test:**

- Initial Height, in.: 3.00
- Initial Diameter, in.: 1.39

**Description of Specimens:** Silty Sand (SM), Tan; A Few Carbonate Concretions Up to 1/4

**Remarks:**

- Project: Dike Stability
- Rocky Mountain Arsenal
- Boring No. 484-U
- Sample No. 4
- Depth/Elev 10.0-11.1
- Tech. JAL
- Laboratory Use: WES
- Date: 31 Mar 78

**Figure 64**
### Shear Strength Parameters

- **φ'**
- **TAN φ'**
- **c'**

### Test Results

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT, W&lt;sub&gt;c&lt;/sub&gt;</td>
<td>7.6%</td>
<td>7.8%</td>
<td>7.5%</td>
</tr>
<tr>
<td>VOID RATIO, ε&lt;sub&gt;0&lt;/sub&gt;</td>
<td>0.589</td>
<td>0.596</td>
<td>0.586</td>
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<tr>
<td>SATURATION, S&lt;sub&gt;a&lt;/sub&gt;</td>
<td>34.8%</td>
<td>35.3%</td>
<td>34.6%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>106.1</td>
<td>105.6</td>
<td>106.3</td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION, ε&lt;sub&gt;c&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>k&lt;sub&gt;50&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT, W&lt;sub&gt;f&lt;/sub&gt;</td>
<td>13.8%</td>
<td>13.4%</td>
<td>13.9%</td>
</tr>
<tr>
<td>VOID RATIO, ε&lt;sub&gt;f&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION, S&lt;sub&gt;f&lt;/sub&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>σ</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>T&lt;sub&gt;max&lt;/sub&gt;</td>
<td>0.67</td>
<td>1.25</td>
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<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>t&lt;sub&gt;f&lt;/sub&gt;</td>
<td>1020</td>
<td>750</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td></td>
<td>0.0039</td>
<td>0.0039</td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>T&lt;sub&gt;ult&lt;/sub&gt;</td>
<td></td>
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</tr>
</tbody>
</table>

### Other Information

- **Type of Specimen**: UNDISTURBED
- **Classification**: SILTY SAND (SM), BROWN
- **Project**: DIKE STABILITY
- **Area**: ROCKY MOUNTAIN ARSENAL
- **Remarks**:
- **Boring No.**: 484-U
- **Sample No.**: 5
- **Depth**: 11.1-12.2
- **Date**: 06 APR 78
- **RCH**: DIRECT SHEAR TEST REPORT
**DIRECT SHEAR TEST REPORT**

**PROJECT**

**ROCKY MOUNTAIN ARSENAL**

**CLASSIFICATION**

**CLAYEY SAND (SC), BROWN**

**TYPE OF SPECIMEN**

**CONTROLLED STRAIN**

**UNDISTURBED**

<table>
<thead>
<tr>
<th>REMARKS</th>
<th>TYPE OF STRAIN</th>
<th>EOT</th>
<th>STRAIN</th>
<th>TYPICAL</th>
<th>NORMAL STRESS</th>
<th>MAXIMUM STRESS</th>
<th>RATE OF STRAIN</th>
<th>SATURATION</th>
<th>VOID RATIO</th>
<th>CONDENSATION PATTERNS</th>
<th>CONDENSATION TIME</th>
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<tbody>
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<td></td>
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<td></td>
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</tbody>
</table>

**TIME FOR CONDENSATION**

**FINAL**

**WATER CONTENT**

**INITIAL**

**VOID RATIO**

**SATURATION**

**DRY DENSITY**

**WATER CONTENT**

**TEST NO.**

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>MAXIMUM STRESS</th>
<th>RATE OF STRAIN</th>
<th>VOID RATIO</th>
<th>SATURATION</th>
<th>WATER CONTENT</th>
<th>TIME FOR 20 FEET CONDENSATION</th>
<th>INITIAL</th>
<th>FINAL</th>
<th>VOID RATIO</th>
<th>SATURATION</th>
<th>DRY DENSITY</th>
<th>WATER CONTENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|          |                |               |            |            |               |                               |         |       |            |            |             |               |
|          |                |               |            |            |               |                               |         |       |            |            |             |               |
|          |                |               |            |            |               |                               |         |       |            |            |             |               |

