

**WELCOME and THANK YOU for joining**

## **Structural Screw Technology in Tall Wood Buildings**

**We will get started shortly  
10.05 PST  
1.05 EST**



## Structural Screw Technology in Tall Wood Buildings

### Presenter Max Closen

- Born and raised in Germany
- **Practical experience**
  - Apprenticeship in Carpentry in Germany
  - Journeyman in Germany
- **University education timber engineering**
  - University of Rosenheim Timber Engineering (Dipl. Ing. (FH))
  - University of British Columbia Timber Engineering (MaSc)



## Structural Screw Technology in Tall Wood Buildings

### The webinar outlook

- Lookout on typical Cross Laminated Timber (CLT) connections
- Summary of recent North American test data
- Summary of proposed design procedures and design values

## Outline

- Group #1 **Panel to beam** connection in Tall Wood
  - Panel to beam connection with CLT
  - Panel to beam connection with glulam
- Group #2 Panel to panel connection in Tall Wood
  - Surface spline connections
  - Half lap connections – 2 types
  - Butt connections
- We present test data and results
  - Statistics
  - Failure modes
  - Proposed design methods/values

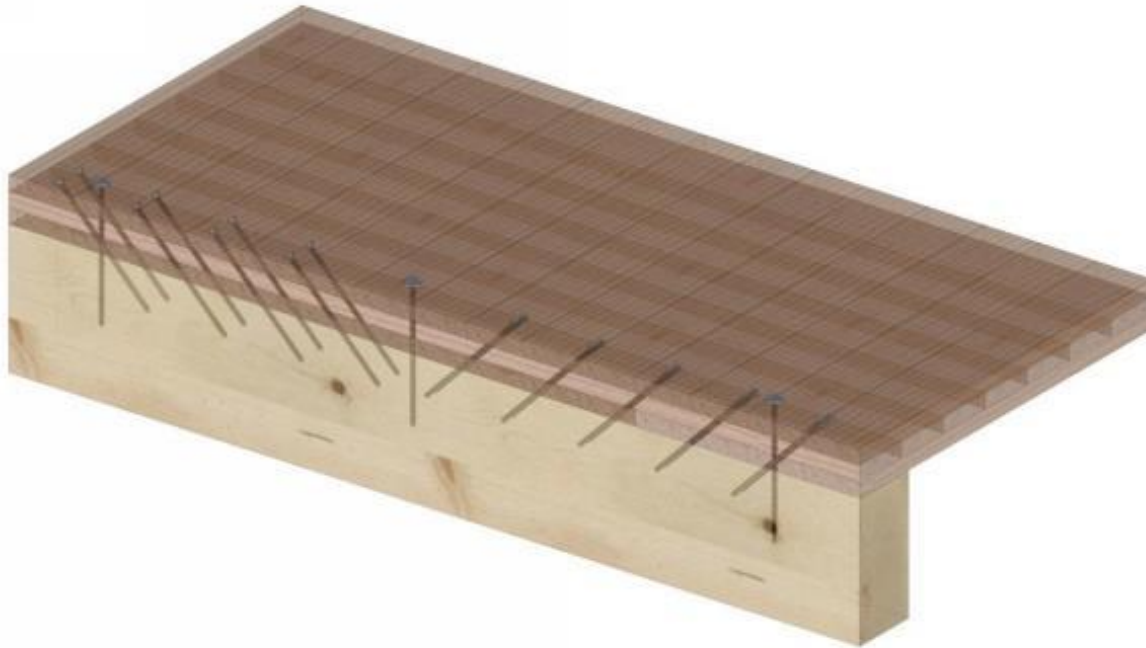


## Outline

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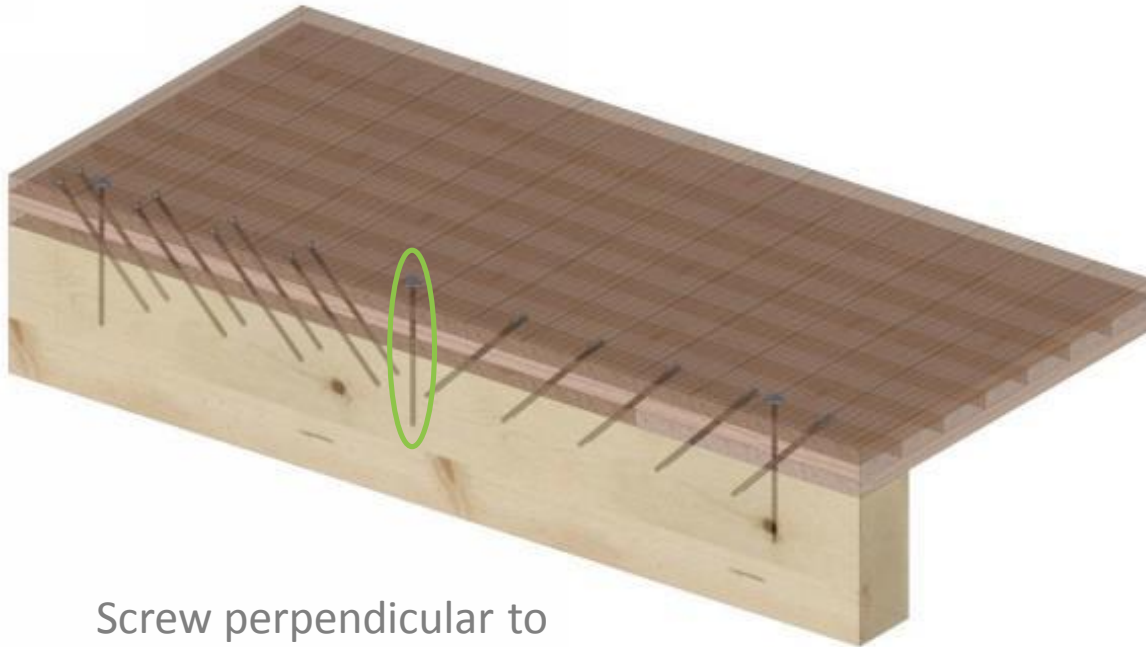
## Panel to Beam Connections

- Panel to beam connection i.e. diaphragm to post - beam structure



## Panel to Beam Connections

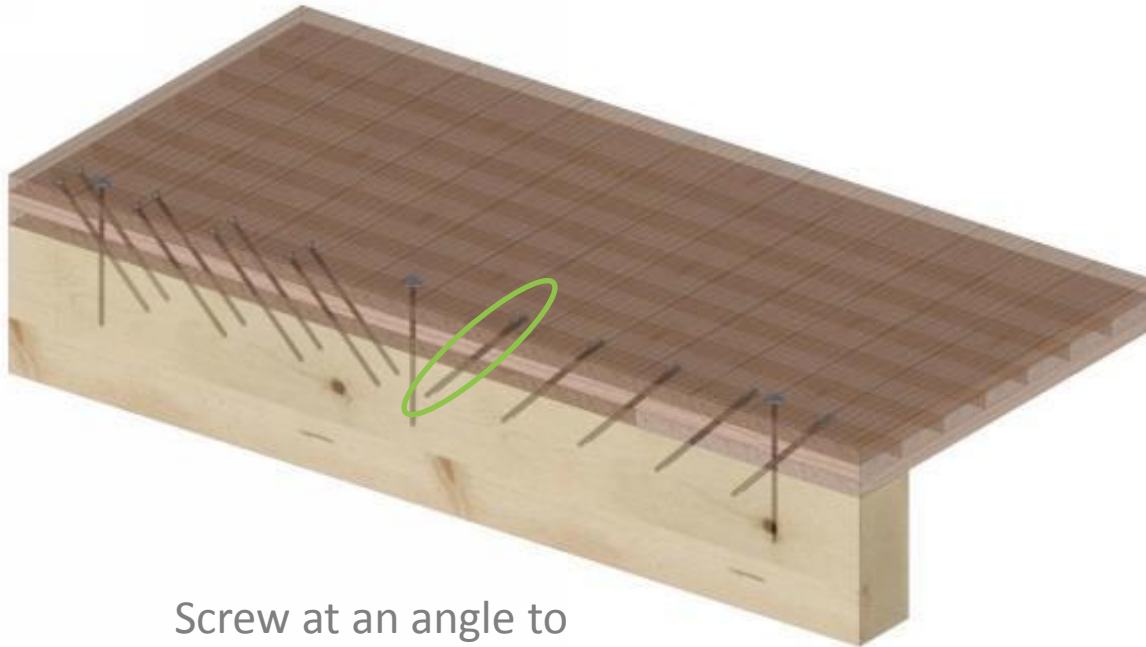
- Connector Layout #1



Screw perpendicular to  
panel plane in shear action

## Panel to Beam Connections

- Connector Layout #2

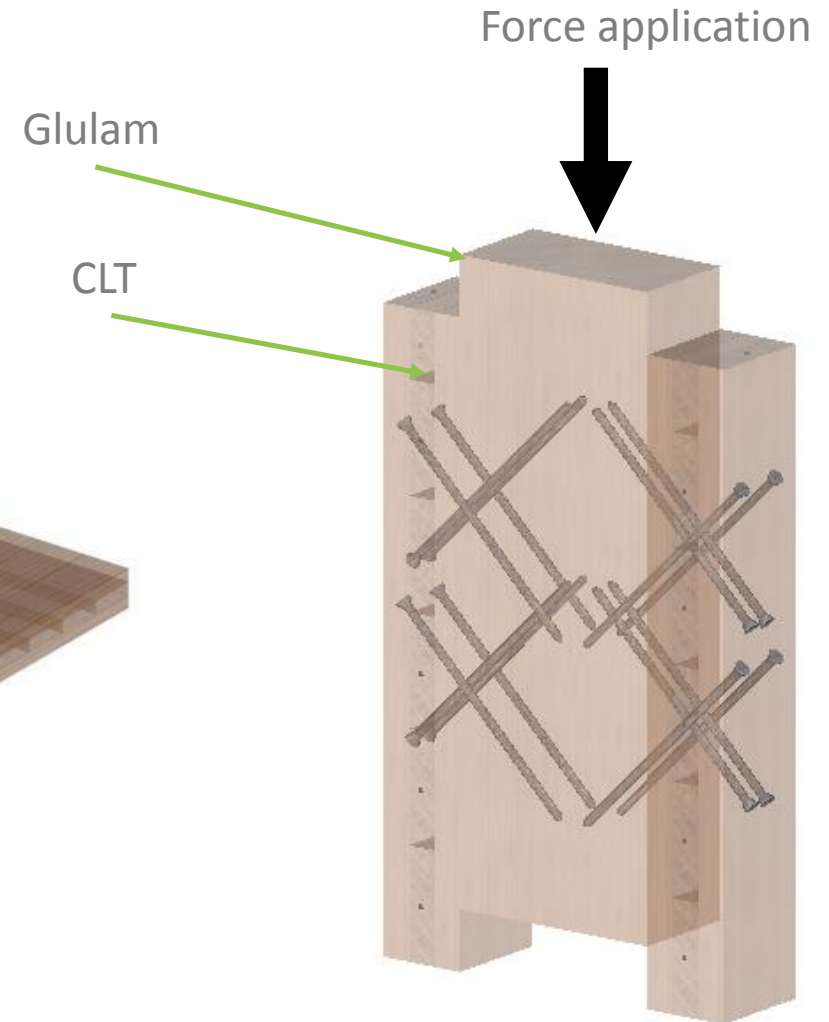
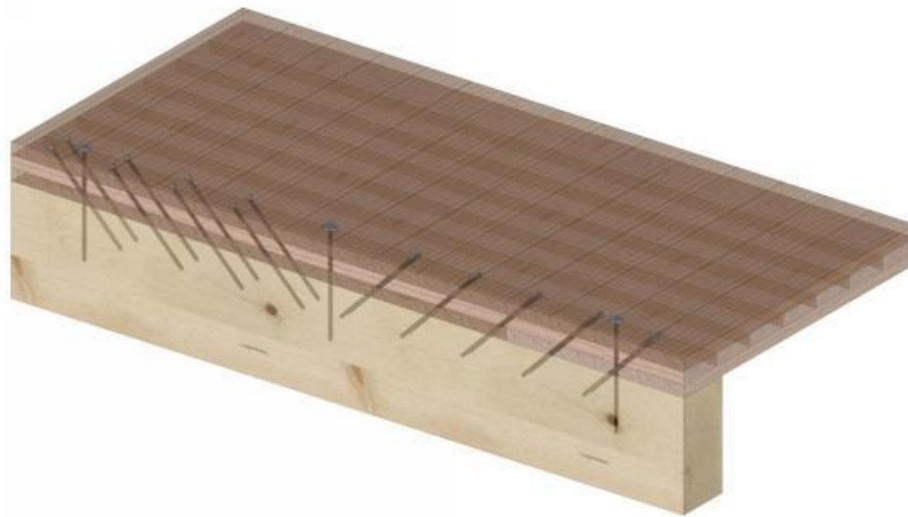


