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

US&R Structure Specialist Training

FEMA

Summary- Testing of Laced Post & Plywood Laced Posts

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

Feb11

1

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

2

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**

3

2001-Test Setup - 150 ton Crane

4

LP-1: 1st Load w/ 38k Slab = 1.2 x Design
Slab lifted by Crane, pullout wood blocks

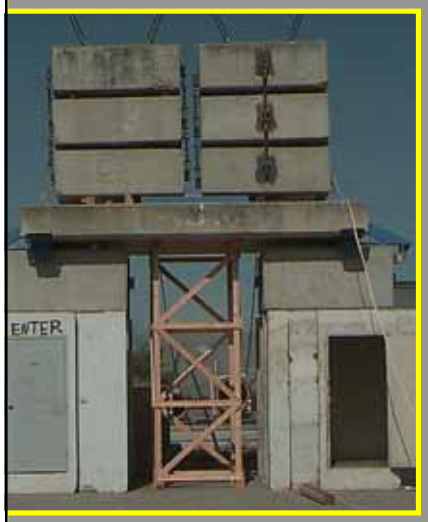
5

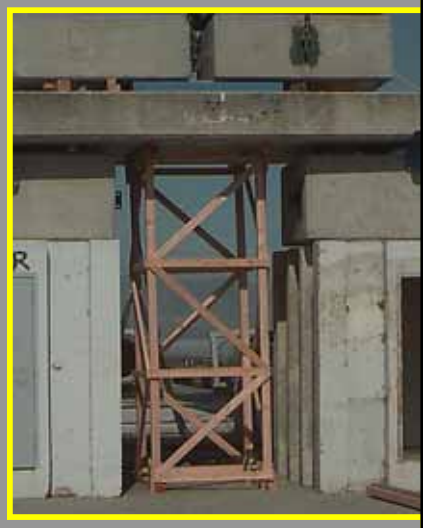
Center 6 blocks over LP-1

- 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

6

2nd: Add 2 blocks = 38k + 25k = 63k
3rd : Add 4 blocks = 38k + 50k = 88k



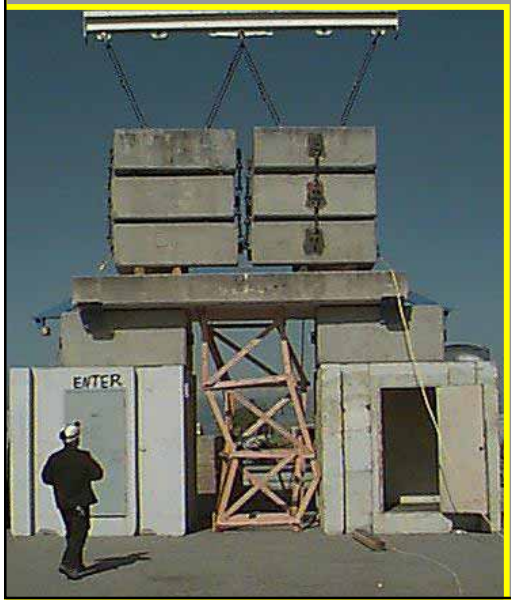


7

Close-up of split header at 88k

Close-up of cupped wedges at 88k

LP-1 at Failure (as final blocks were added)



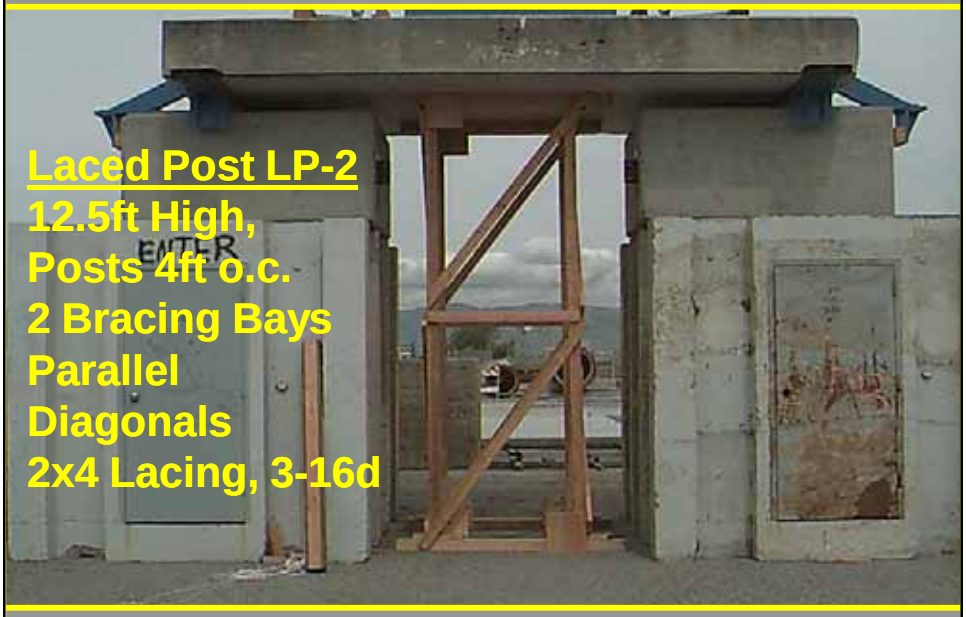
- All 6 blocks added?
- Collapsed w/ hinges at nodes
- Max load = 100k ?