**NORMAL STRESS, σ, T/SQ FT**

**SHEAR STRESS, τ, T/SQ FT**

**VERTICAL DEFORMATION, IN. X 10^-3**
**CONTROLLED-STRAIN TEST**

**DESCRIPTION OF SPECIMENS:** CLAYEY SAND (SC), TAN: SAND IN

**UNUSED PORTIONS OF SAMPLE**

**SAMPLES:**
- LL 44
- PL 16
- PI 29
- CS 2.74

**UNDISTURBED SPECIMEN**

**Q TEST**

**REMARKS:**
- PROJECT DIKE STABILITY
- ROCKY MOUNTAIN ARSENAL

**BORING NO.** 484-U
- SAMPLE NO. 7

**DEPTH/ELEV** 16.1-16.9
- TECH. CR

**LABORATORY USE: WES**
- DATE: 29 MAR 78

**TRIAXIAL COMPRESSION TEST REPORT**

*Figure 67*
### Controlled-Strain Test

**Description of Specimens:** Sandy Clay (CL)

**Light Brown**

<table>
<thead>
<tr>
<th>LL 32</th>
<th>PL 15</th>
<th>PI 17</th>
<th>CS 2.72</th>
<th>Undisturbed Specimen</th>
<th>Q Test</th>
</tr>
</thead>
</table>

**Remarks:**

- Project: Dike Stability
- Location: Rocky Mountain Arsenal
- Boring No.: 484-U
- Sample No.: 8
- Depth/Elevation: 20.0-21.1
- Laboratory: USAE WES
- Date: 20 Mar 70

### Graphs

1. **Shear Stress vs. Normal Stress:**
   - **C = T/sf**
   - **ϕ = Deg**
   - **Trn ϕ =

2. **Deviator Stress vs. Axial Strain:**
   - **Specimen No.:**
     - Δ1 17.7 19.3 17.9
     - Δ2 95.2 93.5 97.6
     - Δ3 61.4 64.3 65.8
     - Δ4 0.784 0.816 0.740
   - **Water Content (%):**
     - Initial 17.7 19.3 17.9
     - Back Pres. 95.2 93.5 97.6
     - Min Prin. Stress 0.5 1.5 3.0
     - Max Dev. Stress 1.87 2.89 4.02
     - Time to Failure 37 19 39
     - Rate of Strain Incr. %
       - Initial Diameter 1.39 1.39 1.40
       - Initial Height 3.00 3.00 3.00

**Figure 68**
DESCRIPTION OF SPECIMENS: CLAYEY SAND (SC).

CONTROLLED-STRAIN TEST

LIGHT BROWN

LL 24 PL 12 PI 12 OS 2-72 UNDISTURBED SPECIMEN Q TEST

REMARKS:

PROJECT DIKE STABILITY

ROCKY MOUNTAIN ARSENAL

BORING NO. 484-U SAMPLE NO. 9

DEPTH/ELEV 21.1-22.2 TECH. JAL

LABORATORY USAE WES DATE 29 MAR 78

TRIAXIAL COMPRESSION TEST REPORT

Figure 69
SPECIMEN NO. | Δ1 | γ2 | X3 | 4
---|---|---|---|---
WATER CONTENT, % | 14.8 | 15.0 | 13.1 | 13.1
DRY DENSITY, PCF | 114.1 | 112.1 | 116.4 | 116.4
SATURATION, % | 81.8 | 78.7 | 77.1 | 77.1
VOID RATIO | 0.494 | 0.520 | 0.464 | 0.464
WATER CONTENT, % | | | | |
DRY DENSITY, PCF | | | | |
SATURATION, % | | | | |
VOID RATIO | | | | |
BACK PRESS., TSF | | | | |
MIN PRIN. STRESS, TSF | 0.5 | 1.5 | 3.0 | 3.0
MAX. DEV. STRESS, TSF | 1.52 | 1.52 | 2.26 | 2.26
TIME TO FAILURE, MIN. | 46 | 45 | 36 | 36
RATE OF STRAIN INCR., % | | | | |
INITIAL DIAMETER, IN. | 1.39 | 1.40 | 1.39 | 1.39
INITIAL HEIGHT, IN. | 3.00 | 3.00 | 3.00 | 3.00