Screw at an angle to  
panel plane in tension



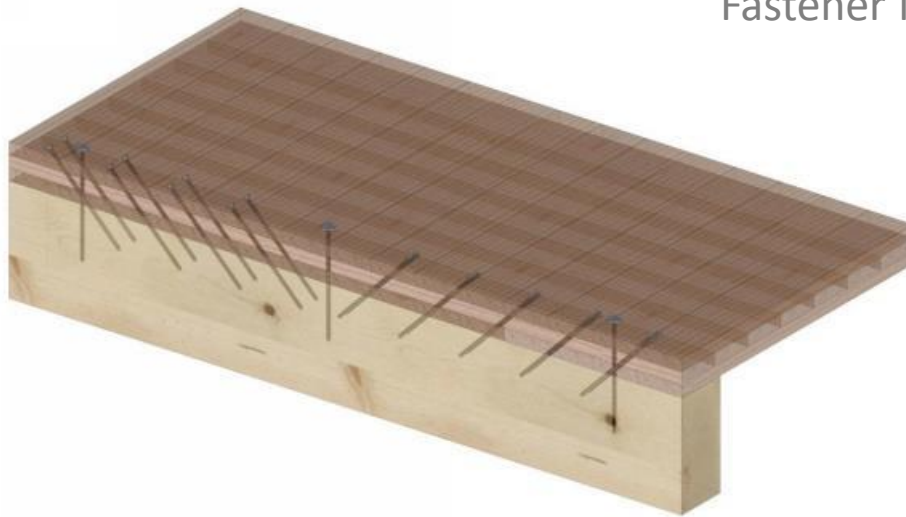
## Panel to Beam Connections

- Setup for testing



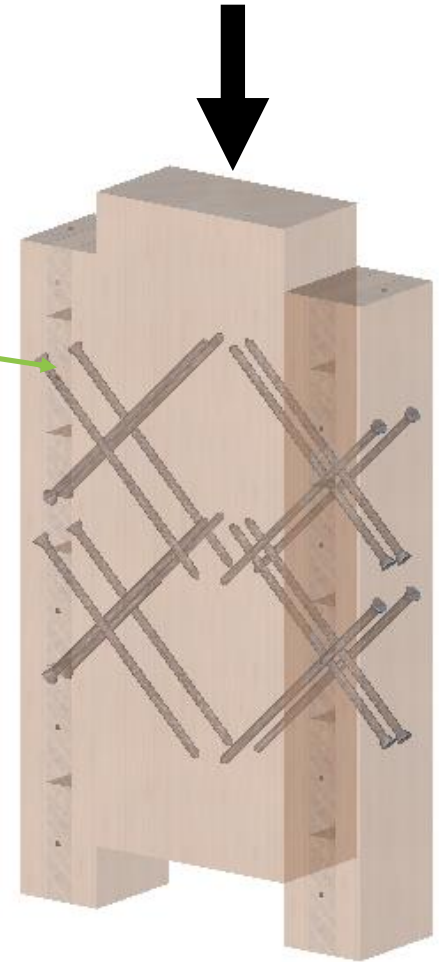
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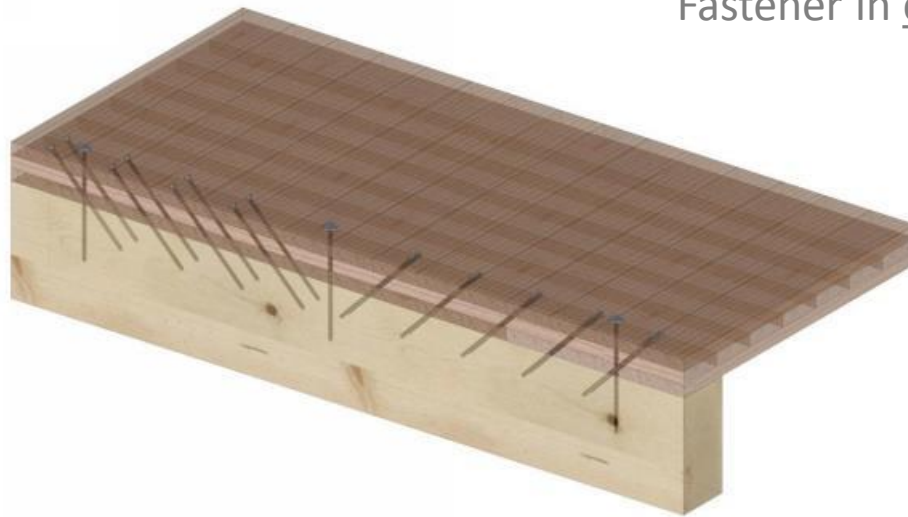
Fastener in tension

Force application



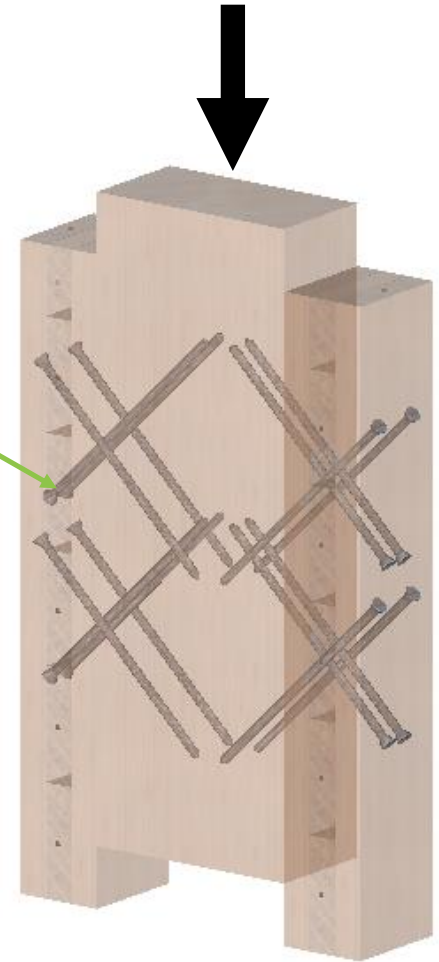
## Panel to Beam Connections

- Setup for testing



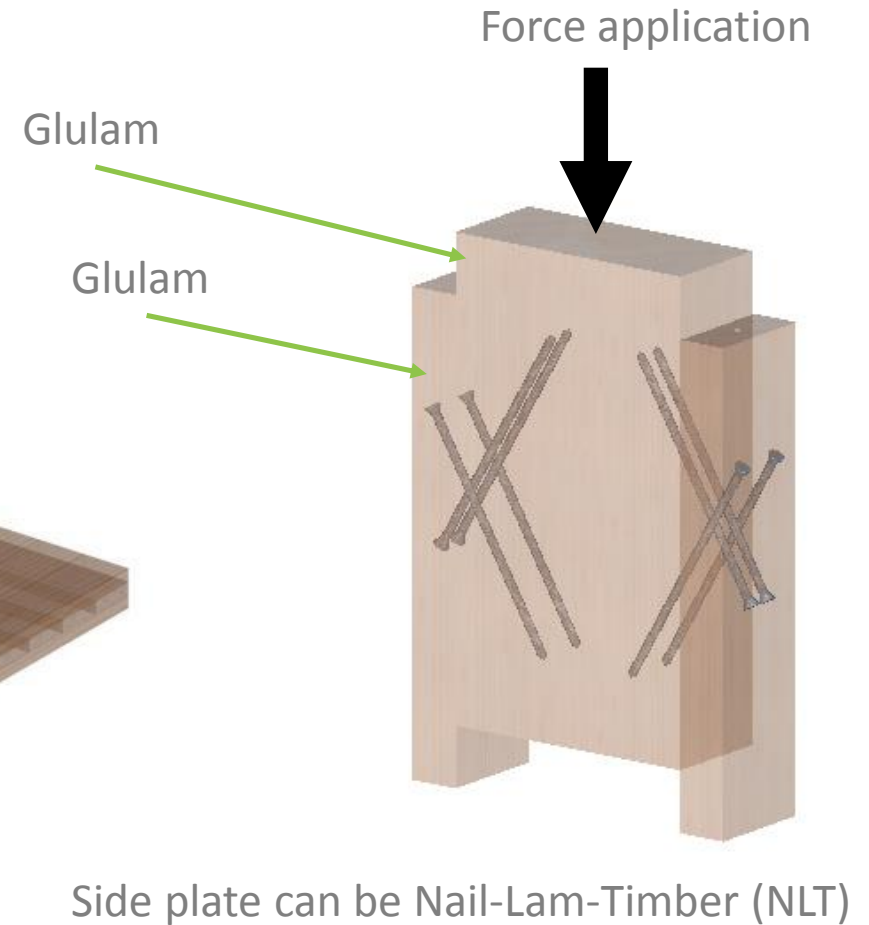
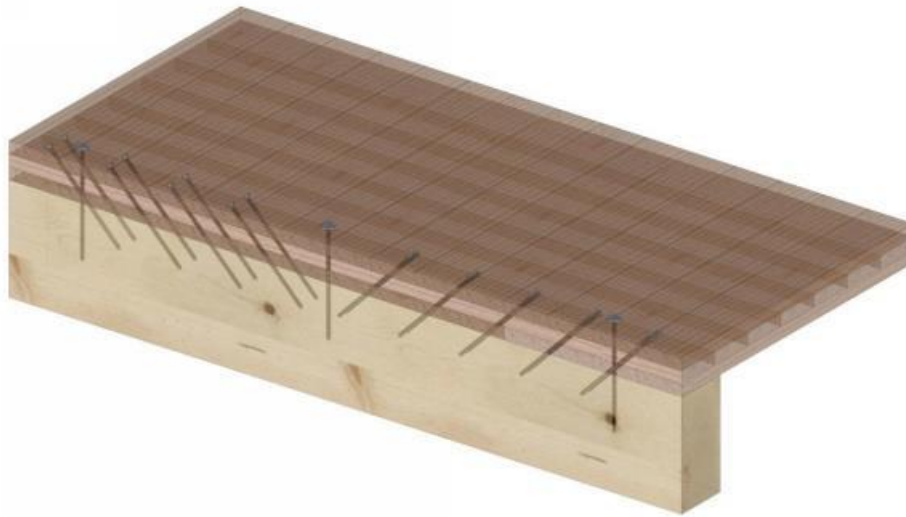
Fastener in compression