9

Close up of collapsed LP-1

10

LP-2 w/ 38k slab - 1.2 x Design Load



11

LP-2 w/ 2 Blocks, 38k + 25k = 63k

12

Add 4 Blocks, Load = 38k + 50k

13

LP-2 fails as add 6 blocks, Load=90k?

14

LP-2 Lacing/System Failure

15

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**

16

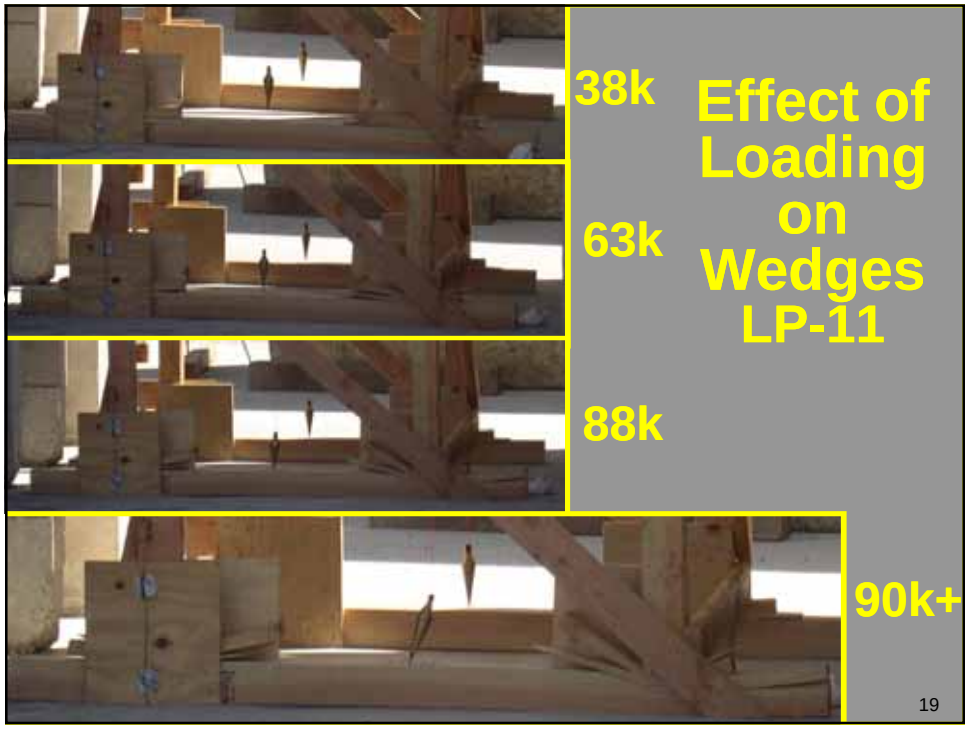
Sep04 Tests – StS-2 Training

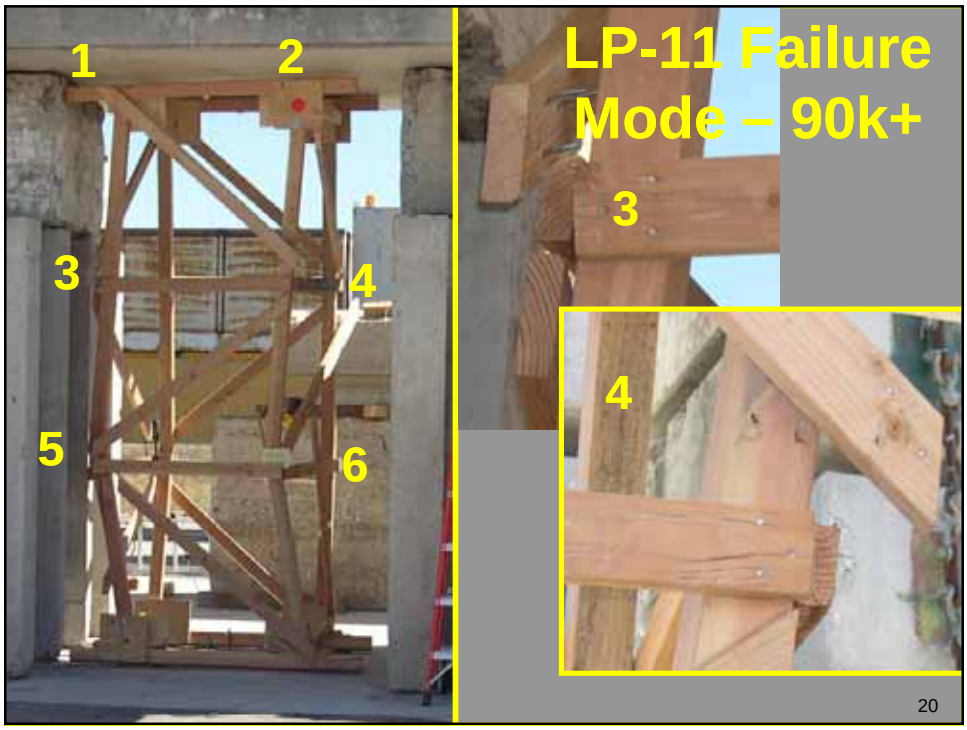
- Laced Posts LP-11, LP-12, & LP-13
- 12.5ft high & posts 4ft o.c.
- 3 bracing bays
  - 3 in K configuration & 1 as reverse K
  - 2x4 Lacing w/ 3-16d ea end
- LP-11 & 12 failed as adding 6 blocks
- LP-13 vert. load w/38k, then 3 cycles of lateral loading
  - Cycle 1=500lb, Cy 2=1000, Cy 3 1200lb & Fail

