

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

Feb11

CA-TF-3 Raker Breaker



Raker/Picket Tests 2

**CA-TF-3 Raker Breaker Test
Test Ended at 13000lb -Picket Deflection**



CA-TF-3 Structure Specialists



Raker System Tests

**StS2 Training 15Sep04
(Dry Conditions)**

Raker/Picket Tests 5

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 = $9.8/7.9 = \text{abt } 1.25$
- **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

Raker/Picket Tests 6



Sole Cleat lifts just prior to Failure
All but 6-16d in ea cleat were removed
to allow failure at 25k for pair



Tests 9

Sole Cleat was Projected-off
Load= 25k for pair



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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/Picket Tests 12

Raker System Tests

StS2 Training 22Mar05

(very wet conditions)

Raker/Picket Tests 13

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 = $9.8/7.9 = \text{abt } 1.25$**
- **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 14

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 15

Rak-22 Nail Slip Failure



Raker/Picket Tests 16

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

Raker/Picket Tests 18

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.



Raker/Picket Tests 19

Rak-24 w/o bracing

Only slight bowing at 25k



Raker/Picket Tests 20

Raker System Tests

StS2 Training 7Nov05

(had rained previously)

Raker/Picket Tests 21

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 = $9.8/7.9 = \text{abt } 1.25$**
- **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**

Raker/Picket Tests 22

Nov05 Test Setup



Cleat Close-up





Raker System Tests

StS2 Training 25May06

It was a wet spring & wood was very "Green"

Raker/Picket Tests 26

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 = $9.8/7.9 = \text{abt } 1.25$
- **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

Raker/Picket Tests 27

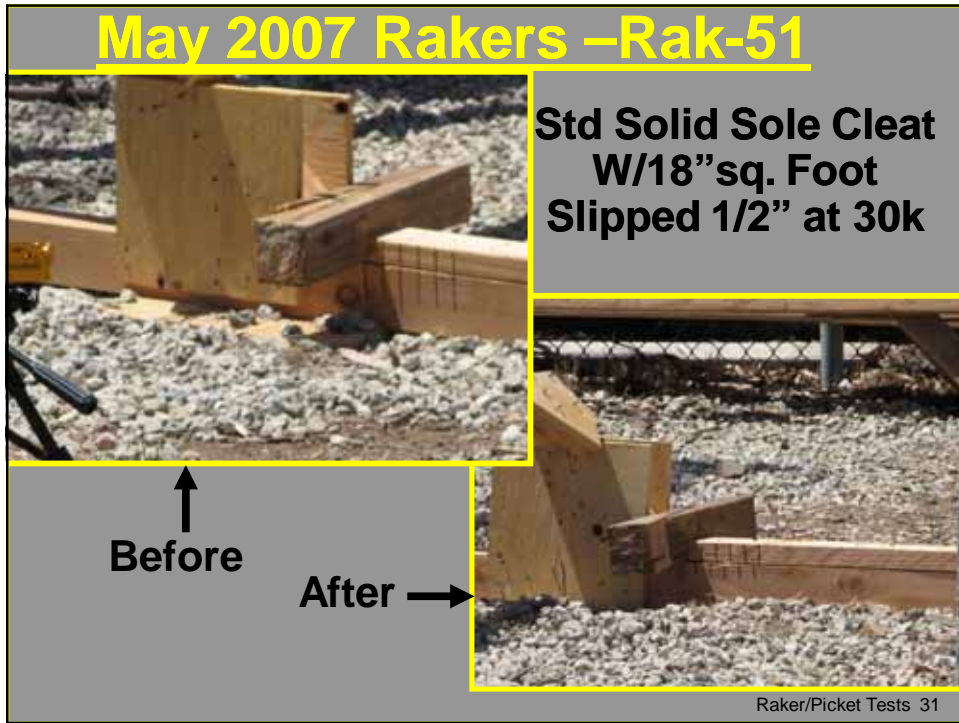




May07 Raker Tests

- 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 conns
 - 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 = $9.8/7.9 = \text{abt } 1.25$
- 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

Raker/Picket Tests 30



May 2007 Rakers

Split Sole Rakers

Rak-53 w/ 18"sq Foot



**Rak-54 w/o
18"sq Foot**



May08 Raker Tests

- **Total of 3 Raker Pairs Tested (5K/Pr Design Load)**
 - Rak-61 Wood, Solid Sole Rakers, w/o Mid Brace
 - Rak-62 & Rak-62, 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 = $9.8/7.9 = \text{abt } 1.25$
- **Ram Load**
 - 24k Max for Rak-61, 62, 63 , 30k Horiz Load on Rakers
- **Only Rak-63 failed as post buckled (knots)**