Force application



## Panel to Beam Connections

- Setup for testing





## Panel to Beam Connections

- Setup for testing

Reaction Frame

Actuator



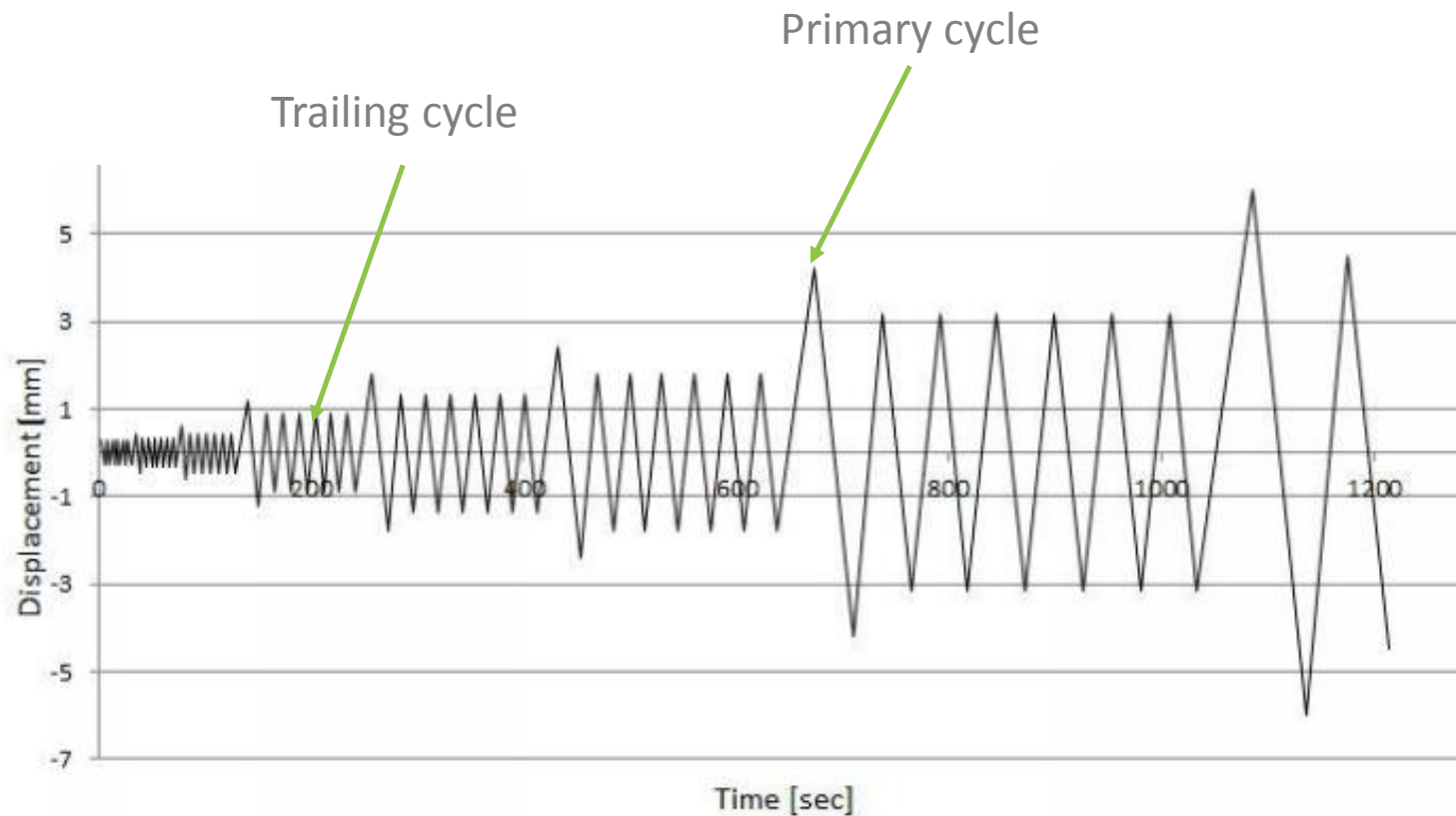
Load application assembly



Reaction Frame

## Panel to Beam Connections

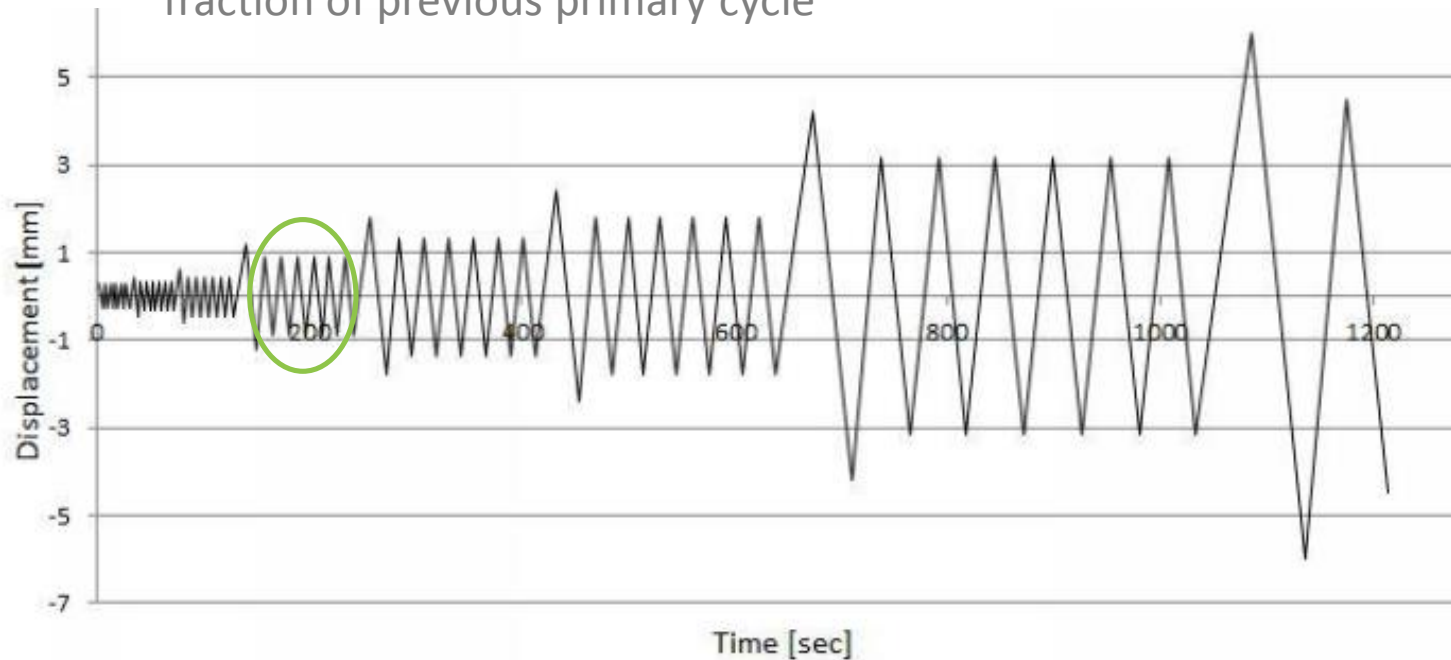
- Loading procedure – displacement controlled CUREE



## Panel to Beam Connections

- Loading procedure – displacement controlled CUREE

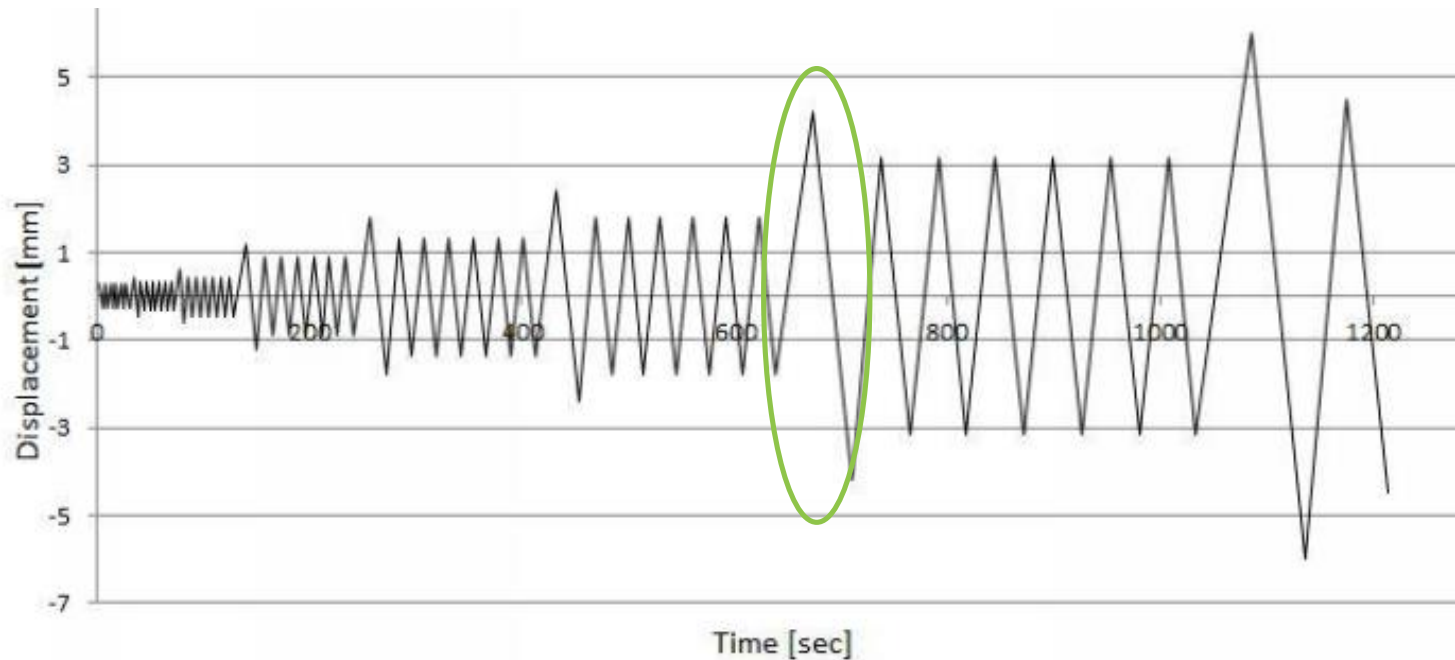
Trailing cycle – displacement applied at fraction of previous primary cycle



## Panel to Beam Connections

- Loading procedure – displacement controlled CUREE

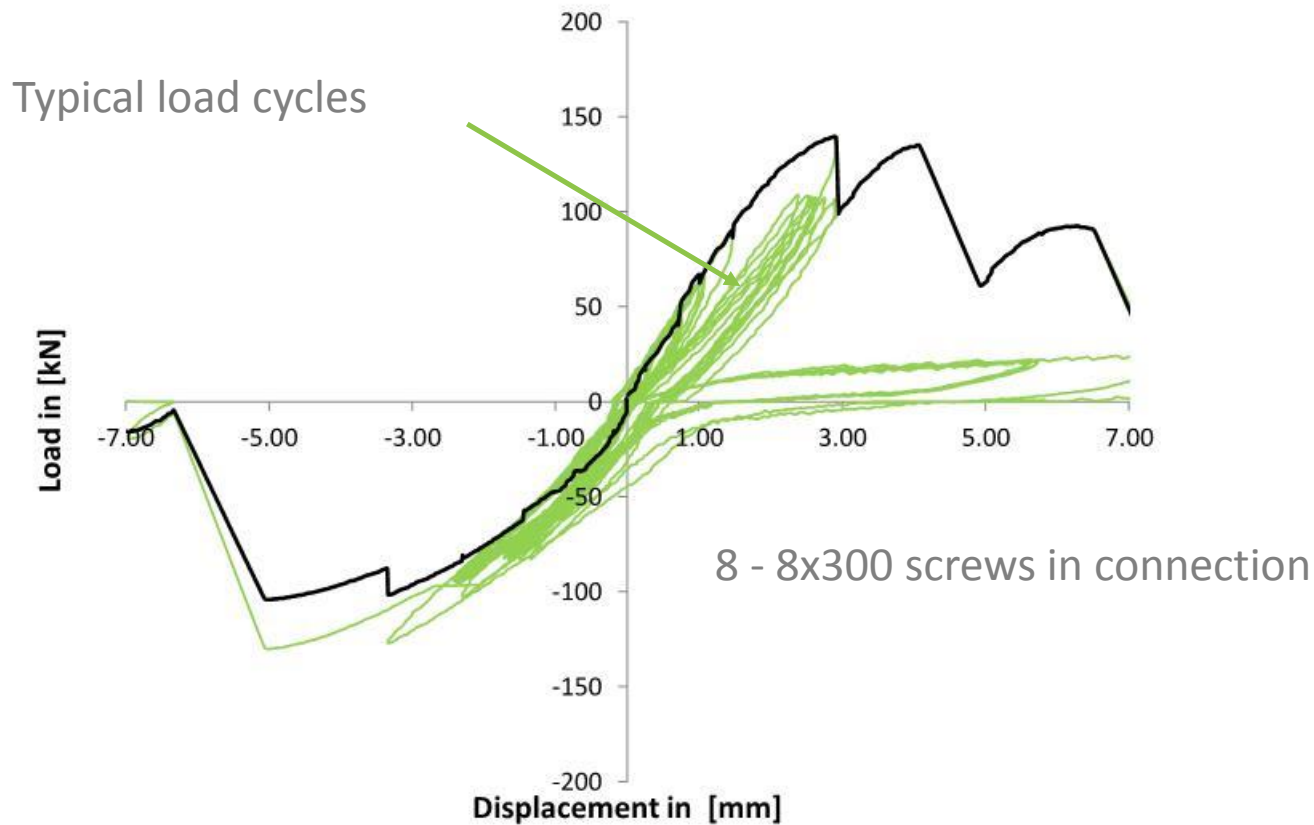
Primary cycle – displacement applied increased