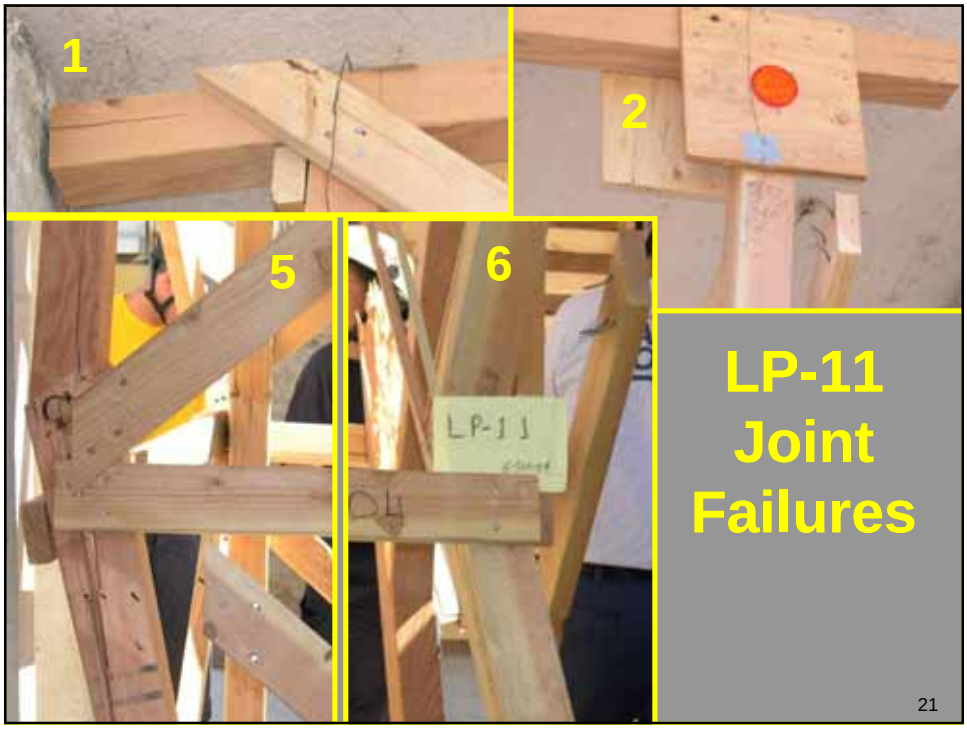
17

LP-11 Setup

18


38k
63k
88k
90k+
Effect of Loading on Wedges LP-11
19


1
2
3
4
5
6
LP-11 Failure Mode – 90k+
3
4
20


1
2
5
6
LP-11
Joint
Failures
21


LP-12 Setup + Lateral Left
22

LP-12 Collapse at 90k +

23

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

24

Mar05 Tests – StS-2 Training

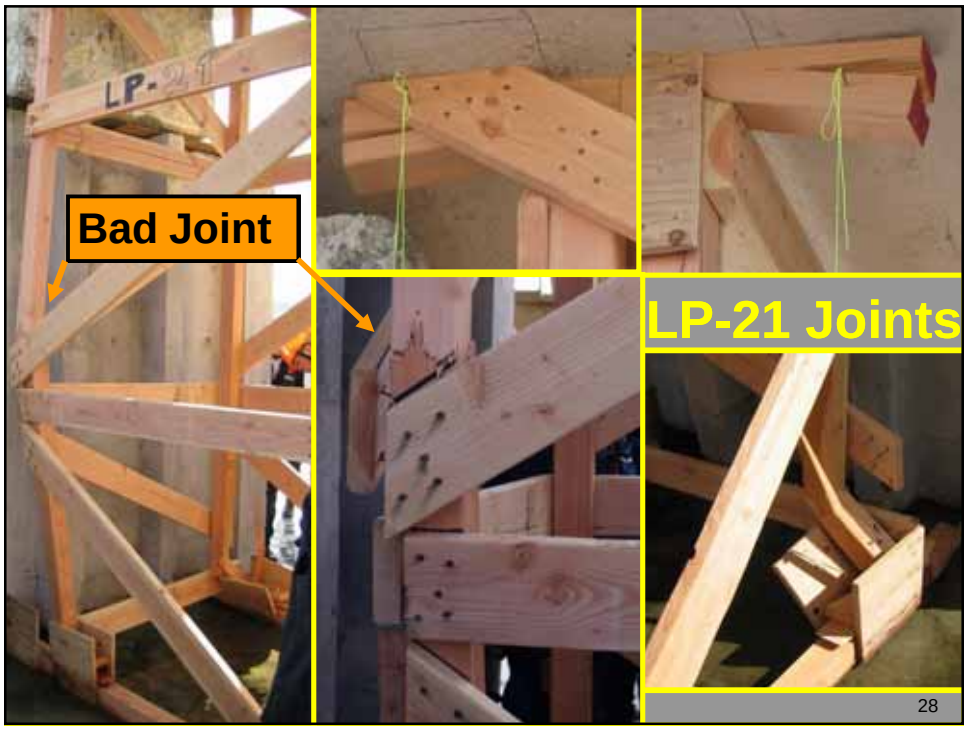
- **Laced Posts LP-21, 22, 23, & 24**
  - **4x4 Posts for LP-21, 22, & 24 w/3 bracing bays**
  - **4 - Paratech Struts for LP-23 w/2 bracing bays**
- **12.5ft high & posts 4ft o.c.**
- **LP-21,22, & 24 =3 bracing bays**
  - **2x6 lacing for LP-21 & 22, 2x4 for LP-24**
- **LP-21 & 24 fail at abt 110k, 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**

