FEMA Urban Search & Rescue Response System / USACE StS Program
StS Training - Summary of Raker and Picket Testing 2000 to 2010

FEMA US&R Response Sys/U.S. Army Corps of Engineers
US&R Structure Specialist Training

Raker Tests
Oct99 Grand Opening
Sep04, Mar & Nov05, May06-10 - StS2

Picket Tests
Sep04, Mar & Nov05, May06-10 - StS2

CA-TF-3 Raker Breaker
CA-TF-3 Raker Breaker Test
Test Ended at 13000lb - Picket Deflection
(17k in Raker)

CA-TF-3 Structure Specialists
Raker System Tests

StS2 Training 15Sep04
(Dry Conditions)

Sep04 Raker Tests

- Total of 4 Raker Pairs Test
  - Rak-11 thru Rak-14
  - Design Load for Raker Pair is 5k
- Load applied at 9.8 ft above Wall Hinge
  - Raker Insertion at 7.9 ft above Wall Hinge
  - Multiplier of Load = 9.8/7.9 = abt 1.25
- Ram Load was 20k max for all tests
  - Horiz Load on Raker Pair was 25k
- Rak-11 thru 13 did not fail, observed deflection
- Rak-14 was forced to fail at 22k
  - The 17-16d nails in Sole Cleat were reduced to only 6
  In order to induce failure
Sole Cleat lifts just prior to Failure
All but 6-16d in ea cleat were removed
to allow failure at 25k for pair

Sole Cleat was Projected-off
Load= 25k for pair
Sep2004 Raker Test Summary

- Design of Cleat is based on Frictionless Load Transfer
- Tests indicate that there is Significant amount of Friction Transfer
- Should Design Load be increased?
  - What is the Weakest Link in the system?
Raker System Tests
StS2 Training 22Mar05
(very wet conditions)

Mar05 Raker Tests

• Total of 3 Raker Pairs Test
  – Rak-21 thur Rak-23 (wood rakers) Rak-24 = Paratech
  – Rak-21 & 22 used Hem-Fir Cleats
  – Design Load = 5k per Raker Pair
• Load applied at 9.8 ft above Wall Hinge
  – Raker Insertion at 7.9 ft above Wall Hinge
  – Multiplier of Load = 9.8/7.9 = abt 1.25
• Ram Load was 20k for tests
  – Horiz Load on Raker Pair was 25k
• Rak-21 did not fail, observed deflection
• Rak-22 failed using 8-16d in Sole Cleat
• Rak-23 failed, using 6-16d in Sole Cleat
• Rak-24 (Paratech) no failure, even w/o bracing
Raker/Picket Tests 15

Rak-22 Setup

- Hem Fir Cleats
  - 8-16d nails to Sole
- Very wet wood
  - out in rain 60 days
- Cleat slipped – did not Fly-off, Load = 25k

Raker/Picket Tests 16

Rak-22 Nail Slip Failure
Rak-23 Setup

- Doug Fir Cleats, Very wet wood
- Cleats did Fly-off, Load = 25k
  - Reduce Cleat nails to 6-16d
  - After support was added under Raker/Sole intersection

Rak-23 Fly-off Failure
Rak-24 Setup

- Paratech Strut Sys w/mid-brace
- No failure at 25k in Raker
  - Initial test w/mid brace & lateral bracing
  - Remove lateral bracing w/ no failure except small bow in strut.

Rak-24 w/o bracing
Only slight bowing at 25k
Raker System Tests
StS2 Training 7Nov05
(had rained previously)

Nov05 Raker Tests
• Total of 4 Raker Pairs Tested
  – Rak-31 thur Rak-33, Wood, Solid Sole Rakers
  – Rak-34, Airshore
  – Design Load = 5k per Raker Pair
• Load applied at 9.8 ft above Wall Hinge
  – Raker insertion at 7.9 ft above Wall Hinge
  – Multiplier of Load = 9.8/7.9 = abt 1.25
• Ram Load
  – 24k for Rak-31 & 32, Horiz Load on Rakers = 30k
  – 18k for Rak-33, Horiz Load on Raker = 22k
• Rak-31 & 32 did not fail, observed deflection
• Rak-33 failed, using 6-16d in Sole Cleat
• Rak-34, mid-brace connection failed at 12k
Airshore Raker