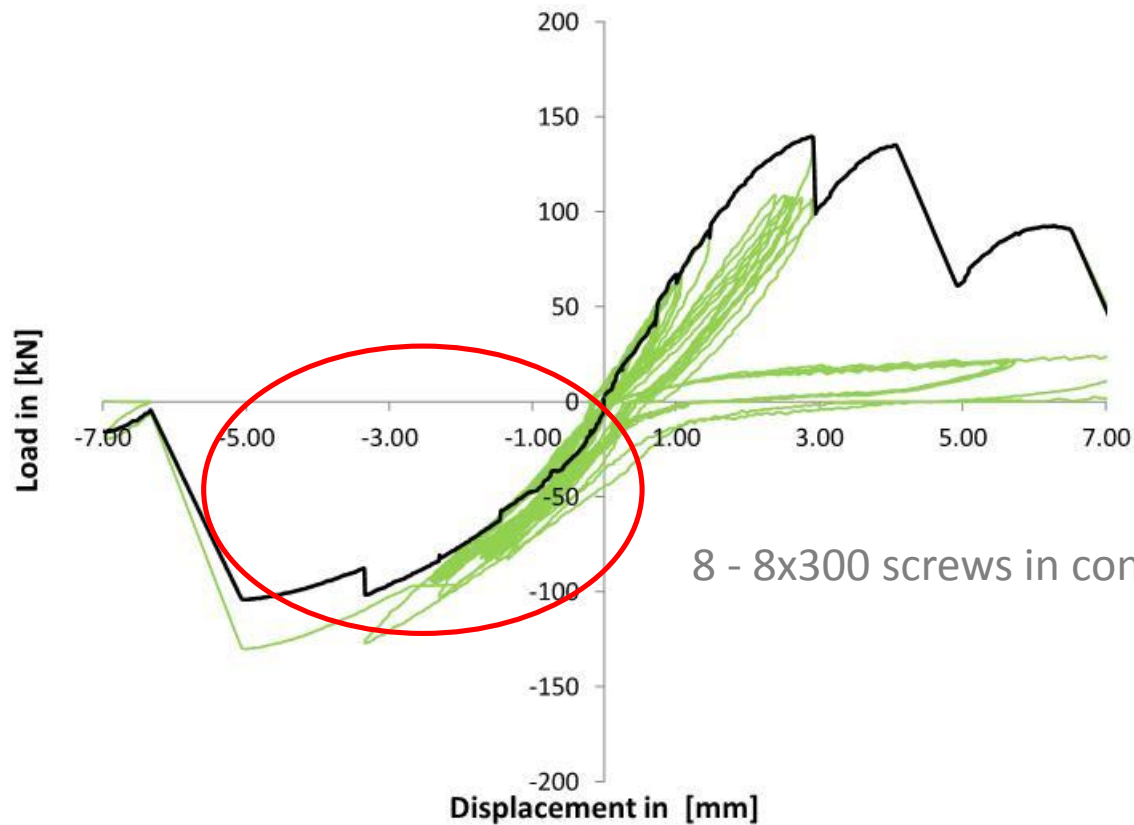
## Panel to Beam Connections

- Typical load displacement curve

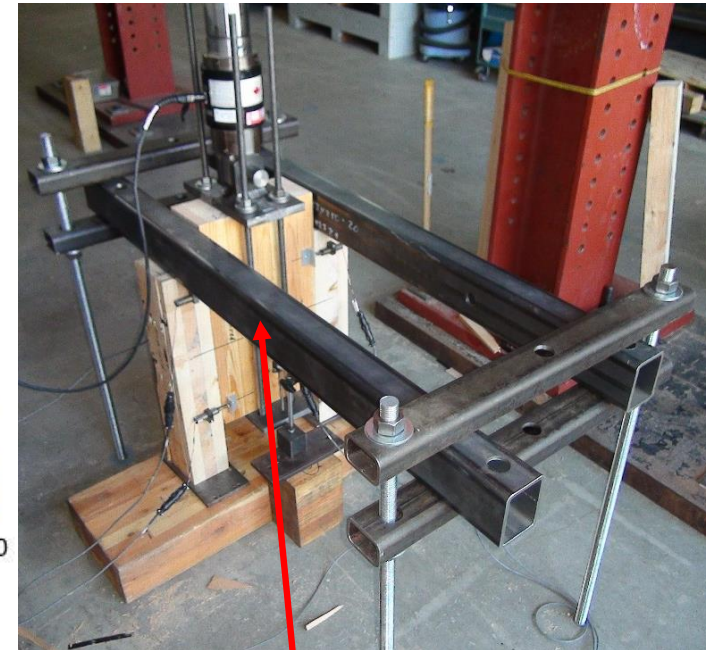


## Panel to Beam Connections

- Typical load displacement curve



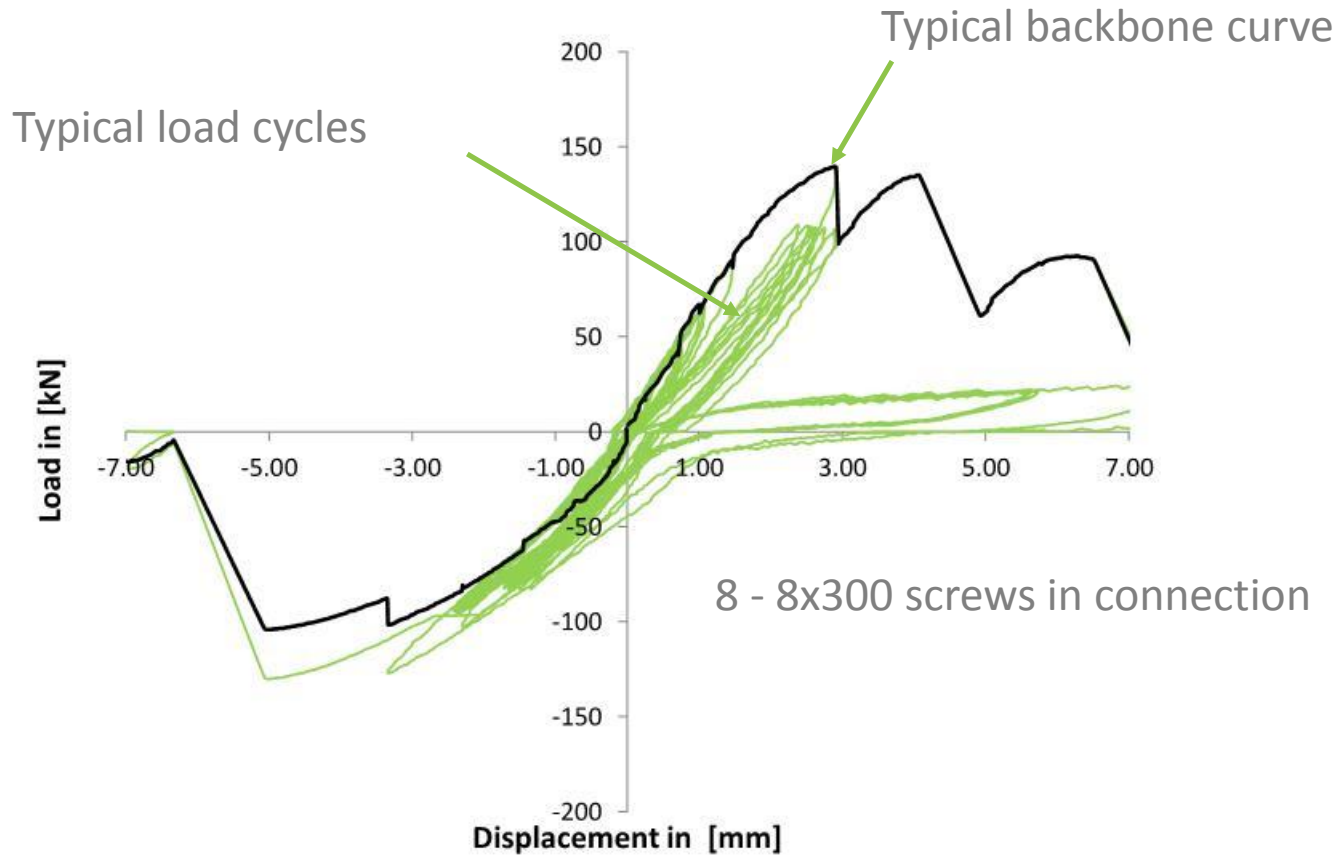
8 - 8x300 screws in connection



Cross beam deflection

## Panel to Beam Connections

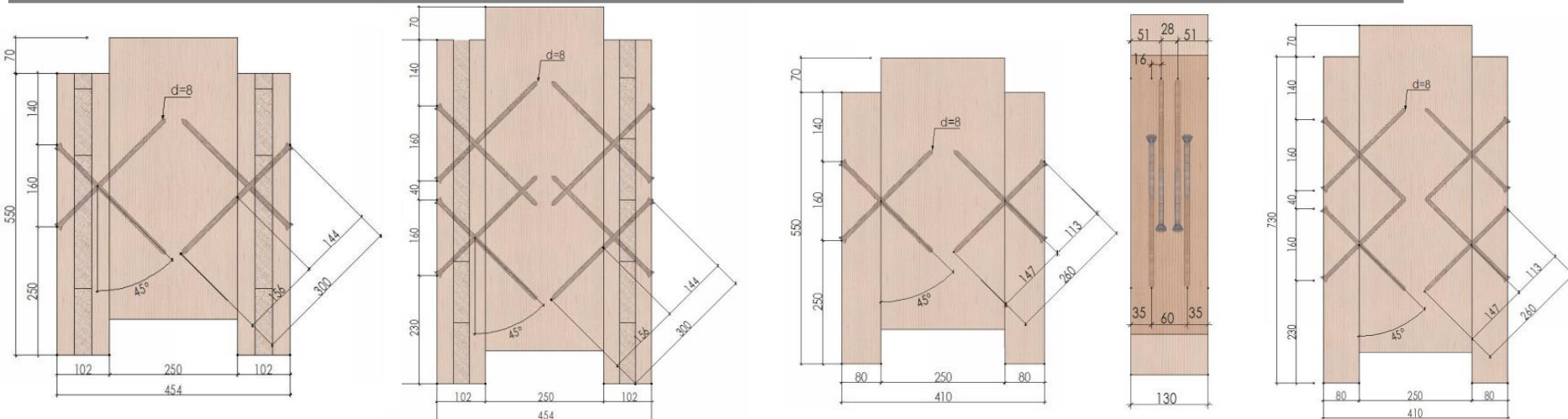
- Typical load displacement curve



## Panel to Beam Connections

Specimen	F <sub>max</sub> [kN]	Displ. F <sub>max</sub> [mm]	0.4 F <sub>max</sub> [kN]	Displ. 0.4 F <sub>max</sub> [mm]	0.7 F <sub>max</sub> [kN]	Displ. 0.7 F <sub>max</sub> [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F <sub>max</sub> [kN/mm]	Stiffness 0.7 F <sub>max</sub> [kN/mm]
CLT to GL 8 - 8x300 FT@45°	143.6	3.48	57.5	1.58	100.5	2.41	41.26	36.39	41.7
CLT to GL 16 - 8x300 FT@45°	268	2.2	107.5	0.77	187.6	1.21	121.8	139.61	155.04
GL to GL 8 - 8x260 FT@45°	154.6	3.8	61.83	1.54	108	2.34	40.68	40.14	46.15
GL to GL 16 - 8x260 FT@45°	245	1.6	98	0.55	171	0.81	153.12	178.12	211.11

