Summary - Testing of Laced Post & Plywood Laced Posts

NASA/AMES, 2001 – Proof of Concept
StS2 - Sep04, Mar-Nov05, May06-10

2001-Testing Apparatus

Initial Tests were conducted at the NASA/AMES, Outdoor Aeronautical Research Facility (OARF), Moffett Field, CA

- 150 Ton Bridge Crane
- 12.5 ft high test setup
- Weight of Loading Slab for 12.5 ft high setup is 38k = 1.2 x Working Load of Laced Post
- Additional concrete weights may be added in 25k increments (pairs of 12.5k blocks)
  - Total for all 8 added blocks = 100k
- Maximum Load Capacity = 38k = 100k = 138k

Note: 1k = 1 kilo-pound = 1,000 lb
2001- Proof of Concept Tests

• Laced Post Shore Specimen
  – Two specimen were tested
  – Specimen LP-1 was 12.5 ft high with 3 diagonals on each face, Posts 4 ft o.c.
  – Specimen LP-2 was 12.5 ft high with 2 diagonals on each face, Posts 4 ft o.c.
  – Working Load = 32k each specimen (based on allow cross-grain bearing)

• 12.5 ft height was selected since it near the story height of office buildings
  – Using 8ft or 10ft would only test the post strength, not the systems

2001-Test Setup - 150 ton Crane

Laced Post LP-1
12.5ft High, Posts 4ft o.c.,
3 Bracing Bays
Reverse K Diagonals
2x4 Lacing, 3-16d
LP-1: 1st Load w/ 38k Slab = 1.2 x Design
Slab lifted by Crane, pullout wood blocks

Center 6 blocks over LP-1
• Each pair of blocks = 25k
• Blocks are suspended from each other by chains
• Lower blocks to add load
• As lowest blocks bear on slab, the chain between them and the next above becomes slack.
• Loading sequence: 38k, 63k, 88k, 113k
2\textsuperscript{nd}: Add 2 blocks = 38k + 25k = 63k

3\textsuperscript{rd}: Add 4 blocks = 38k + 50k = 88k

Close-up of split header at 88k

Close-up of cupped wedges at 88k
LP-1 at Failure
(as final blocks were added)

- All 6 blocks added?
- Collapsed w/ hinges at nodes
- Max load = 100k?

Close up of collapsed LP-1
LPLP--2 w/ 38k slab - 1.2 x Design Load

Laced Post LP-2
12.5ft High,
Posts 4ft o.c.
2 Bracing Bays
Parallel
Diagonals
2x4 Lacing, 3-16d

LP-2 w/ 2 Blocks, 38k + 25k = 63k
Add 4 Blocks, Load = 38k + 50k

LP-2 fails as add 6 blocks, Load=90k?
Summary of 2001 Tests

- Tests verified that cross grain crushing can be observed at loads much lower than those causing system failure
  - Starts to be observed at 1.5 to 2x Design Load
- Laced Post System as constructed has members and connections that are sufficient to brace system to resist 3 times Design Load
- The spacing & number of lacing bays effects the mode of failure
Sep04 Tests – StS-2 Training

- Laced Posts LP-11, LP-12, & LP-13
- 12.5ft high & posts 4ft o.c.
- 3 bracing bays
  - 3 in K configuration & 1 as reverse K
  - 2x4 Lacing w/ 3-16d ea end
- LP-11 & 12 failed as adding 6 blocks
- LP-13 vert. load w/38k, then 3 cycles of lateral loading
  - Cycle 1=500lb, Cy 2=1000, Cy 3 1200lb & Fail
<table>
<thead>
<tr>
<th>Loading Level</th>
<th>Wedge Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>38k</td>
<td></td>
</tr>
<tr>
<td>63k</td>
<td></td>
</tr>
<tr>
<td>88k</td>
<td></td>
</tr>
<tr>
<td>90k+</td>
<td>LP-11 Failure Mode – 90k+</td>
</tr>
</tbody>
</table>
LP-11 Joint Failures

LP-12 Setup + Lateral Left
Summary Sep04

- One can observe significant cupping of 2x4 Wedges at 2x Design Load
- Laced Post System as constructed has members and connections that are sufficient to brace system to resist 3 times Design Load
- Failure often occurs in posts w/knots that are near joints
- There is not much lateral strength or stuffiness
Mar05 Tests – StS-2 Training

• Laced Posts LP-21, 22, 23, & 24
  – 4x4 Posts for LP-21, 22, & 24 w/3 bracing bays
  – 4 - Paratech Struts for LP-23 w/2 bracing bays

• 12.5ft high & posts 4ft o.c.