After mid-brace failure

Raker/Picket Tests 25

Raker System Tests
StS2 Training 25May06
It was a wet spring & wood was very “Green”
May06 Raker Tests

- Total of 4 Raker Pairs Tested (5K/Pr Design Load)
  - Rak-41 & Rak-44, Wood, Solid Sole Rakers, Tested w/o Mid Brace
  - Rak-42 & Rak-43, Wood, Split Sole Rakers using Trough Base, Tested w/o Mid Brace
- Load applied at 9.8 ft above Wall Hinge
  - Raker Insertion at 7.9 ft above Wall Hinge
  - Multiplier of Load = 9.8/7.9 = abt 1.25
- Ram Load
  - 24k Max for All, Horiz Load on Rakers = 30k
- All did not fail, just observed deflection
  - Rak-41 was forced to fail with only 6-nails in Sole Cleat
  - Rak-42 & 43 had failure in Bottom of Trough due to Soft Soil at base of Right Side Raker
May07 Raker Tests

- Total of 4 Raker Pairs Tested (5K/Pr Design Load)
  - Rak-51 Wood, Solid Sole Rakers, w/o Mid Brace
  - Rak-52 Wood, Solid Sole Rakers, w/special conn
  - Rak-53 & Rak-54, Wood, Split Sole Rakers using Trough Base w/ 18”sq foot w/o Mid Brace
- Load applied at 9.8 ft above Wall Hinge
  - Raker Insertion at 7.9 ft above Wall Hinge
  - Multiplier of Load = 9.8/7.9 = abt 1.25
- Ram Load
  - 24k Max for Rak-51, 53, 54, 30k Horiz Load on Rakers
  - 10k for Rak-52 – connector failed at rod to base
- Only Rak-52 failed due to poor metal connector
  - Rak-51 was forced to fail with only 6-nails in Sole Cleat
  - Rak-53, performed well w/ 18”sq. foot under Trough
  - Rak-54, failed Trough w/o 18”sq Foot
**May 2007 Rakers –Rak-51**

Std Solid Sole Cleat W/18”sq. Foot
Slipped 1/2” at 30k

Before

After

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**May 2007 Rakers –Rak-54**

Standard Split Sole setup
May 2007 Rakers

Split Sole Rakers

Rak-53 w/ 18” sq Foot

Rak-54 w/o 18” sq Foot

May 08 Raker Tests

• Total of 3 Raker Pairs Tested (5K/Pr Design Load)
  – Rak-61 Wood, Solid Sole Rakers, w/o Mid Brace
    Trough Base w/ and w/o 18” sq foot w/o Mid Brace

• Load applied at 9.8 ft above Wall Hinge
  – Raker Insertion at 7.9 ft above Wall Hinge
  – Multiplier of Load = 9.8/7.9 = abt 1.25

• Ram Load
  – 24k Max for Rak-61, 62, 63, 30k Horiz Load on Rakers

• Only Rak-63 failed as post buckled (knots)
May09 Raker Tests

- Total of 3 Raker Pairs Tested (5K/Pr Design Load)
  - Rak-71 & 72 Wood, Solid Sole Rakers, w/o Mid Brace
  - Rak-73 Wood, Split Sole Rakers using Trough Base w/ and w/o 18”sq foot w/o Mid Brace
- Load applied at 9.8 ft above Wall Hinge
  - Raker Insertion at 7.9 ft above Wall Hinge
  - Multiplier of Load = 9.8/7.9 = abt 1.25
- Ram Load
  - 24k Max for Rak-72, 73a, 73b, 30k Horiz Load on Rakers
  - 20k for Rak-71, 25k horiz
- Results
  - Rak-71: sole cracked & post buckled at 20k ram
  - Rak-72: no failure, w/ foot under sole at raker
  - Rak-73a & 73b: no failure, w/ or w/o foot – hard ground