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

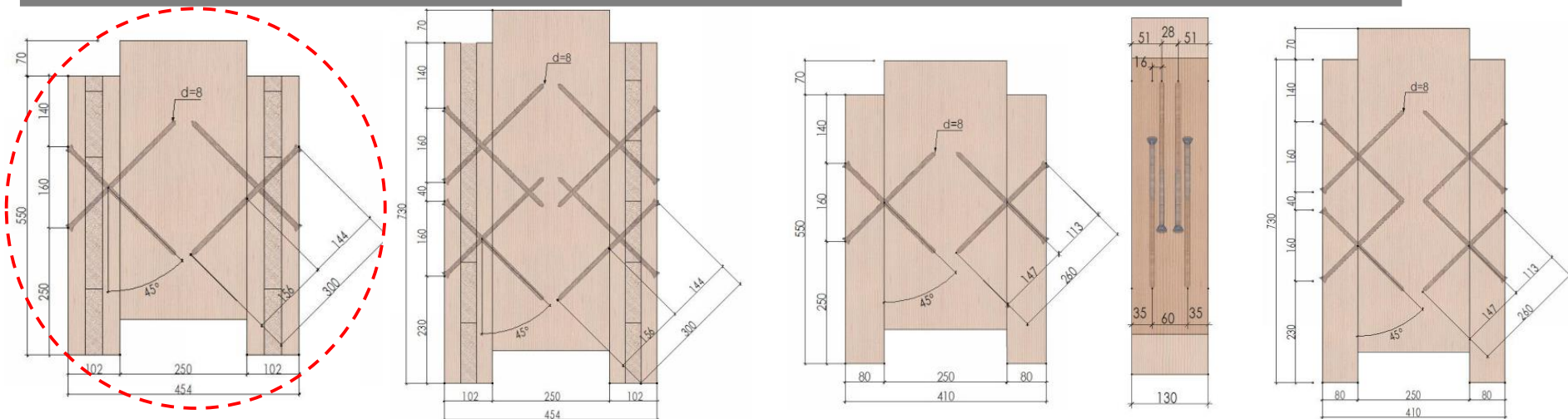




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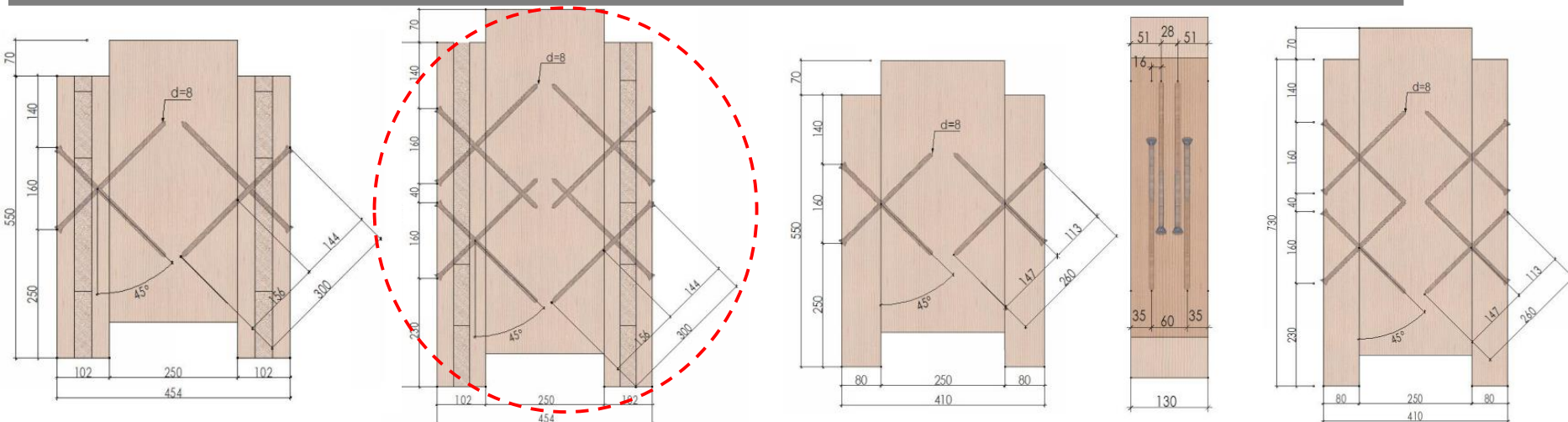
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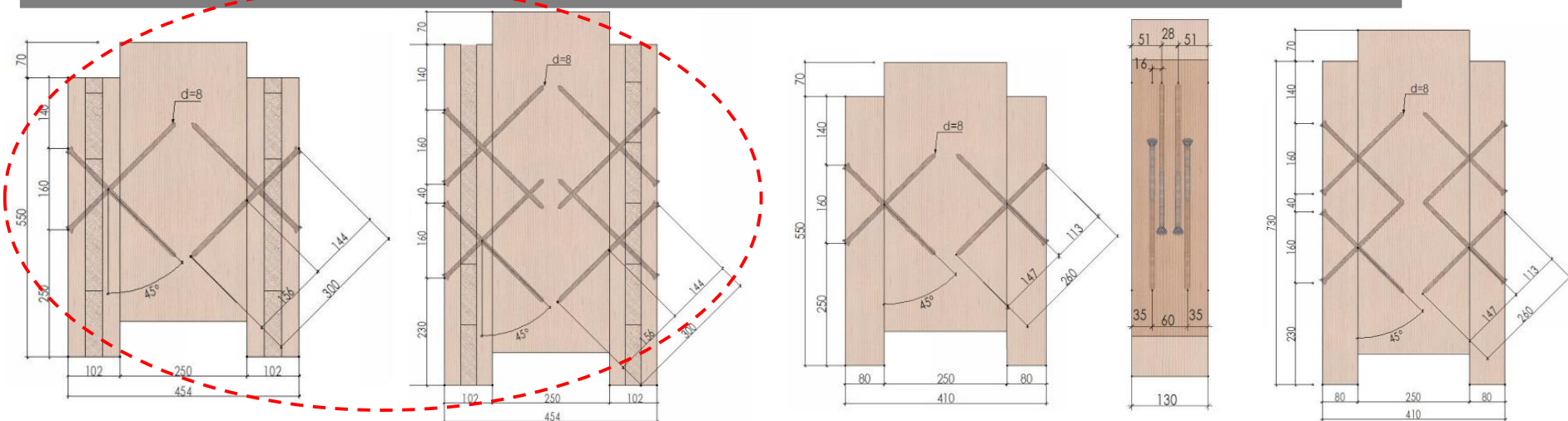
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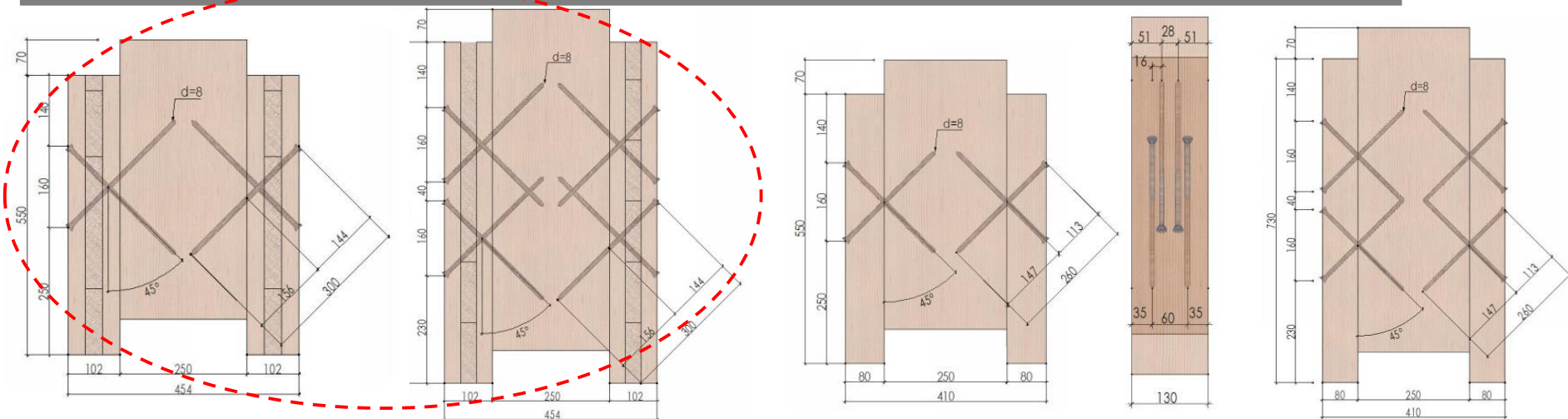
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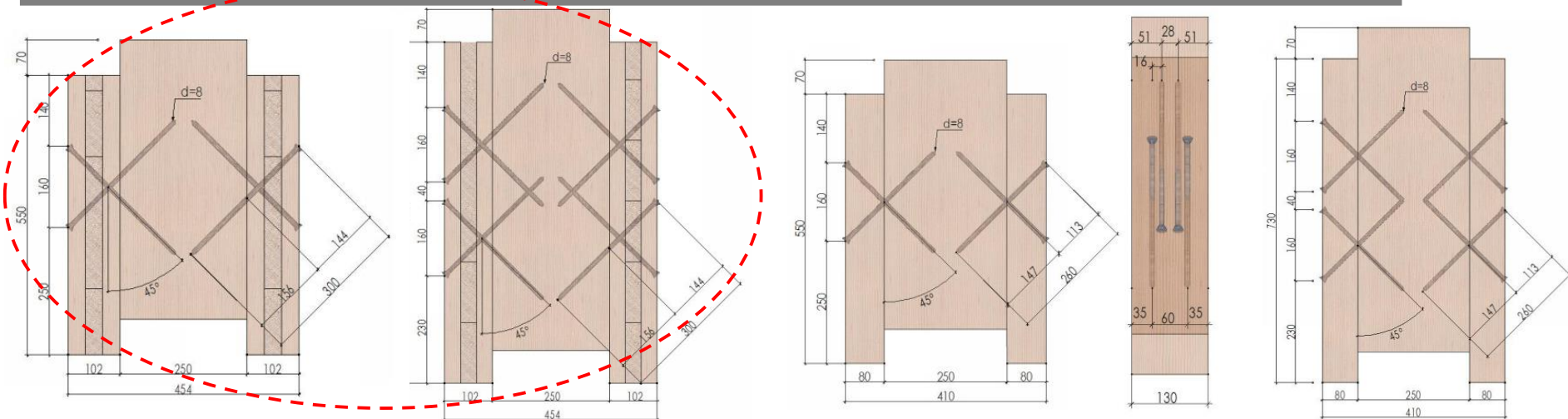
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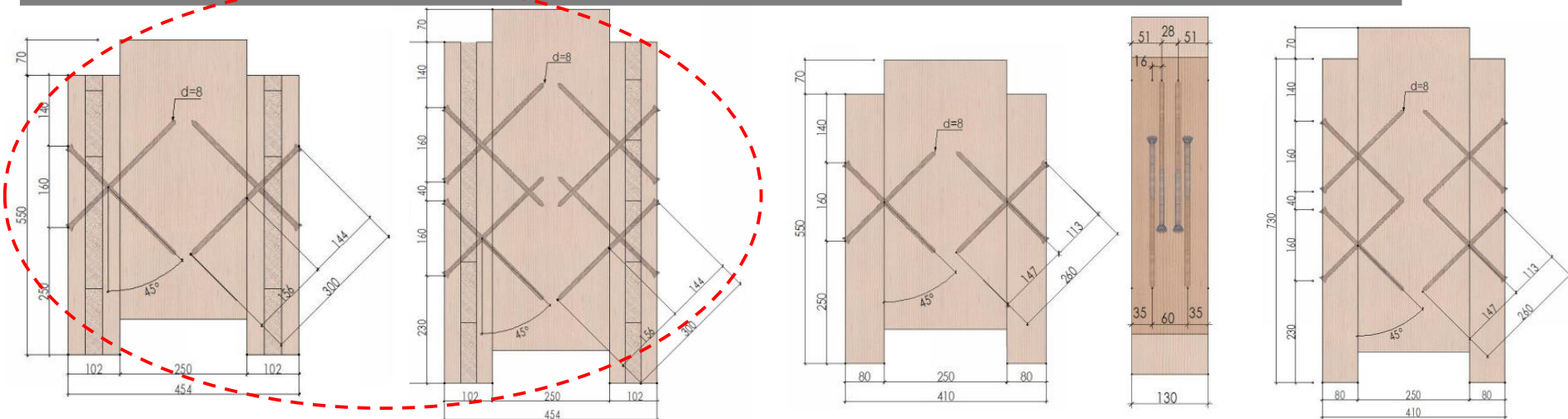




## Panel to Beam Connections

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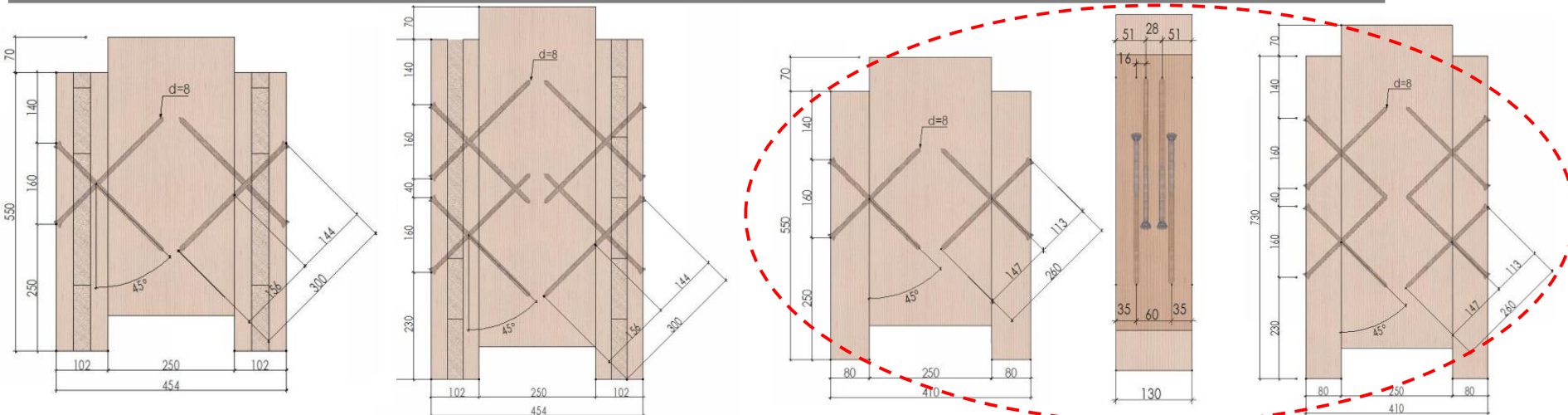




## Panel to Beam Connections

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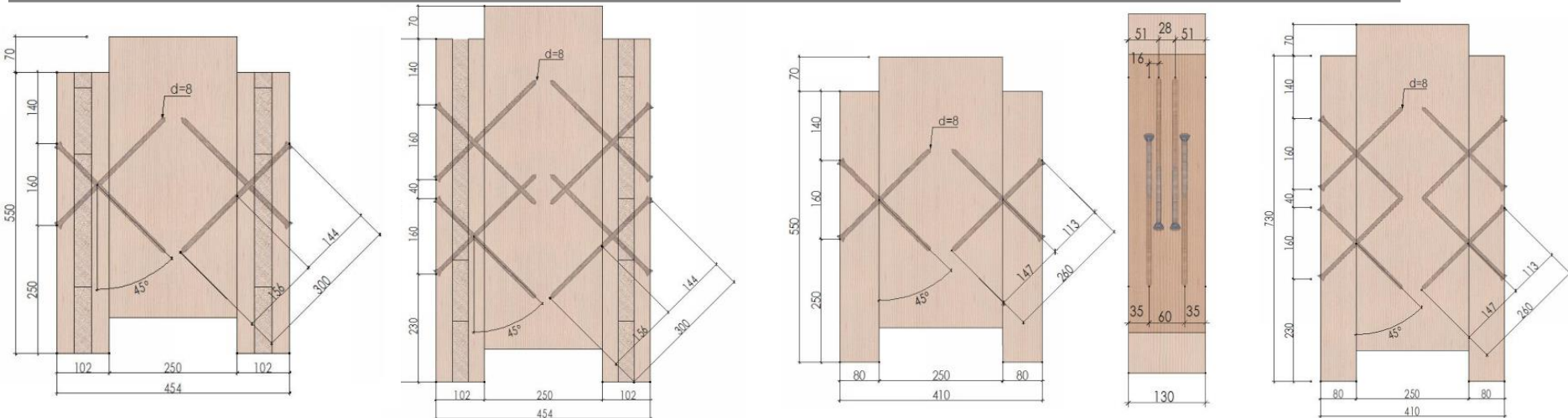


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Specimen	F <sub>max</sub> [kN]	Displ. F <sub>max</sub> [mm]	0.4 F <sub>max</sub> [kN]	Displ. 0.4 F <sub>max</sub> [mm]	0.7 F <sub>max</sub> [kN]	Displ. 0.7 F <sub>max</sub> [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F <sub>max</sub> [kN/mm]	Stiffness 0.7 F <sub>max</sub> [kN/mm]
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double fasteners ≠ double resistance – group effect?