• LP-21, 22, & 24 =3 bracing bays
  – 2x6 lacing for LP-21 & 22, 2x4 for LP-24

• LP-21 & 24 fail at abt 110k, LP-22 = 90k

• LP-23, load w/38k, then 3 cycle lateral
  – Cycle 1=400lb, Cy 2=800, Cy 3 1200lb & Fail

• LP-24, load w/38k +2 cycle of 2” lateral
  – Following lateral, vert. Load to failure = 110k

LP-21 Setup – Wet Conditions
2x6 Lacing, 5-16d
LP-21 – Failure at 110k

Bad Joint

LP-21 Joints
LP-22 Setup — Tested 30 days of drying out —
Posts split at intersection of K’s prior to loading

Failure Load
90k +

LP-22 has poor performance compared to LP-21 due to defects cause by drying

Bad Joint
LP-24 – 38k slab was loaded, then it was loaded laterally thru 2 cycles of 2” deflection. It was then loaded to failure at about 108k.

Summary Mar05
• Same cupping of 2x4 Wedges at 2x Design Load
• Systems normally can resist 3 times Design Load
• Using 2x6 diagonals with 5-16d does not improve overall performance
  – Splitting occurs in posts at multi-member connections
• Laced Post Systems do not have much lateral stuffiness
• Paratech Laced Post system is viable
Nov05 Tests – StS-2 Training

• New loading setup – Use Hydraulic Rams
  – Total Load of blocks (138k) is initially supported on 4-50 Ton Rams
  – Shore is loaded by reducing ram pressure

• Laced Posts LP-31 & LP-32
  – 13ft high & posts 4ft o.c. each way
  – 2x4 Lacing for LP-31
  – 24”Plywood lacing for LP-32 (3/4” ply)

• Plywood Laced Posts PLP-31 & PLP-32
  – 13ft high w/ posts 2ft x 4ft o.c.
  – 12” ply lacing for PLP-31, 24” ply lacing PLP-32
LP-31 Test = 103k (more accurate test)

LP-32 Test = 103k (accurate test)
PLP-31 Test – 88k (Buckle) (plywood too small)

PLP-32 Test – 88k (Buckle) (we can do better?)

Plywood was cut in wrong direction
Plan on doing more tests, using 12” wide ply strips
May06 Tests – StS-2 Training

- Same loading setup as Nov05
  - Total Load of blocks (138k) is initially supported on 4-50 Ton Rams & Shore is loaded by reducing ram pressure
- Laced Posts LP-41 & LP-42
  - 13ft high & posts 4ft o.c. each way
  - 2x4 Lacing for LP-41
  - 12” Ply lacing x 3 for LP-42 (3/4” ply)
- Plywood Laced Posts PLP-41 & PLP-42
  - 13ft high w/ posts 2ft x 4ft o.c.
  - 12” ply lacing x 2 for PLP-41, 12” ply lacing x 3, PLP-42
- Showed that 12” x ¾” ply lacing is inadequate
LP-42 Test = 83k

12” Ply
NOT
Adequate

PLP-41 Test – 65k (Buckle & Post Fail)
May07 Tests – StS-2 Training

- New Vertical Load Testing Frame
  - Use 4-50 Ton Rams, no load averaging manifold
  - Shore is loaded from table at bottom

- Laced Posts LP-51, LP-52 & LP-53
  - 12.2ft high & posts 4ft o.c. each way
  - 2x4 Lacing for LP-51
  - 24” ply lacing x 2 for LP-52 & LP-53 (3/4” ply)