DESCRIPTION OF SPECIMENS: CLAYEY SAND (SC), LIGHT BROWN

LL 30 | PL 13 | P1 17 | G0 2.73 | UNDISTURBED SPECIMEN | O TEST

REMARKS:
PROJECT DIKE STABILITY
ROCKY MOUNTAIN ARSENAL
BORING NO. 484-U | SAMPLE NO. 10
DEPTH/ELEV 25.0-26.0 | TECH. RE
LABORATORY USDA WES | DATE 29 MAR 78
TRIAXIAL COMPRESSION TEST REPORT

Figure 70
**Description of Specimens:** Sandy clay (CL), brown, with small gypsum or carbonate lenses

**Project:** Dike Stability

**Rocky Mountain Arsenal**

**Boiling No.:** 484-U

**Sample No.:** 11

**Depth/Elev.:** 26.0-27.0

**Tech. Ref.:** LABORATORY USAE WES

**Date:** 30 Mar 78

**Triaxial Compression Test Report**

---

**Figure 71**
HORIZ. DEFORMATION, IN.

SHEAR STRENGTH PARAMETERS

\[ \phi' = \text{______} \]

\[ \tan \phi' = \text{______} \]

\[ \sigma' = \text{______} \text{ T/SQ FT} \]

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT, ( w )</td>
<td>10.1%</td>
<td>9.4%</td>
<td>9.1%</td>
</tr>
<tr>
<td>VOID RATIO, ( e_0 )</td>
<td>0.587</td>
<td>0.575</td>
<td>0.574</td>
</tr>
<tr>
<td>SATURATION, ( S_d )</td>
<td>46.5%</td>
<td>44.1%</td>
<td>19.3%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>106.2</td>
<td>107.0</td>
<td>107.1</td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION, ( e_r )</td>
<td>( \text{______} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>( t_{50} )</td>
<td>( \text{______} )</td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT, ( w_f )</td>
<td>15.4%</td>
<td>15.5%</td>
<td>14.5%</td>
</tr>
<tr>
<td>VOID RATIO, ( e_f )</td>
<td>( \text{______} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION, ( S_f )</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>( \sigma )</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{max} )</td>
<td>0.72</td>
<td>1.42</td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>( t_f )</td>
<td>420</td>
<td>1230</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td>( \text{______} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{ult} )</td>
<td>( \text{______} )</td>
<td></td>
</tr>
</tbody>
</table>

TYPE OF SPECIMEN UNDISTURBED

CLASSIFICATION SILTY SAND (SM), BROWN

\[ \text{LL} = 19 \quad \text{PL} = 15 \]

\[ \pi = 4 \quad G_s = 2.70 \]

REMARKS

PROJECT DIKE STABILITY

AREA ROCKY MOUNTAIN ARSENAL

BOREHOLE NO. 485-U

SAMPLE NO. 1

DEPTH 0.0-1.3

DATE 07 APR 78

DIRECT SHEAR TEST REPORT
<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT</td>
<td>W&lt;sub&gt;o&lt;/sub&gt;</td>
<td>8.8%</td>
<td>9.8%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>e&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.467</td>
<td>0.467</td>
</tr>
<tr>
<td>SATURATION</td>
<td>S&lt;sub&gt;o&lt;/sub&gt;</td>
<td>50.9%</td>
<td>56.6%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>Y&lt;sub&gt;d&lt;/sub&gt;</td>
<td>114.9</td>
<td>114.9</td>
</tr>
<tr>
<td>VOID RATIO AFTER CONSOLIDATION</td>
<td>e&lt;sub&gt;c&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIME FOR 50 PERCENT CONSOLIDATION, MIN</td>
<td>t&lt;sub&gt;50&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER CONTENT</td>
<td>W&lt;sub&gt;f&lt;/sub&gt;</td>
<td>14.3%</td>
<td>14.8%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>e&lt;sub&gt;f&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SATURATION</td>
<td>S&lt;sub&gt;f&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>σ</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>τ&lt;sub&gt;max&lt;/sub&gt;</td>
<td>0.73</td>
<td>1.51</td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>t&lt;sub&gt;f&lt;/sub&gt;</td>
<td>870</td>
<td>660</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td>τ&lt;sub&gt;ult&lt;/sub&gt;</td>
<td>0.0038</td>
<td>0.0038</td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>τ&lt;sub&gt;ult&lt;/sub&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TYPE OF SPECIMEN:** UNDISTURBED