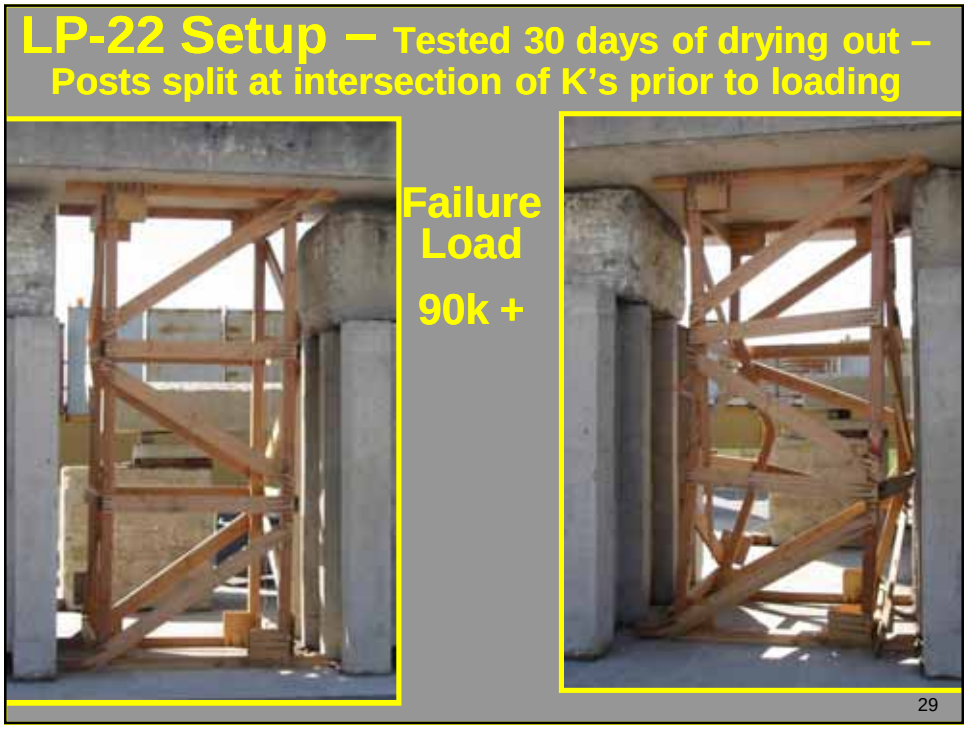
25

LP-21 Setup – Wet Conditions 2x6 Lacing, 5-16d

26


LP-21 – Failure at 110k
LP-21
27


LP-21
Bad Joint
LP-21 Joints
28


LP-22 Setup – Tested 30 days of drying out –
Posts split at intersection of K's prior to loading
Failure Load
90k +
29


LP-22 has poor performance compared to LP-21 due to defects cause by drying
Bad Joint
LP-22
30