- Plywood Laced Posts PLP-51 & PLP-52
  - 12.2ft high w/ posts 2ft x 4ft o.c.
  - 24” ply lacing x 2 for PLP-51 & PLP-52
New-280k Vertical Shore Tester
(Built from old motor test stand)

Initial Tests, NASA Class
4 - 50T Rams under Steel Fl
LP-51=100k 30k

New Loading Sequence
(Record deflection at each level)
• Load to 32k = Design load
• Load to 48k & observe cupping of wedges
• Load to 64k & observe wedges and header splits
• Load to 96k and slowly increase to failure
LP-52 – 100k
LP-53 – 88k
Failure at knots

PLP-51 = 92k
Best Yet
May08 Tests – StS-2 Training

• New 280k Vertical Load Testing Frame
  – Explore limits of shores using 3/4” ply lacing
  – Attempt to minimize effects of knots

• Laced Posts LP-61, LP-62 & LP-63
  – 12.2ft high & posts 4ft o.c. each way
  – 2x4 Lacing for LP-61
  – 24”ply lacing x 4 for LP-62 & 5 for LP-63

• Plywood Laced Posts PLP-61 & PLP-62
  – 12.2ft high w/ posts 2ft x 4ft o.c.
  – 24” ply lacing x 4 for PLP-61
  – 96” ply on 2ft sides for PLP-52

Test Configurations – 12’-2” high

LP-62 115k

LP-63 144k

PLP-61 85k (bad posts) 115k

PLP-62

The intent was to better restrain the posts and force greater deflection in the header/post and post/wedges/sole connections.

Except for PLP-61 the intent was realized – see following
LP-62 115k
Superior performance

LP-63 115k
Very Superior performance
May09 Tests – StS-2 Training

- New 280k Vertical Load Testing Frame
  - Explore use of 96” ply on 2ft side of PLP
  - Explore use of OSB & thinner plywood
  - Develop new standard shore = 2’x4’ PLP

- Ply Laced Posts PLP-71 thru PLP-75
  - 12.2ft high & posts 2ft x 4ft o.c.
  - 24” ply lacing x 2 for all on 4ft side
  - 96”x 5/8 ply on 2ft sides for PLP-71 & 72
  - 96”x 1/2” ply on 2ft side for PLP-73 & 74
  - 96”x 3/4” OSB on 2ft side for PLP-75
  - 24” & 48”x 3/4” ply on 2ft side for PLP-76

Test Configurations – 12’-2” high

- PLP-71, 72: 125k (5/8” ply)
- PLP-73, 74: 110k (1/2” ply)
- PLP-75: 115k (3/4” OSB)
- PLP-76: 115k (3/4” ply)

The intent was to see if plywood could be reduced in thickness.
Also to see if 96” plywood panel could be reduced to 48”
PLP-71,72 125k
V. Good Performance
PLP-73,74,75 were similar

PLP-76 failed at 115k
48”+ 24”ply on 24” sides

Performance as good as when using 96”ply
May10 Tests – StS-2 Training
(Explore use of less than 96” Ply on 24” side - PLP)
• 5 tests of 2’x4’ Ply Laced Posts, PLP81- 85
• All specimen are 12.2 ft High
  – Posts 2ft x 4 ft out to out
  – PLP- 81 = 96” front lacing with 1/2” Ply
  – PLP-82 & 83 = 48” + 24” front lacing, 1/2” & 5/8”
  – PLP-84 & 85 = 2 - 5/8”x 24”ply lacing that are spaced about 12” from gussets at top & bottom
  (It was reasoned that this placement of the ply lacing was more efficient, since the slope of the buckled shape is steeper near the ends)

Test Configurations – 12’-2” high

105k (1/2”ply) 115k,127k (5/8 & 1/2”ply) 120k,140k (5/8 ply)

The intent was to see if 96”plywood could be reduced to a pair of smaller panels, and see if ply thickness could be reduced
The ply lacing was places about 12” from gussets each end
PLP-84 120k  
V. Good Performance

PLP-85 140k  
Outstanding Performance
Summary of All Laced Posts Tests 2002 to 2010