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

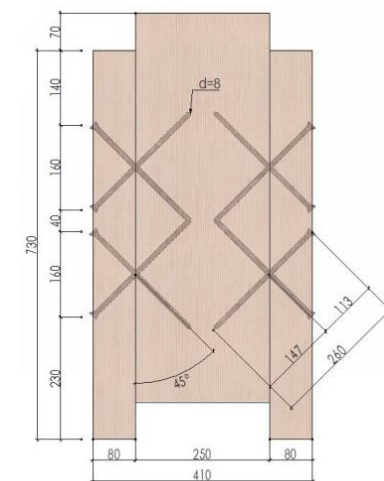
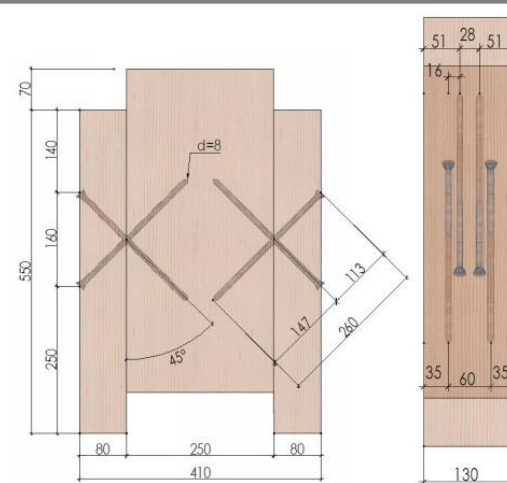
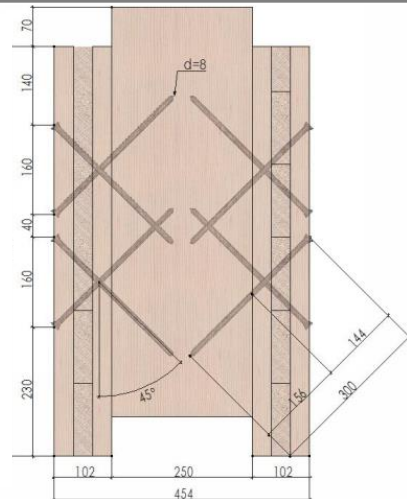
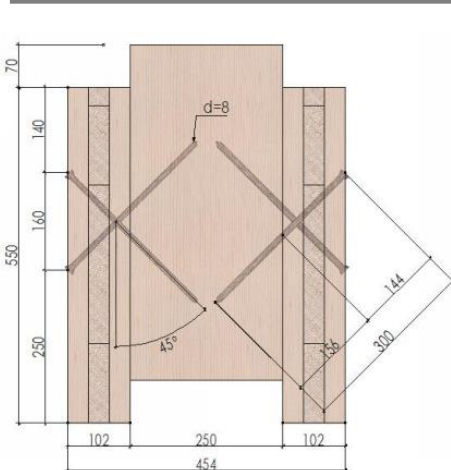


## Panel to Beam Connections

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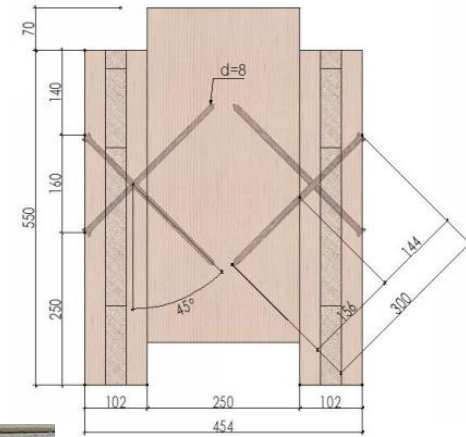
more fasteners = less displacement

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw



## Panel to Beam Connections

- Typical failure mode – screw breakage

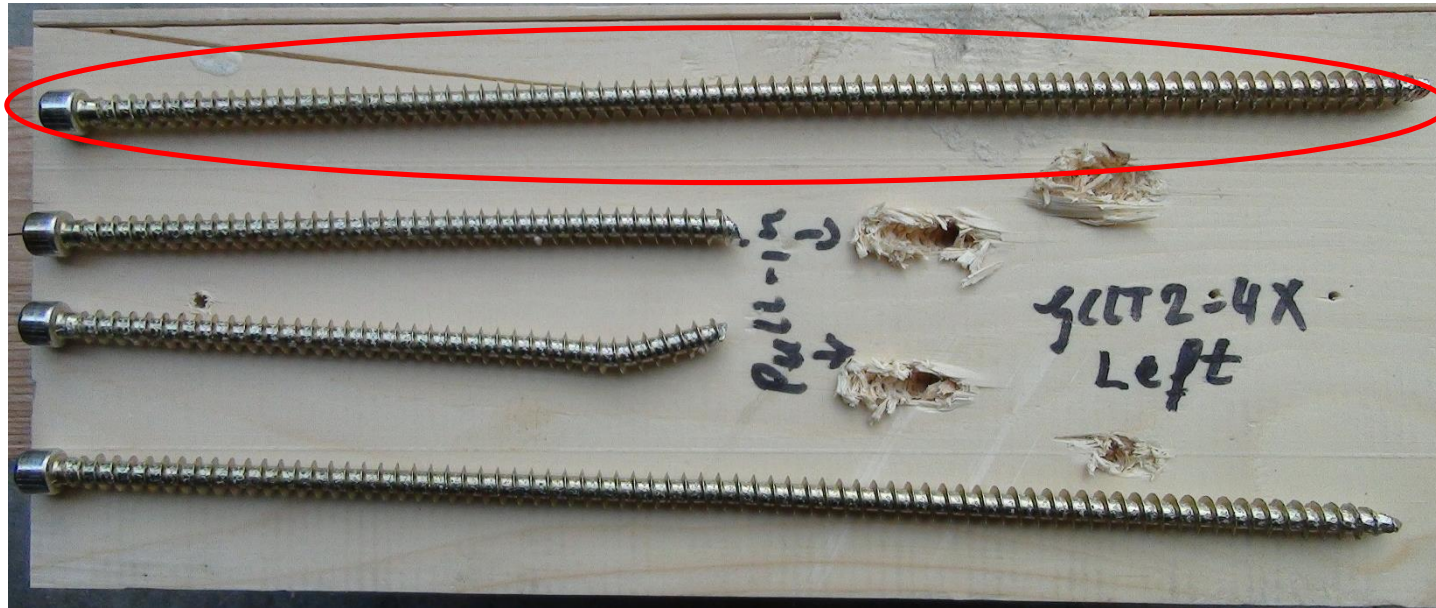
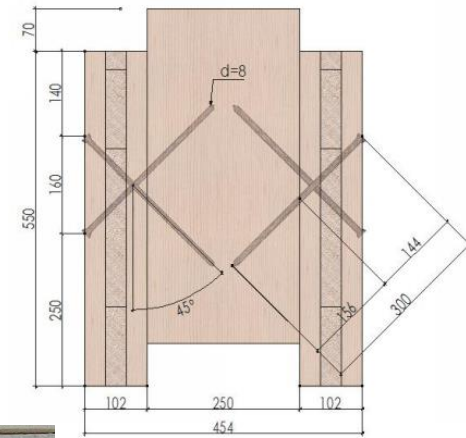




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- Typical failure mode – screw breakage

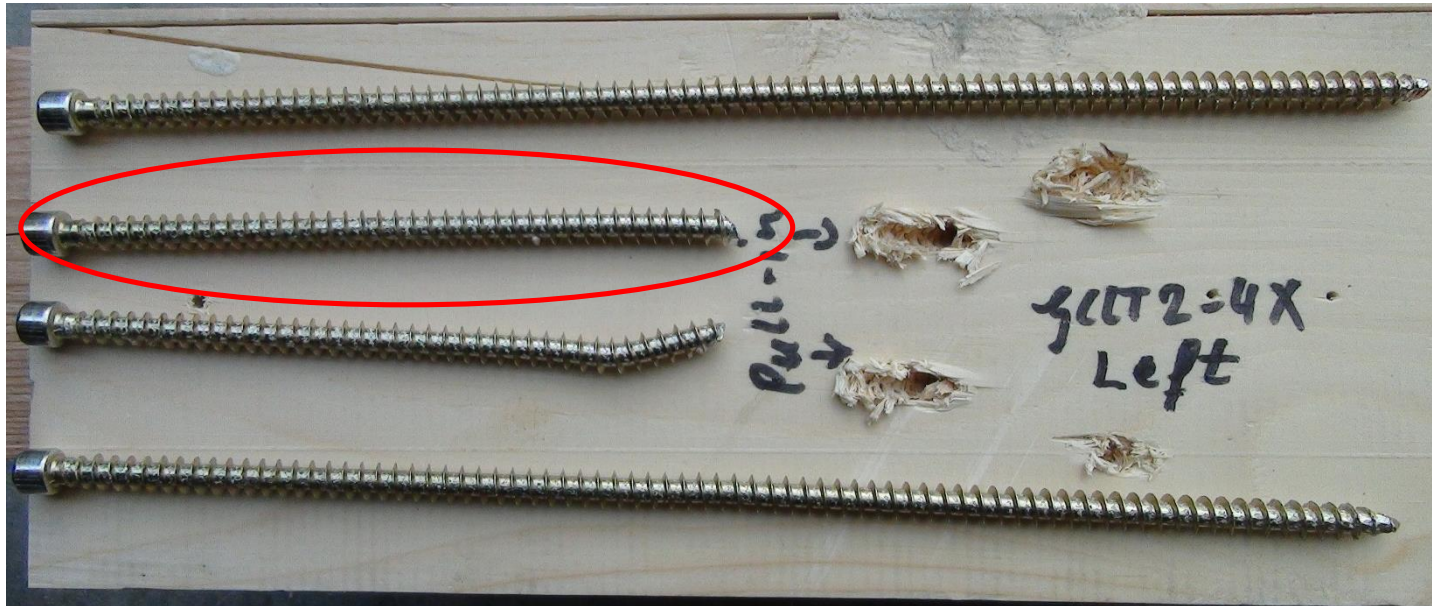
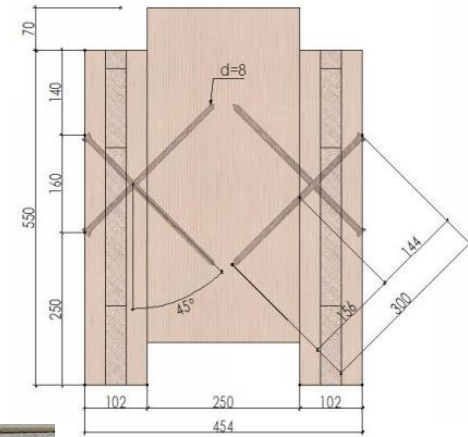
No visible damage



## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure

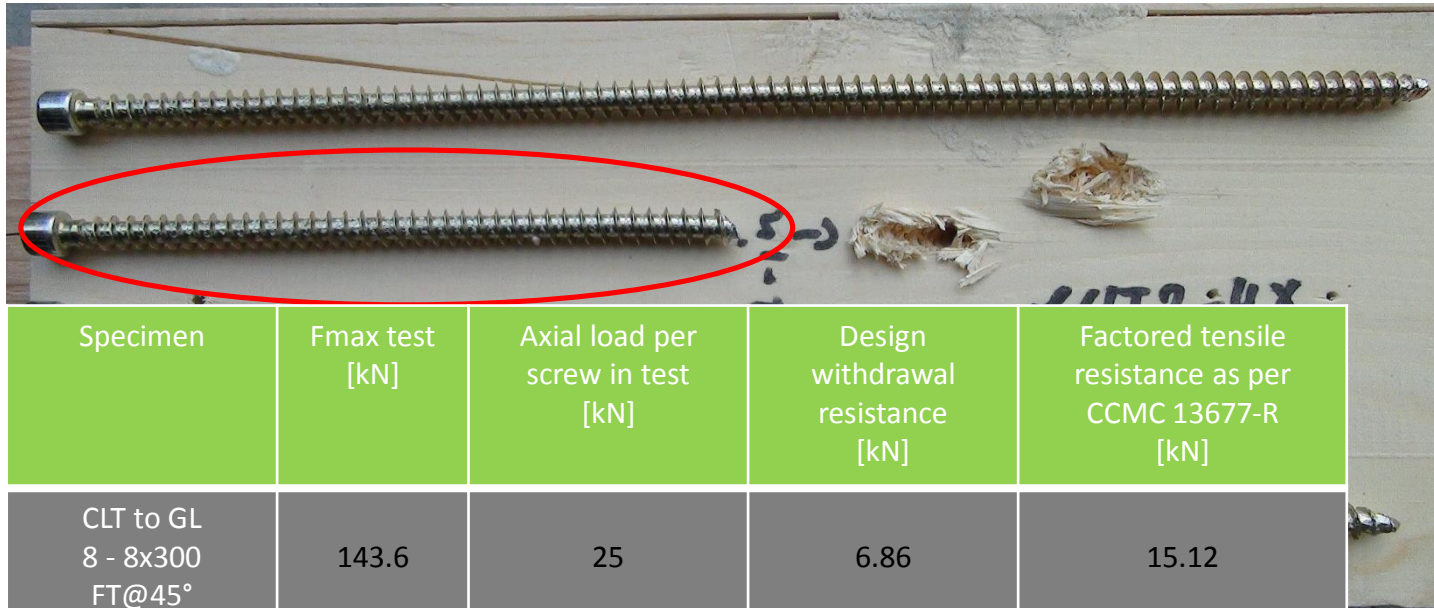
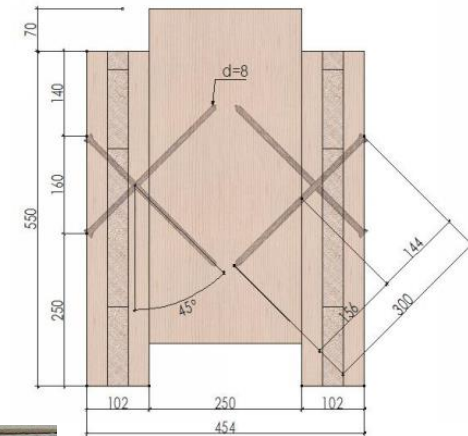




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- Typical failure mode – screw breakage