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

31

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

32

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**

33

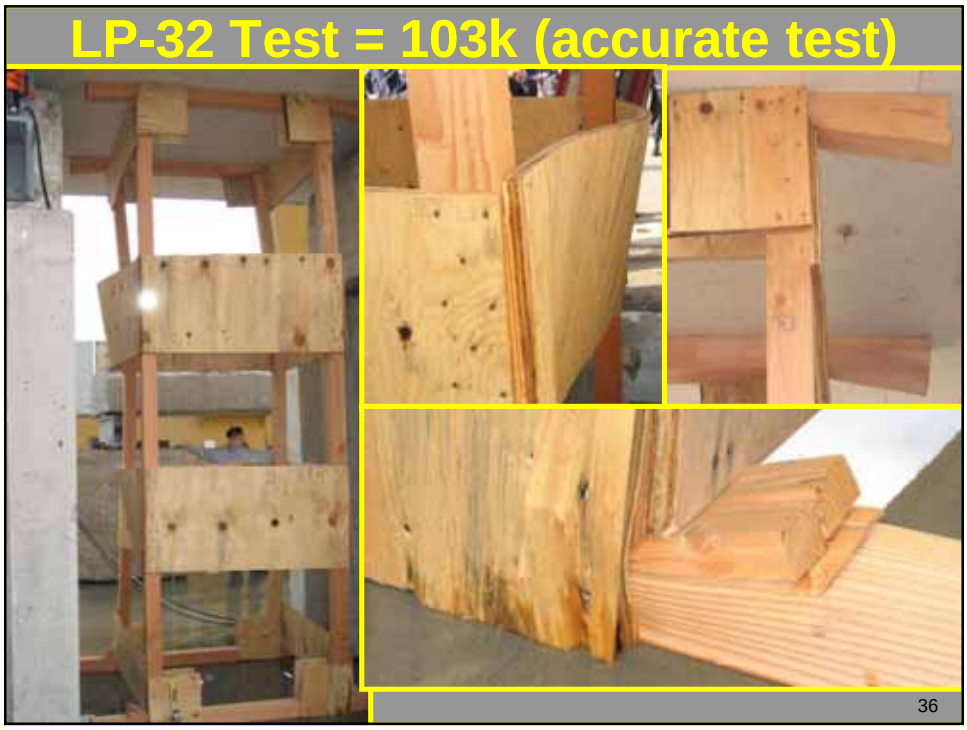
New Loading Setup

4 Rams Lift 138k Total Load
Shore is loaded by reducing press. in Ram

All sides have K brace layout

34

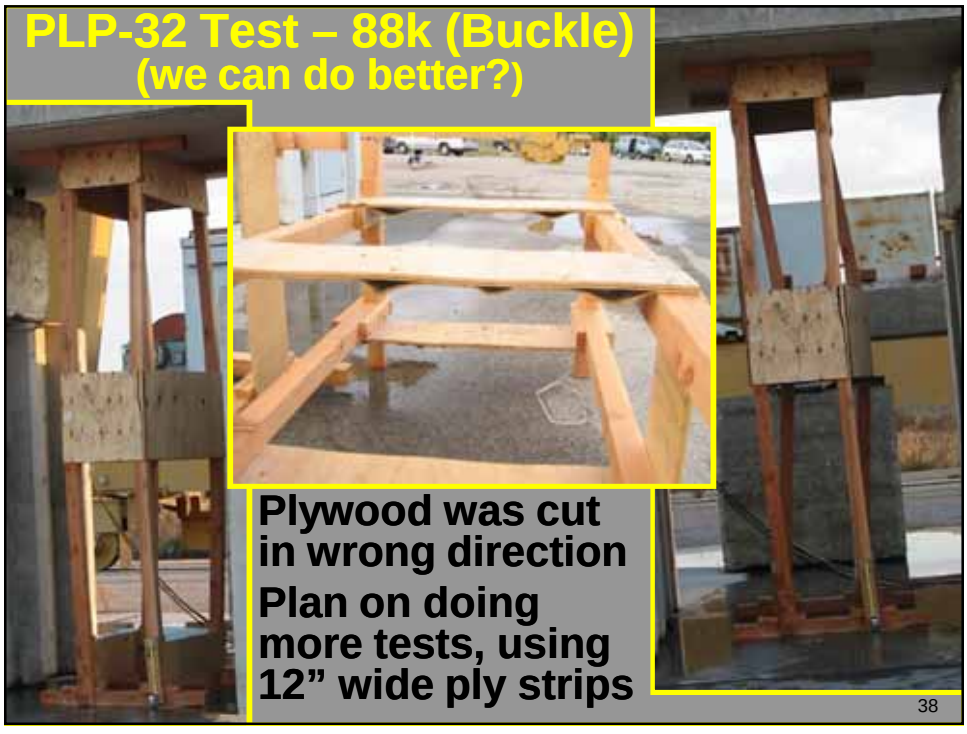

LP-31 Test =103K
(more accurate test)
35


LP-32 Test = 103k (accurate test)
36

PLP-31 Test – 88k (Buckle)
(plywood too small)