May10 Raker Tests

- Total of 3 Raker Pairs Tested (5K/Pr Design Load)
  - Rak-81 & 82 Wood, Solid Sole Rakers, w/o Mid Brace
  - Rak-83 Wood, Split Sole Rakers using Trough Base w/ and w/o 18”sq foot w/o Mid Brace
- Load applied at 9.8 ft above Wall Hinge
  - Raker Insertion at 7.9 ft above Wall Hinge
  - Multiplier of Load = 9.8/7.9 = abt 1.25
- Ram Load
  - 25k Max for Rak-81, 83a, 83b, 30k Horiz Load on Rakers
  - 20k for Rak-72, 25k horiz
- Results
  - Rak-81: no failure & 1/4” cleat slip
  - Rak-82: post split at 20k in ram, 8-16d in cleat = 2” slip
  - Rak-83a & 83b: no failure, w/ or w/o foot – hard ground
### 19 – Solid Sole Raker Tests - Results

<table>
<thead>
<tr>
<th>Raker No.</th>
<th>Cleat Nails</th>
<th>Max Load</th>
<th>Comment – Type of Failure (wood is D.Fir unless noted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rak-1</td>
<td>16</td>
<td>17k</td>
<td>Pickets failed</td>
</tr>
<tr>
<td>Rak-11,12</td>
<td>17</td>
<td>25k</td>
<td>No failure</td>
</tr>
<tr>
<td>Rak-13,14</td>
<td>17</td>
<td>25k</td>
<td>After Full Test, Forced Sole Cleat fly-off</td>
</tr>
<tr>
<td>Rak-21</td>
<td>17</td>
<td>25k</td>
<td>Hem-Fir cleats - No Failure</td>
</tr>
<tr>
<td>Rak-22</td>
<td>17, 8</td>
<td>25k</td>
<td>Hem-Fir cleats – nail slip w/8-16d</td>
</tr>
<tr>
<td>Rak-23</td>
<td>17, 6</td>
<td>25, 23k</td>
<td>After Full Test, Cleat fly-off w/6-16d</td>
</tr>
<tr>
<td>Rak-31,32</td>
<td>17</td>
<td>30k</td>
<td>No failure</td>
</tr>
<tr>
<td>Rak-33</td>
<td>17, 6</td>
<td>30, 22k</td>
<td>After Full Test, Cleat fly-off w/ 6-16d</td>
</tr>
<tr>
<td>Rak-41</td>
<td>14, 6</td>
<td>30, 20k</td>
<td>After Full Test, Cleat fly-off w/6-16d</td>
</tr>
<tr>
<td>Rak-44</td>
<td>14</td>
<td>30k</td>
<td>No Failure</td>
</tr>
<tr>
<td>Rak-51,61</td>
<td>14</td>
<td>30k</td>
<td>No Failure</td>
</tr>
<tr>
<td>Rak-71</td>
<td>14</td>
<td>25K</td>
<td>No Sole Foot, Post Buckled, Sole Split</td>
</tr>
<tr>
<td>Rak-72</td>
<td>14</td>
<td>30K</td>
<td>W/sole foot, No Failure</td>
</tr>
<tr>
<td>Rak-81,82</td>
<td>14</td>
<td>32k</td>
<td>w/o sole foot, post split at 20k for 82</td>
</tr>
</tbody>
</table>

### 10 – Split Sole Raker Tests - Results

<table>
<thead>
<tr>
<th>Raker No.</th>
<th>Cleat Nails</th>
<th>Max Load</th>
<th>Comment – Type of Failure (wood is D.Fir unless noted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rak-42</td>
<td>N/A</td>
<td>30k</td>
<td>Bottom of Right Trough Failed in Soft Soil. Added Foot under to finish test</td>
</tr>
<tr>
<td>Rak-43</td>
<td>30k</td>
<td>Same – Will add fill to Test Area</td>
<td></td>
</tr>
<tr>
<td>Rak-53</td>
<td>30k</td>
<td>Used 18”sq Foot under raker - better</td>
<td></td>
</tr>
<tr>
<td>Rak-54</td>
<td>30k</td>
<td>w/o Foot  Same as Rak-42</td>
<td></td>
</tr>
<tr>
<td>Rak-62</td>
<td>30k</td>
<td>w/o foot, Trough started to fail</td>
<td></td>
</tr>
<tr>
<td>Rak-63</td>
<td>30k</td>
<td>Added foot and buckled raker w/knots</td>
<td></td>
</tr>
<tr>
<td>Rak-73a</td>
<td>30k</td>
<td>w/ Foot, no failure</td>
<td></td>
</tr>
<tr>
<td>Rak-73b</td>
<td>30k</td>
<td>w/o Foot, trough did not fail</td>
<td></td>
</tr>
<tr>
<td>Rak-83a</td>
<td>30k</td>
<td>w/ Foot, trough did not fail</td>
<td></td>
</tr>
<tr>
<td>Rak-83b</td>
<td>34k</td>
<td>w/o Foot, trough did not fail</td>
<td></td>
</tr>
</tbody>
</table>
Raker Test Summary