Raker/Picket Tests 34

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 = $9.8/7.9 = \text{abt } 1.25$
- **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

Raker/Picket Tests 35

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 = $9.8/7.9 = \text{abt } 1.25$
- **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

Raker/Picket Tests 36

19 – Solid Sole Raker Tests - Results

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

Raker/Picket Tests 37

10 – Split Sole Raker Tests - Results

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

Raker/Picket Tests 38

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

Raker/Picket Tests 39

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

Raker/Picket Tests 40

Picket Test Layout – StS1, Sep04



Raker/Picket Tests 41

Removed Test Specimen Sep04



Raker/Picket Tests 42

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

Raker/Picket Tests 43

Picket Tests-Mar05



Raker/Picket Tests 44



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**

Raker/Picket Tests 46

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" dia, Airshore, Hi-yield Strength Picket, 40" long, w/24" embed**
 - Did not yield, but failed soil at 1750lb

Raker/Picket Tests 47



Pickets Nov05

Raker/Picket Tests 48

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

Raker/Picket Tests 49

Pickets May06



Raker/Picket Tests 50

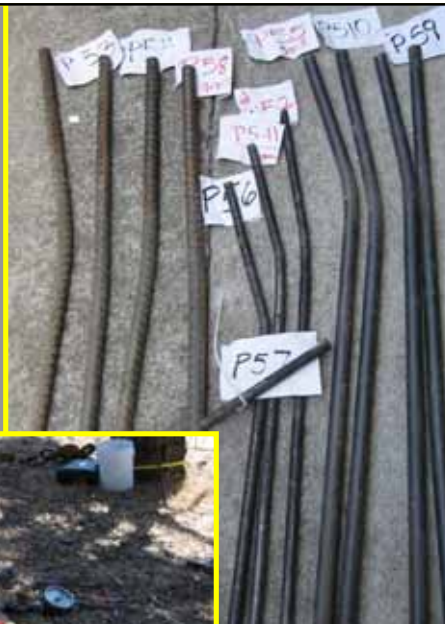
Summary of Results - May07 (dry soil conditions)

- 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 - 5/8"dia w/30" embed = 1000 to 1500lb to failure by yielding picket within 4" of surface
 - Better results than previous
 - 4 - *8 rebar x 45" long, w/36"embed = 1150 to 2250lb 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

Raker/Picket Tests 51

Pickets May07

Picket Setup



Raker/Picket Tests 52

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

Raker/Picket Tests 53

Pickets May08



Raker/Picket Tests 54

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

Raker/Picket Tests 55

Pickets May09



Raker/Picket Tests 56

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

Raker/Picket Tests 57

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 not 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**

Raker/Picket Tests 58

Double Picket Tests May10

Using pairs of 1"dia x 36" Bar



Double Picket Tests - May10

- Front picket yields in 2 places; rear in one
- **Average of 4 tests = 3200lb at failure**
- Do more tests in 2011+



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Holding Power of Picket Holdfast in Loamy Soil

Holdfast	Pounds
Single picket	700
1-1 picket holdfast	1,400
1-1-1 picket holdfast	1,800
2-1 picket holdfast ..	2,000
3-2-1 picket holdfast	4,000

Note. Wet earth factors:

Clay and gravel mixtures	0.9
River clay and sand	0.5

Existing Picket Load Data

Raker/Picket Tests 61

Lateral Load Capacity of Pin in Cohesive Soil 1-inch dia, 48-inch pin, driven 36 inches into soil		
Soil Type	Soil Capacity, lb/sq ft	Pin Design Load
Very Soft	800	260
Poor	1400	500
Average	2200	750
Good/Hard	3200	1000
Lateral Load Capacity in Cohesionless Soil 1-inch dia, 48-inch pin, driven 36 inches into soil		
Soil Type	Soil Density, lb/cu ft	Pin Design Load
Very Loose	90	45
Loose	100	50
Medium	115	55
Dense	125	63
Very Dense	135	67

Raker/Picket Tests 62

Exist Picket Load Data

Questions & Discussion



Raker/Picket Tests 63