**CLASSIFICATION:** SILTY SAND (SM), BROWN

<table>
<thead>
<tr>
<th>LL</th>
<th>18</th>
<th>PL</th>
<th>14</th>
<th>PI</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>G&lt;sub&gt;s&lt;/sub&gt;</td>
<td>2.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**REMARKS**

**PROJECT:** DIKE STABILITY

**AREA:** ROCKY MOUNTAIN ARSENAL

**BORING NO.:** 485-U

**SAMPLE NO.:**

**DEPTH:** 5.0-6.0

**DATE:** 08 APR 78
### Shear Strength Parameters

- $\phi' = $ ____________
- $\tan \phi' = $ ____________
- $\epsilon' = $ ____________/T/SQ FT

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content, $w_i$</td>
<td>13.0%</td>
<td>12.9%</td>
<td>13.0%</td>
</tr>
<tr>
<td>Void Ratio, $e$</td>
<td>0.497</td>
<td>0.500</td>
<td>0.504</td>
</tr>
<tr>
<td>Saturation, $S_i$</td>
<td>70.6%</td>
<td>70.0%</td>
<td>69.6%</td>
</tr>
<tr>
<td>Dry Density, LB/CT FT</td>
<td>$\gamma_d$</td>
<td>112.6</td>
<td>112.3</td>
</tr>
<tr>
<td>Void Ratio After Consolidation, $e_r$</td>
<td>$t_{50}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, Min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content, $w_i$</td>
<td>14.9%</td>
<td>14.6%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Void Ratio, $e_r$</td>
<td>$t_r$</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Saturation, $S_r$</td>
<td>$t_{ult}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Stress, T/SQ FT</td>
<td>$\sigma$</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/SQ FT</td>
<td>$\tau_{max}$</td>
<td>0.70</td>
<td>1.38</td>
</tr>
<tr>
<td>Actual Time to Failure, Min</td>
<td>$t_r$</td>
<td>1050</td>
<td>630</td>
</tr>
<tr>
<td>Rate of Strain, IN./MIN</td>
<td>$\epsilon_r$</td>
<td>0.000140</td>
<td>0.000140</td>
</tr>
<tr>
<td>Ultimate Shear Stress, T/SQ FT</td>
<td>$\tau_{ult}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Geotechnical Properties

- **Type of Specimen**: UNDISTURBED
- **Classification**: SILTY SAND (SM), BROWN
- **LL**: 20
- **PL**: 16
- **PI**: 4
- **Gs**: 2.70
- **Project**: DIKE STABILITY
- **Area**: ROCKY MOUNTAIN ARSENAL
- **Boring No.**: 485-U
- **Sample No.**: 3
- **Date**: 09 APR 78
- **Depth (FL)**: 6.0-7.0
- **RCH**: DIRECT SHEAR TEST REPORT

---

*Figure 74*
## Shear Strength Parameters

<table>
<thead>
<tr>
<th>Water Content (Wc)</th>
<th>6.1%</th>
<th>7.0%</th>
<th>7.1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void Ratio (e0)</td>
<td>0.694</td>
<td>0.697</td>
<td>0.706</td>
</tr>
<tr>
<td>Saturation (S0)</td>
<td>23.7%</td>
<td>27.1%</td>
<td>27.2%</td>
</tr>
<tr>
<td>Dry Density (γd)</td>
<td>99.5</td>
<td>99.3</td>
<td>98.8</td>
</tr>
<tr>
<td>Void Ratio (eC)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50% Consolidation (t50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Content (Wf)</td>
<td>14.7%</td>
<td>14.7%</td>
<td>14.1%</td>
</tr>
<tr>
<td>Void Ratio (e1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation (Sf)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Stress (σ)</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Maximum Shear Stress (τmax)</td>
<td>0.56</td>
<td>1.36</td>
<td>1.87</td>
</tr>
<tr>
<td>Actual Time to Failure (tf)</td>
<td>1230</td>
<td>1200</td>
<td>960</td>
</tr>
<tr>
<td>Rate of Strain (in./min)</td>
<td>0.0036</td>
<td>0.0036</td>
<td>0.0036</td>
</tr>
<tr>
<td>Ultimate Shear Stress (τult)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Type of Specimen