37

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

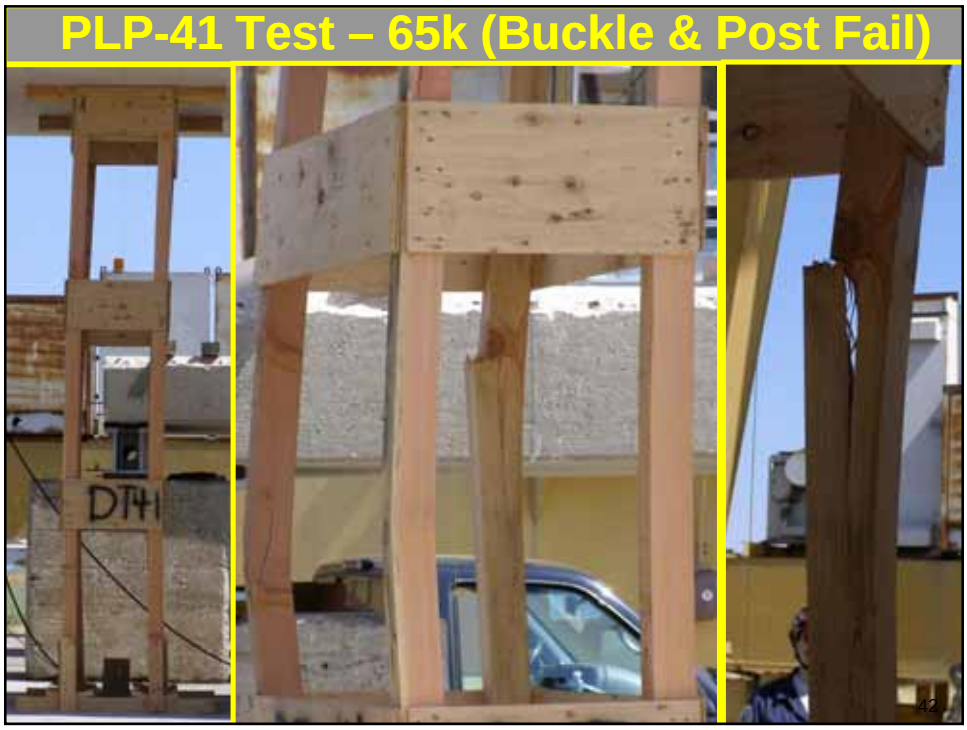
38

May06 Tests – StS-2 Training

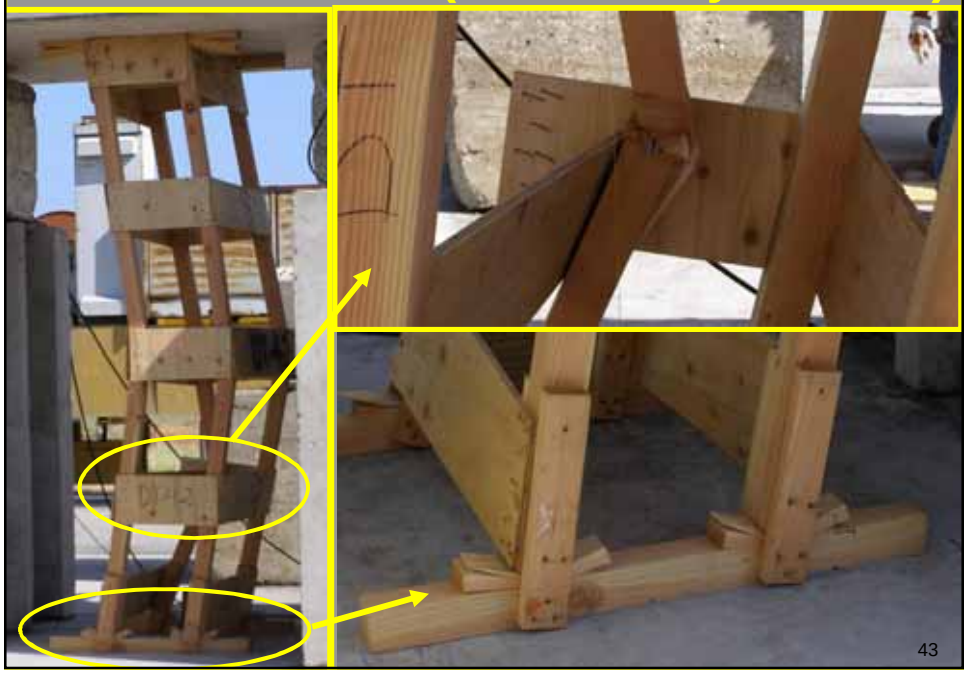
- Same loading setup as Nov05
  - Total Load of blocks (138k) is initially supported on 4-50 Ton Rams & Shore is loaded by reducing ram pressure
- Laced Posts LP-41 & LP-42
  - 13ft high & posts 4ft o.c. each way
  - 2x4 Lacing for LP-41
  - 12"Ply lacing x 3 for LP-42 (3/4" ply)
- Plywood Laced Posts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

39


LP-42 Test = 83k
LP-42
12” Ply
NOT
Adequate
41


PLP-41 Test – 65k (Buckle & Post Fail)
DT41
42

PLP-42 Test – 67k (Buckle & Sys Failure)



43

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

44

New-280k Vertical Shore Tester

(Built from old motor test stand)