- 12- Laced Post using 2x4 lacing were tested
  - All had 4x4 Posts on 4ft x 4ft spacing
  - LP-23 was additional test using Paratech Struts and 2 bays of 2x6 lacing. It was loaded with 38k, and 3 cycles of lateral loading. Not in table

- 6 - 4ft x 4ft Ply Laced Posts were tested
  - All had 4x4 posts and 3/4” plywood

- 18 - 2ft x 4ft Ply Laced Posts were tested

Tables showing the results follow

<table>
<thead>
<tr>
<th>Shore</th>
<th>Lacing</th>
<th>Failure</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP-1</td>
<td>2x4</td>
<td>100k</td>
<td>Failed at post knots</td>
</tr>
<tr>
<td>LP-2</td>
<td>2x4</td>
<td>90k+</td>
<td>Total system failure - Poor</td>
</tr>
<tr>
<td>LP-11</td>
<td>2x4</td>
<td>90k+</td>
<td>Failed at post knots</td>
</tr>
<tr>
<td>LP-12</td>
<td>2x4</td>
<td>90k+</td>
<td>Failed at post knots</td>
</tr>
<tr>
<td>LP-13</td>
<td>2x4</td>
<td>N/A</td>
<td>Lat. load test at 38k only</td>
</tr>
<tr>
<td>LP-21</td>
<td>2x6</td>
<td>110k+</td>
<td>Good performance</td>
</tr>
<tr>
<td>LP-22</td>
<td>2x6</td>
<td>90k+</td>
<td>Posts were split prior to test. Failed at many joints</td>
</tr>
<tr>
<td>LP-24</td>
<td>2x4</td>
<td>100k+</td>
<td>2 cycles of 2” lateral w/38k then load to failure. V.good</td>
</tr>
<tr>
<td>LP-31</td>
<td>2x4</td>
<td>103k</td>
<td>New Loading Sys=accurate</td>
</tr>
<tr>
<td>LP-41, 61</td>
<td>2x4</td>
<td>103k</td>
<td>Similar to LP-31</td>
</tr>
<tr>
<td>LP-51</td>
<td>2x4</td>
<td>90k</td>
<td>New load frame w/no load averaging between posts</td>
</tr>
</tbody>
</table>
Sum of 12 L. Post Tests – 2x Diag

- One can observe significant cupping of 2x4 Wedges at 2x Working Load
  - Splitting of Headers may occur at 2x to 3x Working Load, depending on slope & direction of grain
- 4x4 - Laced Post Systems consistently resist 3 times Working Load
- Failure often occurs in posts w/knots that are near joints
- The Direction of the Diagonal Braces may not have a significant effect.
- The use of 2x6 Diagonals with 4x4 posts may not produce increased strength, depending on splitting of the posts due to nail concentration
- Total deflection is about 1.5 to 2” at failure

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<th>Shore</th>
<th>Lacing</th>
<th>Failure</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP-32</td>
<td>24”Ply</td>
<td>103k</td>
<td>Fail Sim to 2x Diag Tests</td>
</tr>
<tr>
<td>LP-42</td>
<td>12”Ply</td>
<td>83k</td>
<td>Failed in Sys Buckling 12”Ply is NOT Adequate</td>
</tr>
<tr>
<td>LP-52</td>
<td>24”Ply</td>
<td>100k</td>
<td>Same as LP-32</td>
</tr>
<tr>
<td>LP-53</td>
<td>24”Ply</td>
<td>88k</td>
<td>Failed at poor post</td>
</tr>
<tr>
<td>LP-62</td>
<td>24”Ply</td>
<td>115k</td>
<td>Closer space is ply better</td>
</tr>
<tr>
<td>LP-63</td>
<td>24”Ply</td>
<td>144k</td>
<td>Ply was too close – not practical</td>
</tr>
</tbody>
</table>
Sum of 6-PLP 4’x4’ Tests

- Using 24” Ply lacing appears to produce same results as for Std Laced Post w/ 2x
  - Deflection is about same as Std Laced Post
  - Tested 24” strips w/ equal spacing
  - Later tests show that 24” strips should be spaced closer to the top & bottom of shore
  - May have better results w/ closer spacing of ply lacing, but may be impractical