- **Undisturbed**

- **Silty Sand (SM), Brown**

- **LL**: 19
- **PL**: 16
- **PI**: 2
- **G**: 2.70

### Project

- **Dike Stability**
- **Rocky Mountain Arsenal**

### Area

- **Boring No.**: 485-U
- **Sample No.**: 1
- **Depth EL**: 10.0 - 11.0
- **Date**: 12 Apr 78

---

**Direct Shear Test Report**

---

**Figure 75**
### Shear Strength Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>( w_0 )</td>
<td>( w_f )</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>( e_0 )</td>
<td>( e_f )</td>
</tr>
<tr>
<td>Saturation</td>
<td>( S_0 )</td>
<td>( S_f )</td>
</tr>
<tr>
<td>DRY DENSITY, LB/FT^3</td>
<td>( \gamma_s )</td>
<td>( \gamma_s )</td>
</tr>
</tbody>
</table>

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT</td>
<td>( w_0 )</td>
<td>7.3%</td>
<td>7.1%</td>
</tr>
<tr>
<td>VOID RATIO</td>
<td>( e_0 )</td>
<td>0.630</td>
<td>0.614</td>
</tr>
<tr>
<td>SATURATION</td>
<td>( S_0 )</td>
<td>31.2%</td>
<td>31.2%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/CU FT</td>
<td>( \gamma_s )</td>
<td>103.4</td>
<td>104.4</td>
</tr>
</tbody>
</table>

### Type of Specimen
- **UNDISTURBED**

### Classification
- **SILTY SAND (SM), RED**

### Project Details
- **DIKE STABILITY**
- **ROCKY MOUNTAIN ARSENAL**

### Remarks

### Table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORMAL STRESS, T/SQ FT</td>
<td>( \sigma )</td>
</tr>
<tr>
<td>MAXIMUM SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{max} )</td>
</tr>
<tr>
<td>ACTUAL TIME TO FAILURE, MIN</td>
<td>( t_f )</td>
</tr>
<tr>
<td>RATE OF STRAIN, IN./MIN</td>
<td>( \epsilon )</td>
</tr>
<tr>
<td>ULTIMATE SHEAR STRESS, T/SQ FT</td>
<td>( \tau_{ult} )</td>
</tr>
</tbody>
</table>

### Dimensions
- **Type of Specimen:** 3.00 IN. SQUARE
- **Thickness:** 0.584 IN.

### Additional Details
- **BOREHOLE NO.:** 485-U
- **Sample No.:** 5
- **Depth:** 11.0-12.0 FT
- **Date:** 11 APR 78

**Figure 76**
SHEAR STRENGTH PARAMETERS

$\phi' = \quad \tan \phi' = \quad c' = \quad T/\text{SQ FT}$

CONTROLLED STRESS
CONTROLLED STRAIN

TEST NO. | 1 | 2 | 3
---|---|---|---
WATER CONTENT $w_s$ | 7.7% | 7.6% | 7.8% |
VOID RATIO $e_0$ | 0.614 | 0.611 | 0.625 |
SATURATION $S_o$ | 33.8% | 33.6% | 33.7% |
DRY DENSITY, LB/CU FT $\gamma_d$ | 104.4 | 104.6 | 103.7 |
VOID RATIO AFTER CONSOLIDATION $e_c$ |
TIME FOR 50 PERCENT CONSOLIDATION, MIN $t_{50}$ |
WATER CONTENT $w_f$ | 17.4% | 15.2% | 15.6% |
VOID RATIO $e_f$ |
SATURATION $S_f$ | % | % | % |
NORMAL STRESS, T/SQ FT $\sigma$ | 1.0 | 2.0 | 3.0 |
MAXIMUM SHEAR STRESS, T/SQ FT $\tau_{\text{max}}$ | 0.64 | 1.37 | 2.04 |
ACTUAL TIME TO FAILURE, MIN $t_r$ | 630 | 870 | 1140 |
RATE OF STRAIN, IN./MIN $e_{\text{ult}}$ | 0.00037 | 0.00037 | 0.00037 |
ULTIMATE SHEAR STRENGTH, T/SQ FT $\tau_{\text{ult}}$ |