4 - 50T Rams under Steel Fl

LP-51=100k **30k**

Initial Tests, NASA Class

45

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**

46


LP-52 – 100k
LP-53 – 88k
Failure at knots
47

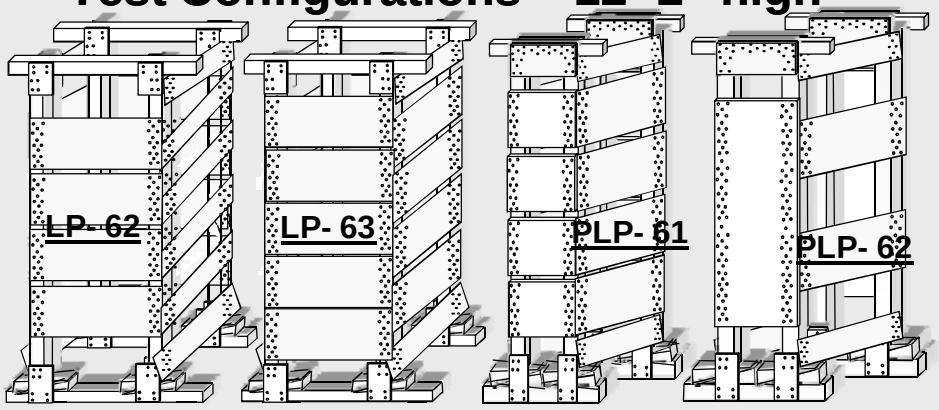

PLP-51 = 92k
Best Yet
48

May08 Tests – StS-2 Training

- **New 280k Vertical Load Testing Frame**
  - **Explore limits of shores using ¾" 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**

49

Test Configurations – 12'-2" high

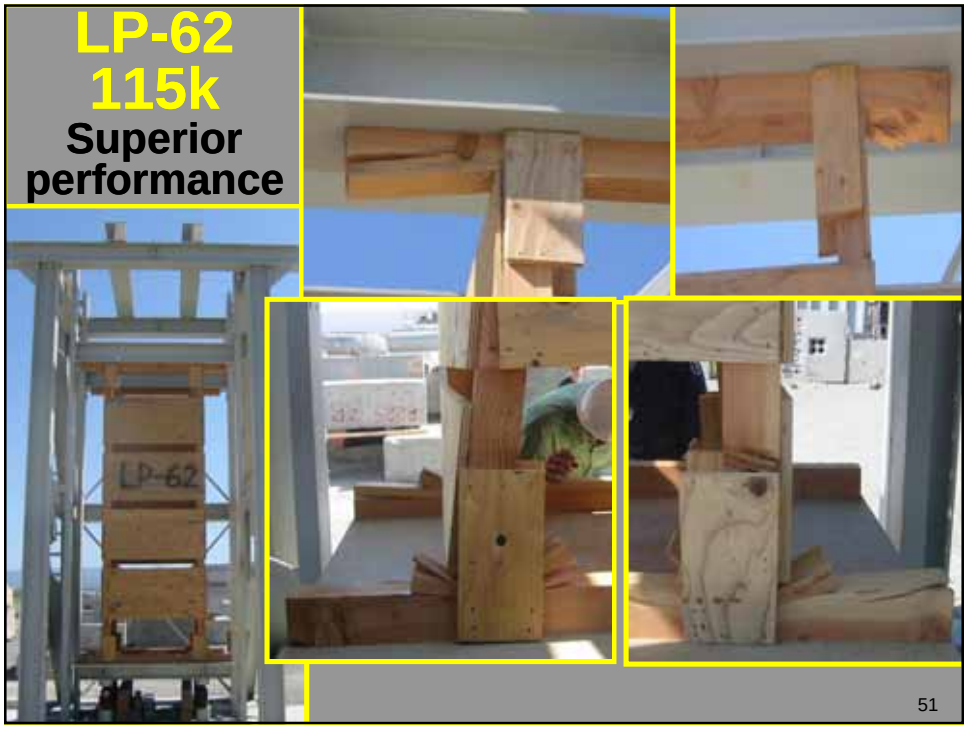


115k **144k** **85k (bad posts)** **115k**

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

50


LP-62
115k
Superior performance
LP-62
51

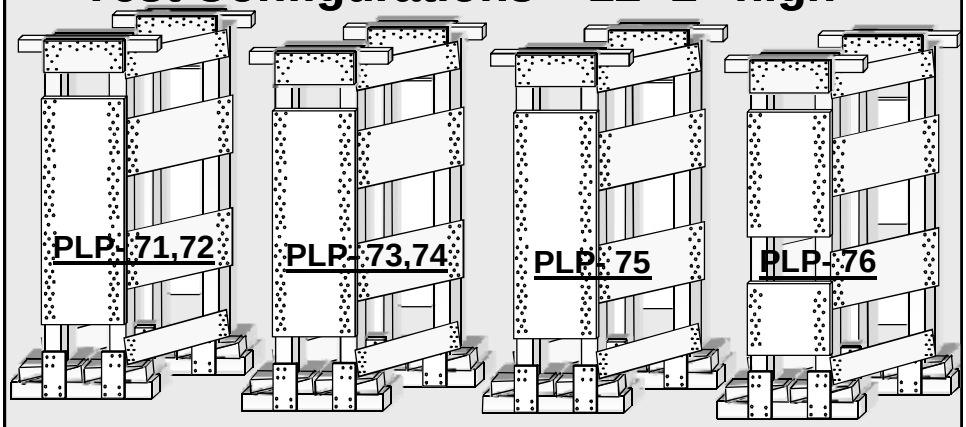

LP-63
115k
Very Superior performance
LP-63
52

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

53

Test Configurations – 12’-2” high



125k (5/8”ply) 110k (1/2”ply) 115k (3/4”OSB) 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”