- Using 12” Ply lacing is Inadequate
  - Single Cycle Buckling occurred

<table>
<thead>
<tr>
<th>Shore</th>
<th>Lacing</th>
<th>Failure</th>
<th>Comment (3/4”Ply UNO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLP-31</td>
<td>2-24”</td>
<td>88k</td>
<td>Failed in Elastic Buckling</td>
</tr>
<tr>
<td>PLP-32</td>
<td>1-24”</td>
<td>88k</td>
<td>Same – re-tested to 65k</td>
</tr>
<tr>
<td>PLP-41</td>
<td>2-12”</td>
<td>65k</td>
<td>Failed, buckle + posts</td>
</tr>
<tr>
<td>PLP-42</td>
<td>3-12”</td>
<td>67k</td>
<td>Same – 12” Ply Inadequate</td>
</tr>
<tr>
<td>PLP-51</td>
<td>2-24”</td>
<td>90k</td>
<td>Failed at poor post</td>
</tr>
<tr>
<td>PLP-61</td>
<td>4-24”</td>
<td>85k</td>
<td>Failed at poor post</td>
</tr>
<tr>
<td>PLP-62</td>
<td>1-96”</td>
<td>115k</td>
<td>V.good, do additional tests</td>
</tr>
<tr>
<td>PLP-71,72</td>
<td>1-96”</td>
<td>125k+</td>
<td>5/8”Ply V. good</td>
</tr>
<tr>
<td>PLP-73,74,81</td>
<td>1-96”</td>
<td>105k+</td>
<td>1/2”Ply V. good</td>
</tr>
<tr>
<td>PLP-75</td>
<td>1-96”</td>
<td>115k</td>
<td>3/4”OSB V. good</td>
</tr>
<tr>
<td>PLP-76</td>
<td>48”+24”</td>
<td>115k</td>
<td>3/4”Ply, (48” + 24” no 96”)</td>
</tr>
<tr>
<td>PLP-82,83</td>
<td>48”+24”</td>
<td>115k+</td>
<td>PLP-82 = 5/8”ply, PLP-83 = 1/2”ply</td>
</tr>
<tr>
<td>PLP-84,85</td>
<td>2-24”</td>
<td>120k+</td>
<td>5/8”ply, space ply lacing near ends</td>
</tr>
</tbody>
</table>
Sum of 18-PLP 2’x4’ Tests

• Using 24” Ply lacing appears to produce same results as for Std Laced Post w/ 2x
  – Deflection is about same as Std Laced Post
  – Tested 96”, 48”+24” & 2-24” lacing
  – Tests show that 24” lacing, spaced closer to the top & bottom of shore was best
  – May have equal results using 96” or 48”+24” lacing, but this is less practical

• Using 12” Ply lacing is Inadequate
  – Single Cycle Buckling occurred

Proposed PLP Standard Shores

• A new standard PLP Shore will be proposed, using 24” ply lacing on all 4 sides of the 2ft x 4ft and 4ft x 4ft configuration of the 4x4 posts
  – These shores may be used up to 13ft total height
  – 5/8” plywood may be used for the gussets and lacing
  – The ply lacing should be placed about 12” from the gussets at top & bottom of shore.
  – Minimum, practical height is 10ft

• 2011 Testing will be done with 1/2” ply & 5/8” OSB
Mar05 Tests – StS-2
Cribbing Specimen CB-21

6.5ft High, 4ft x 4ft Box Crib
4 – 4x4x4ft per layer
w/overlapped corners

Crib-CB-21 Layout
6” max travel of Loading Slab
CB-21 - first set of 25k Conc Blocks crushes Crib 6” – Test Stopped = 42k

CB-21 Crushing Close-up
Bearing is 870psi
Summary of Mar05 Crib Test

- Significant crushing can be observed when a Crib is loaded above Working Load
- Crib stability is heavily influenced by the uniformity of applied load and density of the wood at the bearings
- Cribbing give adequate warning of overload,
  - Crushing is Significant
  - Crushing makes easily recognized sounds
  - Members become significantly distorted