TYPE OF SPECIMEN | UNDISTURBED
CLASSIFICATION | SILT SAND (SM), BROWN

LL | 21 | PL | 17 | PI | 4 | Gs | 2.70

PROJECT | DIKE STABILITY
ROCKY MOUNTAIN ARSENAL

AREA

BOREING NO. | 485-U | SAMPLE NO. | 6
DEPTH EL | 15.7-17.0 | DATE | 12 APR 78
RCH

DIRECT SHEAR TEST REPORT
**Shear Strength Parameters**

\[ \sigma' = \ \tan \phi' = \ \sigma' \text{ T/SQ FT} \]

<table>
<thead>
<tr>
<th>Test No.</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content ( w_0 )</td>
<td>17.1%</td>
<td>17.3%</td>
<td>17.9%</td>
</tr>
<tr>
<td>Void Ratio ( e_0 )</td>
<td>0.752</td>
<td>0.706</td>
<td>0.743</td>
</tr>
<tr>
<td>Saturation ( S_0 )</td>
<td>62.1%</td>
<td>66.9%</td>
<td>65.7%</td>
</tr>
<tr>
<td>Dry Density, LB/CU FT ( \gamma_d )</td>
<td>97.3</td>
<td>99.9</td>
<td>97.8</td>
</tr>
<tr>
<td>Void Ratio After Consolidation ( e_c )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, Min ( t_{50} )</td>
<td>10</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Initial Water Content ( w_i )</td>
<td>24.3%</td>
<td>23.6%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Void Ratio ( e_i )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturation ( S_i )</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Normal Stress, T/SQ FT ( \sigma )</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/SQ FT ( \tau_{max} )</td>
<td>0.65</td>
<td>1.30</td>
<td>1.64</td>
</tr>
<tr>
<td>Actual Time to Failure, Min ( t_f )</td>
<td>1890</td>
<td>1260</td>
<td>1170</td>
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<td>Rate of Strain, IN./MIN</td>
<td>0.0016</td>
<td>0.0016</td>
<td>0.0016</td>
</tr>
</tbody>
</table>

**Type of Specimen**
- Undisturbed

**Classification**
- Sandy Silty Clay (CL), Tan and Red Marbled

**Remarks**

**Project**
- Dike Stability

**Rocky Mountain Arsenal**

**Boring No.**
- 485-U

**Sample No.**
- 7

**Depth**
- 20.35-21.6

**Date**
- 12 Apr 78
### Shear Strength Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>$w_o$</td>
<td>$w_f$</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>$e_o$</td>
<td>$e_f$</td>
</tr>
<tr>
<td>Saturation</td>
<td>$S_o$</td>
<td>$S_f$</td>
</tr>
<tr>
<td>DRY DENSITY, LB/FT$^3$</td>
<td>$\gamma_d$</td>
<td>%</td>
</tr>
<tr>
<td>Void Ratio After Consolidation</td>
<td>$e_c$</td>
<td>%</td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, MIN</td>
<td>$t_{50}$</td>
<td>%</td>
</tr>
<tr>
<td>Normal Stress, T/FT$^2$</td>
<td>$\sigma$</td>
<td>%</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/FT$^2$</td>
<td>$\tau_{\text{max}}$</td>
<td>%</td>
</tr>
<tr>
<td>Actual Time to Failure, MIN</td>
<td>$t_f$</td>
<td>%</td>
</tr>
<tr>
<td>Rate of Strain, IN/IN</td>
<td>$\varepsilon_{\text{ult}}$</td>
<td>%</td>
</tr>
</tbody>
</table>