- A Properly constructed Raker System has Significant reserve strength
- System performance will probably depend on adequacy of Sole Anchorage
- Design Load (5k) should not be increased
  - Difficult to know what is applied force.
  - Rakers may become a significant part of the damaged structure’s Lateral Load Resisting Sys
- Rakers using Pneumatic Struts, Evaluation
  - Paratech Sys appears to perform well
  - Airshore Sys had premature failure of mid-brace connection – needs re-test of modified system

Picket Tests
15Sep04, 22Mar05, 7Nov05, May06-09

Picket Types
1”dia x 48”- 50ksi Yield
5/8” x 36” Screed Pins
1” dia x 42” High-Yield
#8 x 45” Rebar
Summary of Results - Sep04

• In Semi - Compacted Class 2 Base
  – 42” Embed = 1600lb Yield
  – 36” Embed = 1300lb Yield

• In Compacted Select Fill over Bay Mud
  – 42” Embed = 925lb Yield
  – 36” Embed = 765lb Yield

• Yield occurred within 6” of surface
  – 9 Specimen
Summary of Results - Mar05
(very wet conditions)

- In Well compacted Class 2 Base (3 tests)
  - 42” Embed = 2000lb Yield
  - 36” Embed = 2200lb Yield
  - 30” Embed of 5/8” screed pin = 1000lb Yield
- In Semi-compacted Class 2 Base
  - 42” Embed = 2000lb Yield (only one good test)
- In Compacted Select Fill over Bay Mud
  - 30” Embed of 5/8” screed pin = 900lb Yield

Many more tests are needed to establish Reliable Data
Summary of Results - Nov05 (moist soil conditions)

- All in Compacted Select Fill over Bay Mud
  - Four - 1” dia w/42” embed = 1750 to 2500lb to failure by yielding picket within 6” of surface
  - Two – 1” dia w/36” embed = 1750 & 2000lb to failure by yielding picket 3” from surface
  - Two – 5/8” dia w/30” embed
    - One failure by yielding at 1000lb, 3” from surface
    - One fractured during driving
  - One – 1”, Airshore, Hi-yield Strength Picket, 40” long, w/24” embed
    - Did not yield, but failed soil at 1750lb
Summary of Results - May06
(moist soil conditions)

• All in Compacted Select Fill over Bay Mud
  – 4 - 1” dia w/42” embed = 1700 to 2050lb to failure by yielding picket within 6” of surface
    • 1 – failed by yielding at 2900lb
  – 3 – 5/8” dia w/30” embed = 1000 to 1250lb to failure by yielding picket within 4” of surface
    • 1 - Fractured at 1000
  – 4 – 1” dia, Airshore, Hi-yield Strength Picket, 40” long, w/24” embed = 2500 to 3000lb to failure by yielding picket within 9” of surface
Summary of Results - May07 (dry soil conditions)

- All in Compacted Select Fill over Bay Mud
  - 4 - 1” dia w/42” embed = 1600 to 2000 lb to failure by yielding picket within 6” of surface
  - 4 – 5/8” dia w/30” embed = 1000 to 1500 lb to failure by yielding picket within 4” of surface
    - Better results than previous
  - 4 – *8 rebar x 45” long, w/36” embed = 1150 to 2250 lb to failure by yielding picket within 9” of surface
    - If throw out 1150 value, 1900 to 2200
    - Slightly better than 1” dia x 42” embed
Summary of Results - May08
(dry soil conditions)