54

PLP-71,72 125k
V. Good Performance
PLP-73,74,75 were similar

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

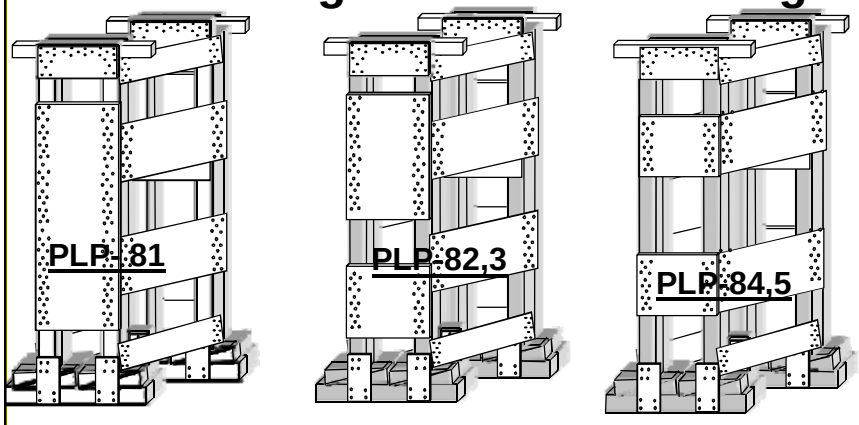
Performance as good as when using 96"ply

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



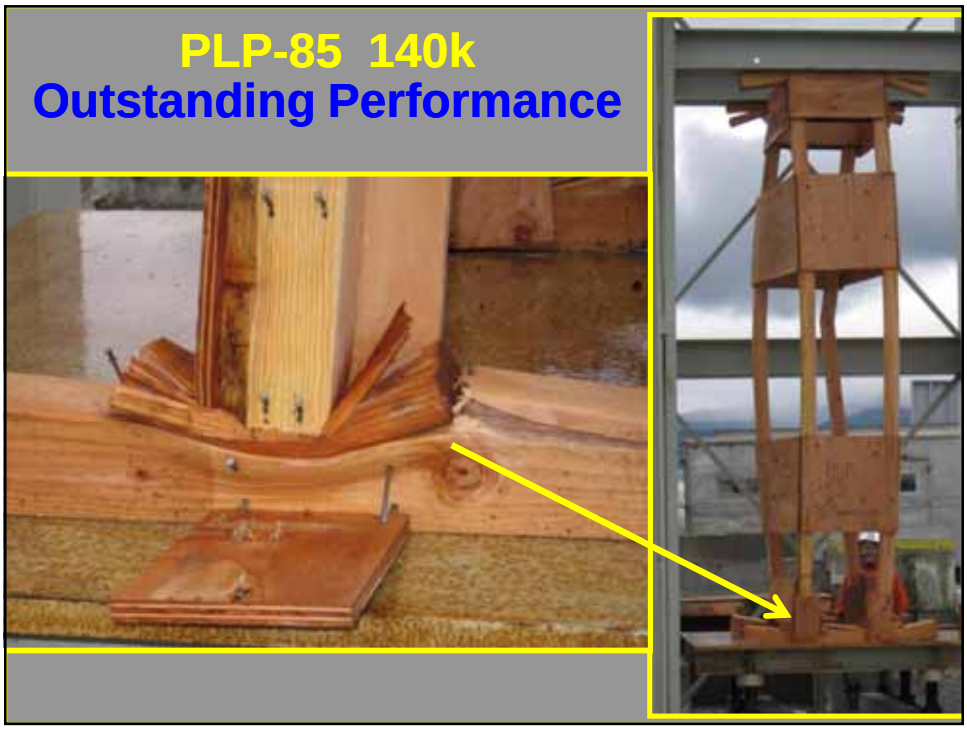
105k (1/2"ply) 115k,127k (5/8 &1/2"ply) 120k,140k (5/8 ply)

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

58


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 w/ 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

61

Sum of 12 Laced Post Tests (w/ Diag 2x)

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

62

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

63

6 - LP 4'x4'Tests (w/Ply Lacing =PLP)

Shore	Lacing	Failure	Comment
LP-32	24"Ply	103k	Fail Sim to 2x Diag Tests
LP-42	12"Ply	83k	Failed in Sys Buckling 12"Ply is NOT Adequate
LP-52	24"Ply	100k	Same as LP-32
LP-53	24"Ply	88k	Failed at poor post
LP-62	24"Ply	115k	Closer space is ply better
LP-63	24"Ply	144k	Ply was too close – not practical

64

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**

65

18-PLP 2ft x 4ft Tests w/ply lacing

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

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**

67

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**

68

Mar05 Tests – StS-2
Cribbing Specimen CB-21

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

69

Crib-CB-21 Layout
6” max travel of Loading Slab

70

CB-21- first set of 25k Conc Blocks crushes Crib 6" – Test Stopped = 42k

71

CB-21 Crushing Close-up

Bearing is 870psi

72

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

73