### Test Results

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content</td>
<td>$w_o$</td>
<td>16.4%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>$e_o$</td>
<td>0.561</td>
<td>0.564</td>
</tr>
<tr>
<td>Saturation</td>
<td>$S_o$</td>
<td>79.5%</td>
<td>80.5%</td>
</tr>
<tr>
<td>DRY DENSITY, LB/FT$^3$</td>
<td>$\gamma_d$</td>
<td>108.8</td>
<td>108.6</td>
</tr>
<tr>
<td>Void Ratio After Consolidation</td>
<td>$e_c$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time for 50 Percent Consolidation, MIN</td>
<td>$t_{50}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal Stress, T/FT$^2$</td>
<td>$\sigma$</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Maximum Shear Stress, T/FT$^2$</td>
<td>$\tau_{\text{max}}$</td>
<td>0.69</td>
<td>1.39</td>
</tr>
<tr>
<td>Actual Time to Failure, MIN</td>
<td>$t_f$</td>
<td>1080</td>
<td>1080</td>
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<tr>
<td>Rate of Strain, IN/IN</td>
<td>$\varepsilon_{\text{ult}}$</td>
<td>00031</td>
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</table>

### Type of Specimen
- **Undisturbed**

### Classification
- **Clayey Sandy Gravel (GC), Brown**

### LL | FL | PI | FI | G' | 2.72
---|---|---|---|---|---
36 | 14 | 22 | | | 

### Remarks

### Project
- **Dike Stability**
- **Rocky Mountain Arsenal**

### Direct Shear Test Report
- **Boring No.**: 485-U
- **Sample No.**: 8
- **Date**: 13 APR 78
<table>
<thead>
<tr>
<th>ARC CENTER (x, y)</th>
<th>SAFETY FACTOR (w/ EARTHQUAKE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15.0, 5210</td>
<td>6.30</td>
</tr>
<tr>
<td>-15.0, 5215</td>
<td>6.21*</td>
</tr>
<tr>
<td>-15.0, 5220</td>
<td>6.44</td>
</tr>
<tr>
<td>-20.0, 5220</td>
<td>7.42</td>
</tr>
<tr>
<td>-20.0, 5225</td>
<td>7.07</td>
</tr>
<tr>
<td>-10.0, 5215</td>
<td>6.91</td>
</tr>
<tr>
<td>-17.5, 5209</td>
<td>-</td>
</tr>
<tr>
<td>-12.5, 5207.5</td>
<td>-</td>
</tr>
<tr>
<td>-15.0, 5207.5</td>
<td>-</td>
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<tr>
<td>-12.5, 5210</td>
<td>-</td>
</tr>
<tr>
<td>-12.5, 5210</td>
<td>-</td>
</tr>
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</table>

*MINIMUM

Note: Q TEST and S TEST values are provided for different coordinates, with some values marked as asterisks to indicate minimum conditions.
**SAFETY FACTOR (w/ EARTHQUAKE)**

<table>
<thead>
<tr>
<th>ARC CENTER (X, Y)</th>
<th>Q TEST</th>
<th>S TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20.0, 5212.5</td>
<td>8.60</td>
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<td>-17.5, 5212.5</td>
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<td>1.00</td>
</tr>
<tr>
<td>-20.0, 5217.5</td>
<td>7.11</td>
<td>0.90</td>
</tr>
<tr>
<td>-12.5, 5210.0</td>
<td>5.10</td>
<td>-</td>
</tr>
<tr>
<td>-12.5, 5212.5</td>
<td>5.09*</td>
<td>-</td>
</tr>
<tr>
<td>-12.5, 5215.0</td>
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<td>-10.0, 5212.5</td>
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*MINIMUM
SELECTED MEASURED SOIL PARAMETERS

<table>
<thead>
<tr>
<th>SOIL</th>
<th>DENSITY, PCF</th>
<th>Q TEST</th>
<th>S TEST</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>132</td>
<td>30</td>
<td>900</td>
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<tr>
<td>2</td>
<td>115</td>
<td>15</td>
<td>840</td>
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</table>
### SAFETY FACTOR (W/ EARTHQUAKE)