• All in Compacted Select Fill over Bay Mud
  – 4 - 1” dia w/42” embed = 1600 to 2000lb to failure by yielding picket within 6” of surface
  – 4 – *8 rebar x 45” long, w/36” embed = 1750 to 2250lb to failure by yielding picket within 9” of surface
  • Slightly better than 1” dia x 42” embed

Pickets May08
Summary of Results - May09
(dry soil conditions)

• All in Compacted Select Fill over Bay Mud
  – 4 - #8 rebar w/30” embed = 1750- to 2150lb to failure by yielding picket within 9” of surface
  – 4 – "8 rebar w/24” embed = 1650 to 2500lb to failure by yielding picket within 9” of surface

– Showed that 36” pickets w/ 30” & 24” embed were just as strong as 48” with 42” embed
Summary of Single Picket Tests

- 1”x 48” Pickets w/42” embed
  - 37 Tests w/yield at 1750 to 2500lb (one - 2900lb)
- 1”x 48” Pickets w/36” embed
  - Three Tests w/yield at 1500 to 2200lb
- 1”x 40” Airshore Hi-yield w/30” embed
  - One test, no-yield, soil failure at 1750lb
  - Four Tests w/yield at 2500 to to 3000lb
- #8 x 45” Rebar w/ 36” embed
  - Eight tests w/yield at 1150 to 2200
  - Throw-out 1150, yield at 1900 to 2200
- #8 x 45” Rebar w/ 30 & 24” embed
  - Eight tests w/yield at 1650 to 5
  - 13 Tests w/yield at 900 to 1500lb

Picket Test Conclusion – 2009

- Picket Yield values are not closely related to hardness and/or wetness of Soil in the cohesive soil at CATF-3 Site
- Higher Yield Strength Steel of the Airshore Picket produces higher results
- Strengths of 5/8” Screed Pins were surprisingly high
- Design Strengths of Pickets in similar, Cohesive Soils should net be greater than
  - 750lb for 1” Bar & #8 Rebar with as little as 24” embed
  - 1000lb for 1” x 42” Airshore Pickets
  - 400lb for 5/8” x 36” Screed Pins
- Not Recommended in Cohesionless Soils
Double Picket Tests May10

Using pairs of 1” dia x 36” Bar

• Front picket yields in 2 places; rear in one
• Average of 4 tests = 3200lb at failure
• Do more tests in 2011+
Existing Picket Load Data

Holding Power of Picket Holdfast in Loamy Soil

<table>
<thead>
<tr>
<th>Holdfast</th>
<th>Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single picket</td>
<td>700</td>
</tr>
<tr>
<td>1-1 picket holdfast</td>
<td>1,400</td>
</tr>
<tr>
<td>1-1-1 picket holdfast</td>
<td>1,800</td>
</tr>
<tr>
<td>2-1 picket holdfast</td>
<td>2,000</td>
</tr>
<tr>
<td>3-2-1 picket holdfast</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Note: Wet earth factors:
- Clay and gravel mixtures: 0.9
- River clay and sand: 0.5

Lateral Load Capacity of Pin in Cohesive Soil

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil Capacity, lb/sq ft</th>
<th>Pin Design Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Soft</td>
<td>800</td>
<td>260</td>
</tr>
<tr>
<td>Poor</td>
<td>1400</td>
<td>500</td>
</tr>
<tr>
<td>Average</td>
<td>2200</td>
<td>750</td>
</tr>
<tr>
<td>Good/Hard</td>
<td>3200</td>
<td>1000</td>
</tr>
</tbody>
</table>

Lateral Load Capacity in Cohesionless Soil

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Soil Density, lb/cu ft</th>
<th>Pin Design Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Loose</td>
<td>90</td>
<td>45</td>
</tr>
<tr>
<td>Loose</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Medium</td>
<td>115</td>
<td>55</td>
</tr>
<tr>
<td>Dense</td>
<td>125</td>
<td>63</td>
</tr>
<tr>
<td>Very Dense</td>
<td>135</td>
<td>67</td>
</tr>
</tbody>
</table>
Questions & Discussion