<table>
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<tr>
<th>ARC CENTER (X, Y)</th>
<th>Q TEST</th>
<th>S TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>-17.5, 5207.5</td>
<td>-</td>
<td>3.12</td>
</tr>
<tr>
<td>-15.0, 5207.5</td>
<td>-</td>
<td>1.11*</td>
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<tr>
<td>-12.5, 5207.5</td>
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<td>1.31</td>
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<tr>
<td>-15.0, 5205.0</td>
<td>-</td>
<td>1.15</td>
</tr>
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<td>-15.0, 5210.0</td>
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*MINIMUM
### SELECTED MEASURED SOIL PARAMETERS

<table>
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<th>DENSITY, PCF</th>
<th>Ø TEST</th>
<th>S TEST</th>
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<td></td>
<td></td>
<td>Ø</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>132</td>
<td>31.3</td>
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</tr>
<tr>
<td>2</td>
<td>115</td>
<td>15.0</td>
<td>840</td>
</tr>
</tbody>
</table>

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO
The image shows a graph with Elevation in feet M.S.L. on the y-axis and Downstream distance on the x-axis. There are three curves on the graph, each labeled with different safety factors:

- FS = 0.73 for S Strength
- FS = 4.43 for Q Strength

A table is also present with the following data:

<table>
<thead>
<tr>
<th>ARC CENTER (X, Y)</th>
<th>Q TEST</th>
<th>S TEST</th>
</tr>
</thead>
<tbody>
<tr>
<td>-22.5, 5205.0</td>
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<td>0.83*</td>
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<tr>
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<td>0.86</td>
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<td>0.89</td>
</tr>
<tr>
<td>-20.0, 5200.0</td>
<td>-</td>
<td>0.84</td>
</tr>
<tr>
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<td>-</td>
<td>0.88</td>
</tr>
<tr>
<td>17.5, 5217.5</td>
<td>4.61</td>
<td>-</td>
</tr>
<tr>
<td>15.0, 5217.5</td>
<td>4.43*</td>
<td>-</td>
</tr>
<tr>
<td>12.5, 5217.5</td>
<td>4.59</td>
<td>-</td>
</tr>
<tr>
<td>15.0, 5215.0</td>
<td>4.44</td>
<td>-</td>
</tr>
<tr>
<td>15.0, 5220.0</td>
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</table>

The *MINIMUM values are highlighted in the table.
OM BORING

<table>
<thead>
<tr>
<th>SOIL</th>
<th>DENSITY, PCF</th>
<th>Q TEST</th>
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</thead>
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<td>1</td>
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<td>31.3</td>
</tr>
<tr>
<td>2</td>
<td>115</td>
<td>15.0</td>
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</tbody>
</table>

\( \narrow \) HW 5199.5

\( \narrow \) GW = 5184.5

EL 5185

IL #1

IL #2
### SELECTED MEASURED SOIL PARAMETERS

<table>
<thead>
<tr>
<th>SOIL</th>
<th>DENSITY, PCF</th>
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\[ \Delta \text{GW} = 5184.5 \]

DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

[Image of page with measurements and soil parameters]
CALCULATED FACTOR OF SAFETY

COHESION PARAMETER, C (KSF)

NOTE:
\[ \phi = 32^\circ \]
SEISMIC COEFFICIENT = 0.05

BORING 482

COHESION SENSITIVITY
DIKE STABILITY ANALYSIS
BASIN F
ROCKY MOUNTAIN ARSENAL
DENVER, COLORADO

Figure 84
<table>
<thead>
<tr>
<th>Boring</th>
<th>Shear Strength Source</th>
<th>Minimum Safety Factors</th>
<th>Upstream Slope</th>
<th>Downstream Slope</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Q-test</td>
<td>Q-test</td>
</tr>
<tr>
<td>482</td>
<td>Estimated</td>
<td>1.87</td>
<td>-</td>
<td>0.87</td>
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<tr>
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<td>Measured</td>
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<tr>
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<tr>
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<td>-</td>
<td>1.25</td>
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<tr>
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<td>0.93</td>
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<td>Measured</td>
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<td>4.43*</td>
</tr>
</tbody>
</table>

* seismic coefficient = 0.05
Pool Elevation vs Factor of Safety
Dike Stability Analysis
Basin F
Rocky Mountain Arsenal
Denver, Colorado