Tension failure

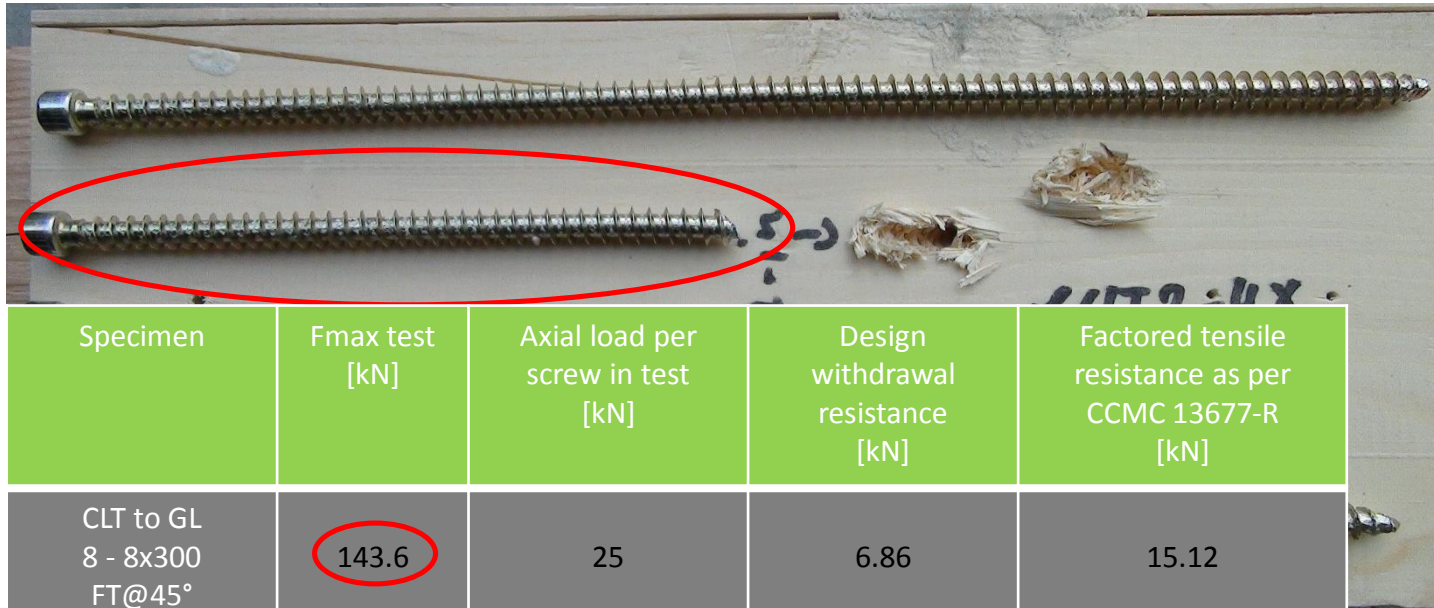
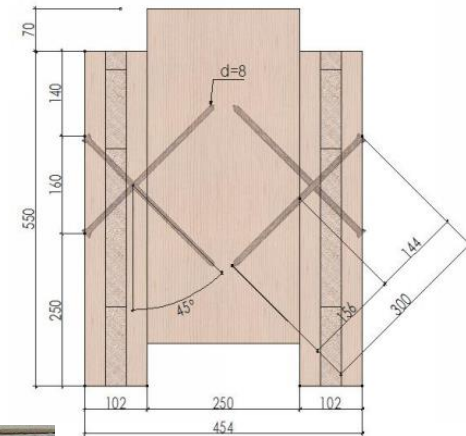


Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
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## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure

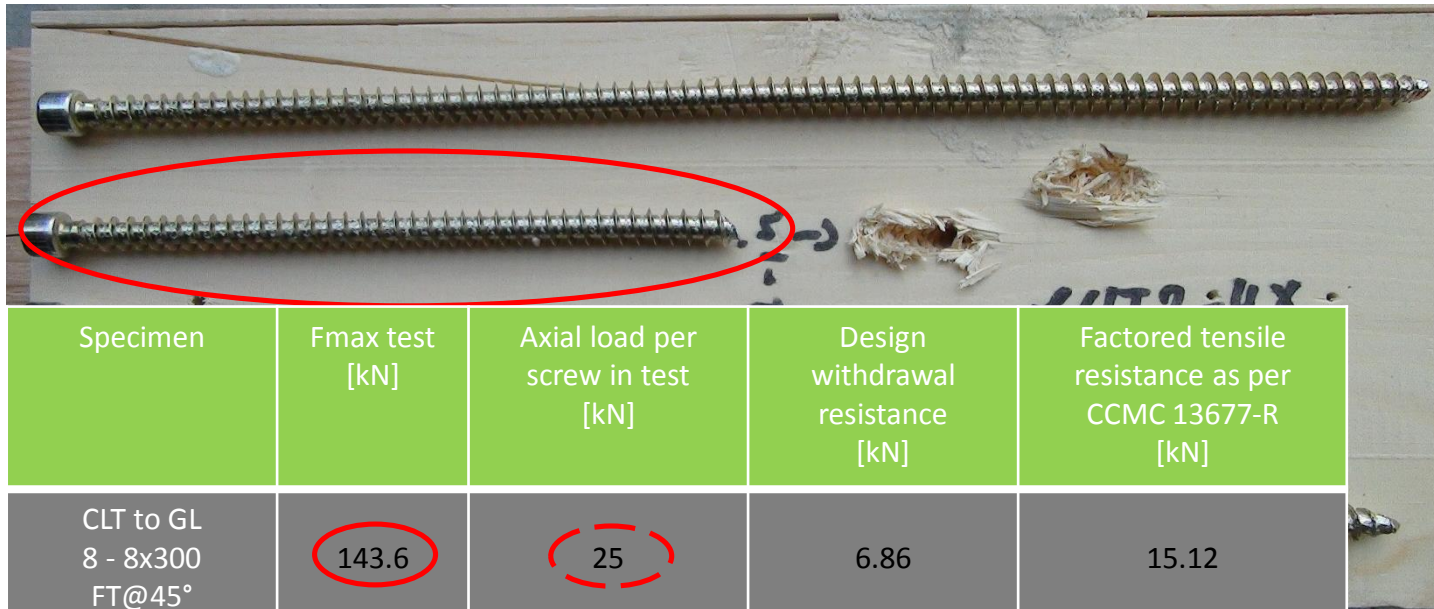
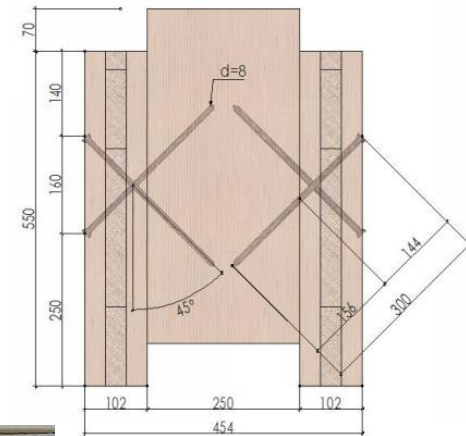


Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12

## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure

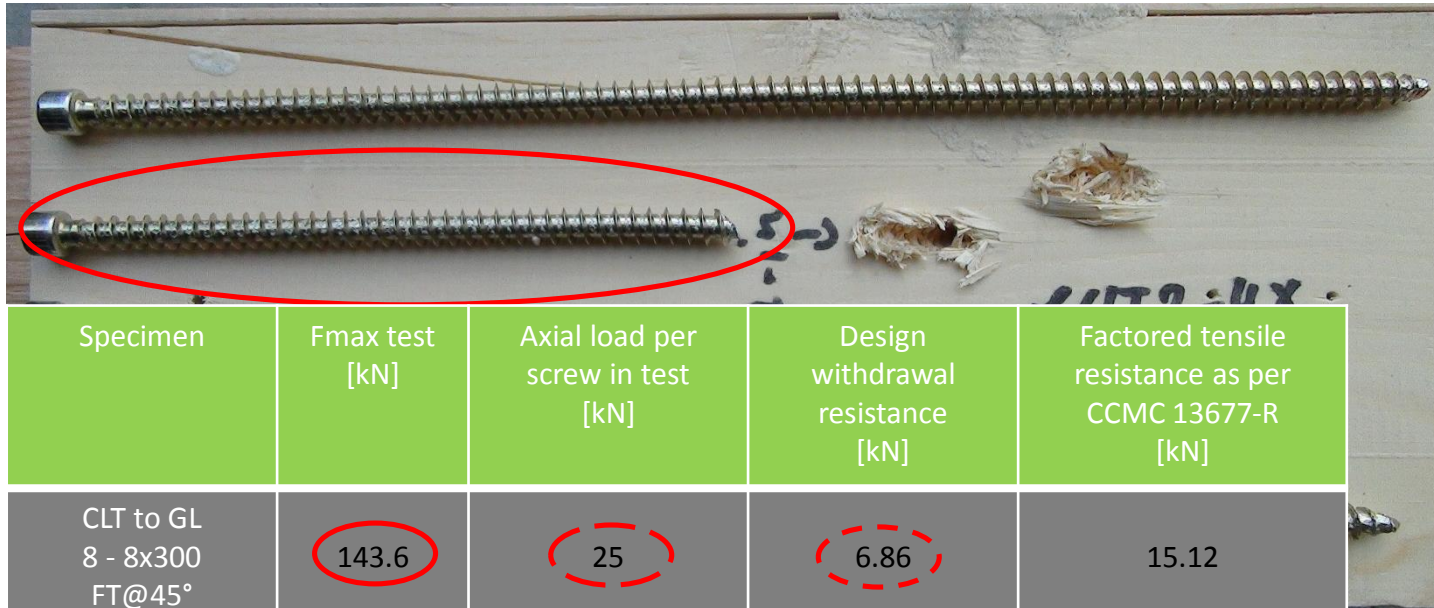
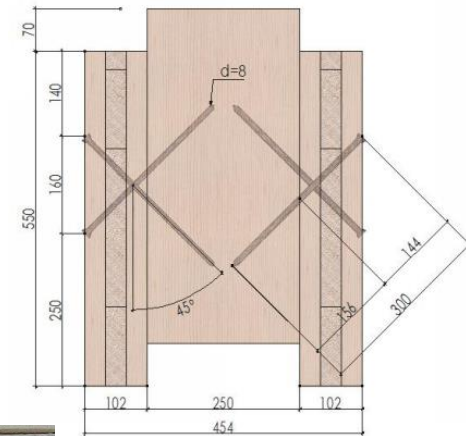


Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12

## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure



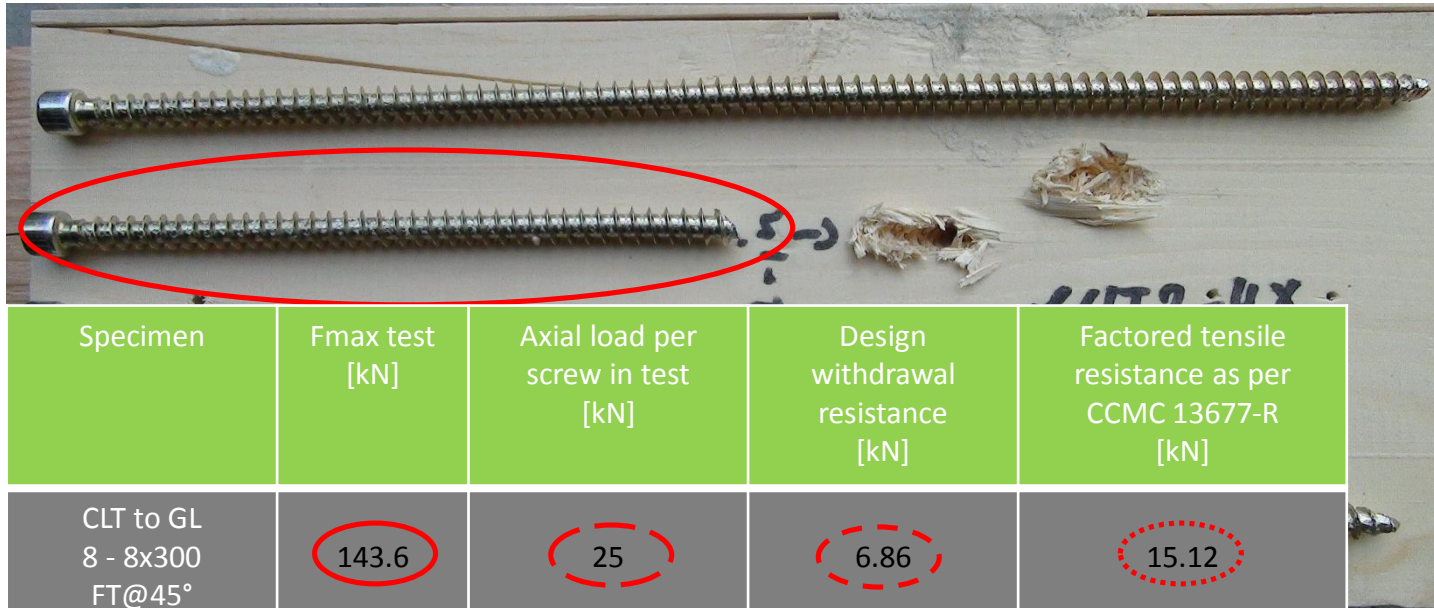
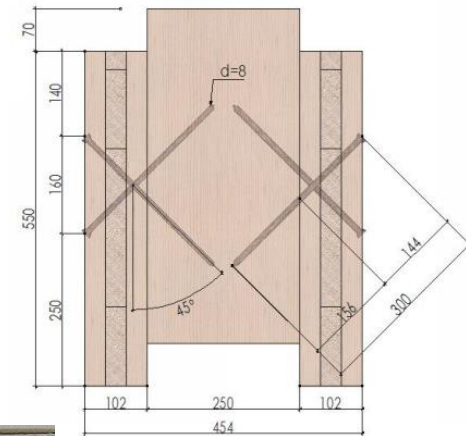
Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12



## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure

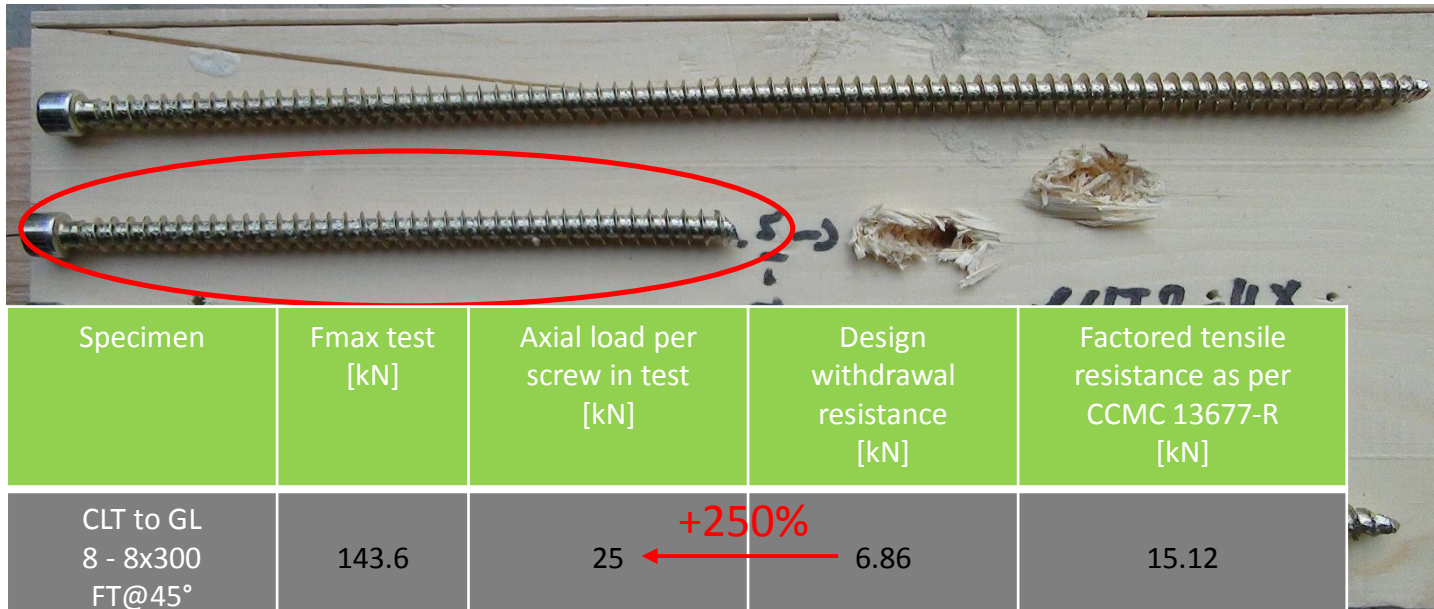
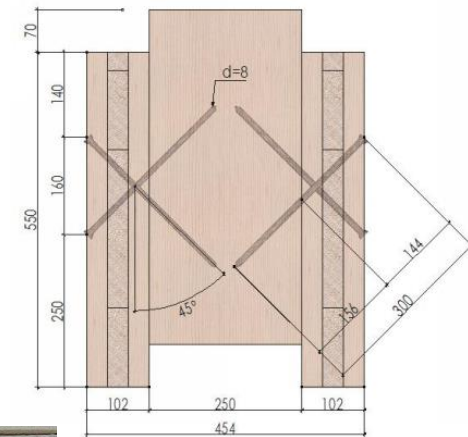


Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12

## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure



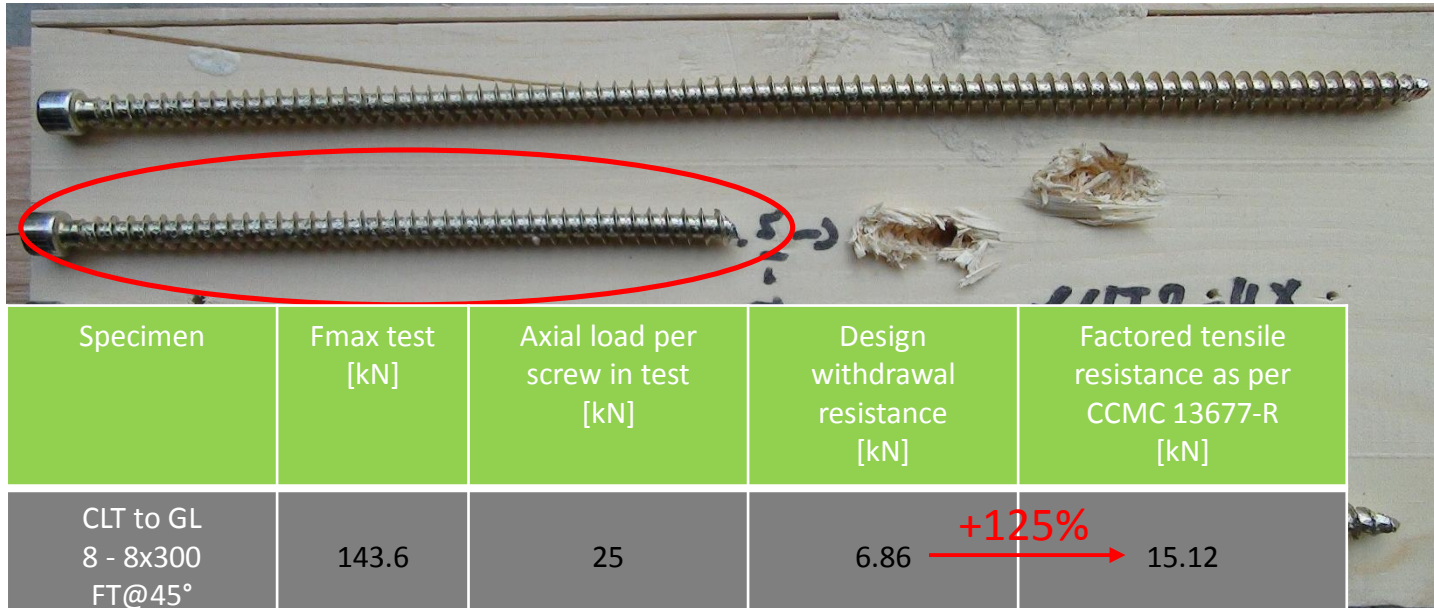
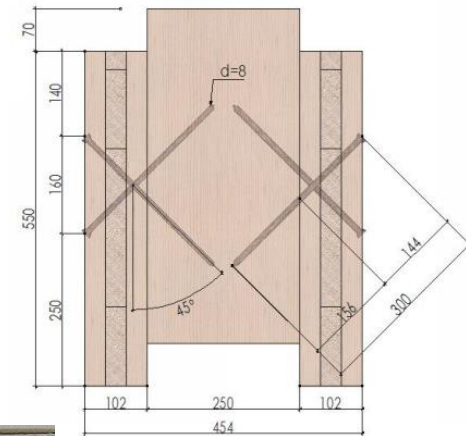
Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25 <span style="color: red;">← +250%</span>	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12



## Panel to Beam Connections

- Typical failure mode – screw breakage

Tension failure



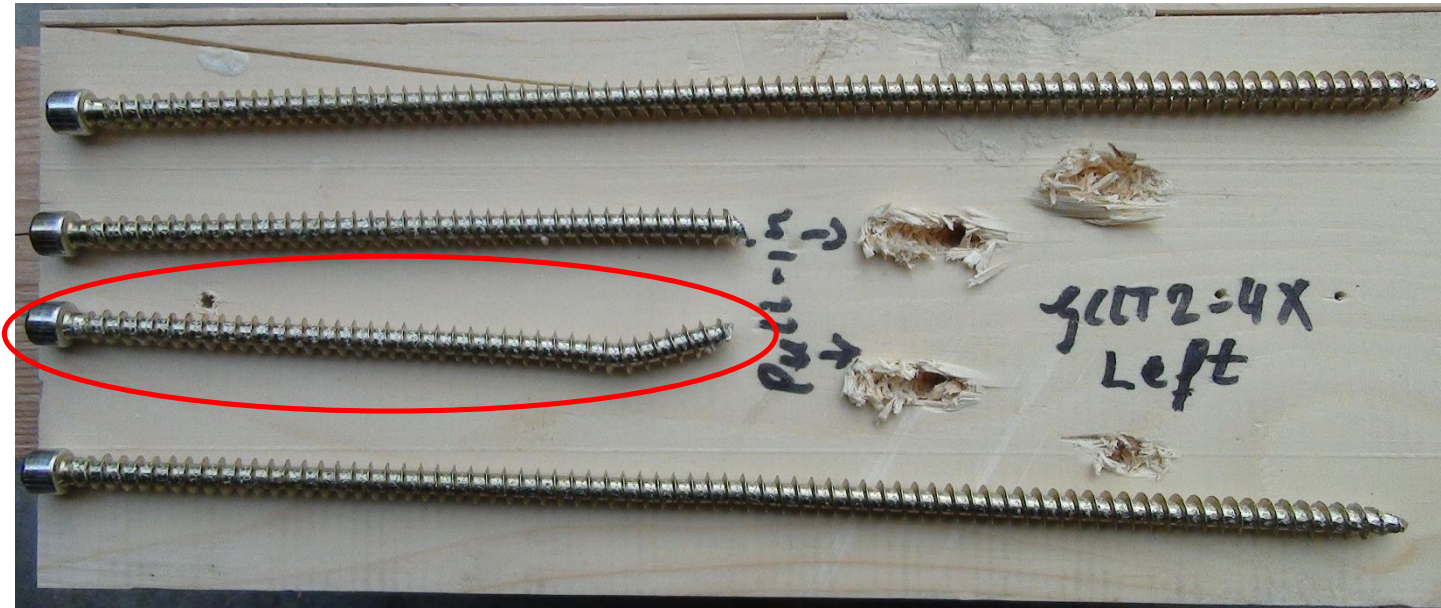
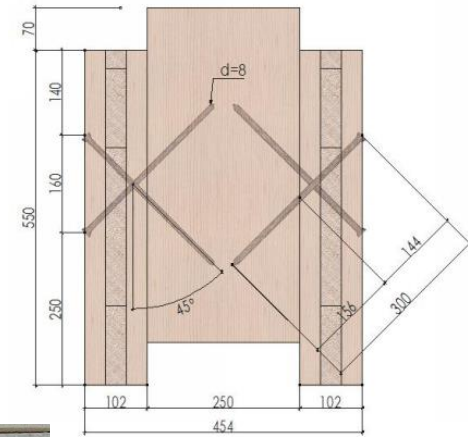
Specimen	Fmax test [kN]	Axial load per screw in test [kN]	Design withdrawal resistance [kN]	Factored tensile resistance as per CCMC 13677-R [kN]
CLT to GL 8 - 8x300 FT@45°	143.6	25	6.86	15.12
CLT to GL 16 - 8x300 FT@45°	268	23.7	6.86	15.12

+125%

## Panel to Beam Connections

- Typical failure mode – screw breakage

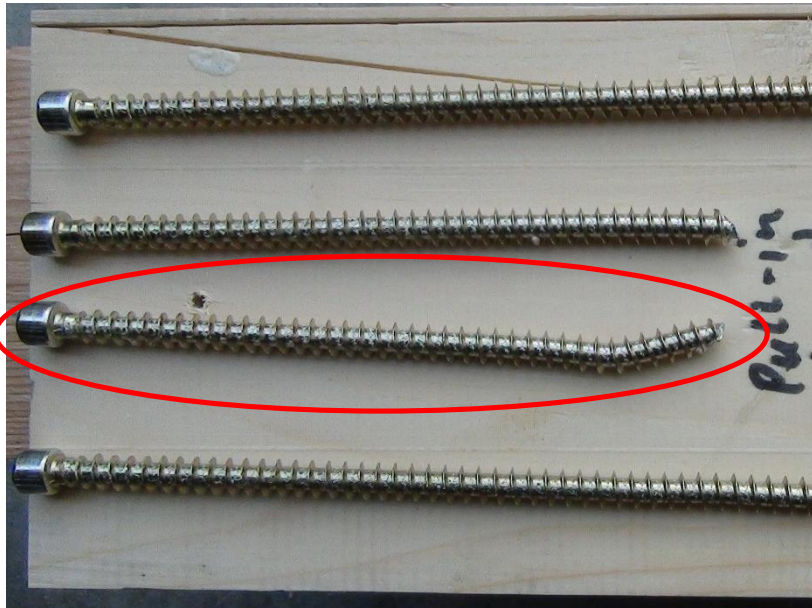
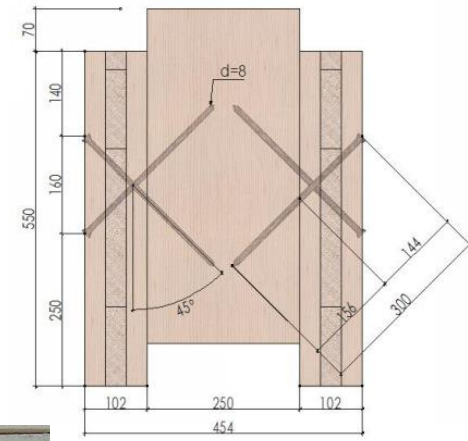
Tension and  
bending failure



## Panel to Beam Connections

- Typical failure mode – screw breakage

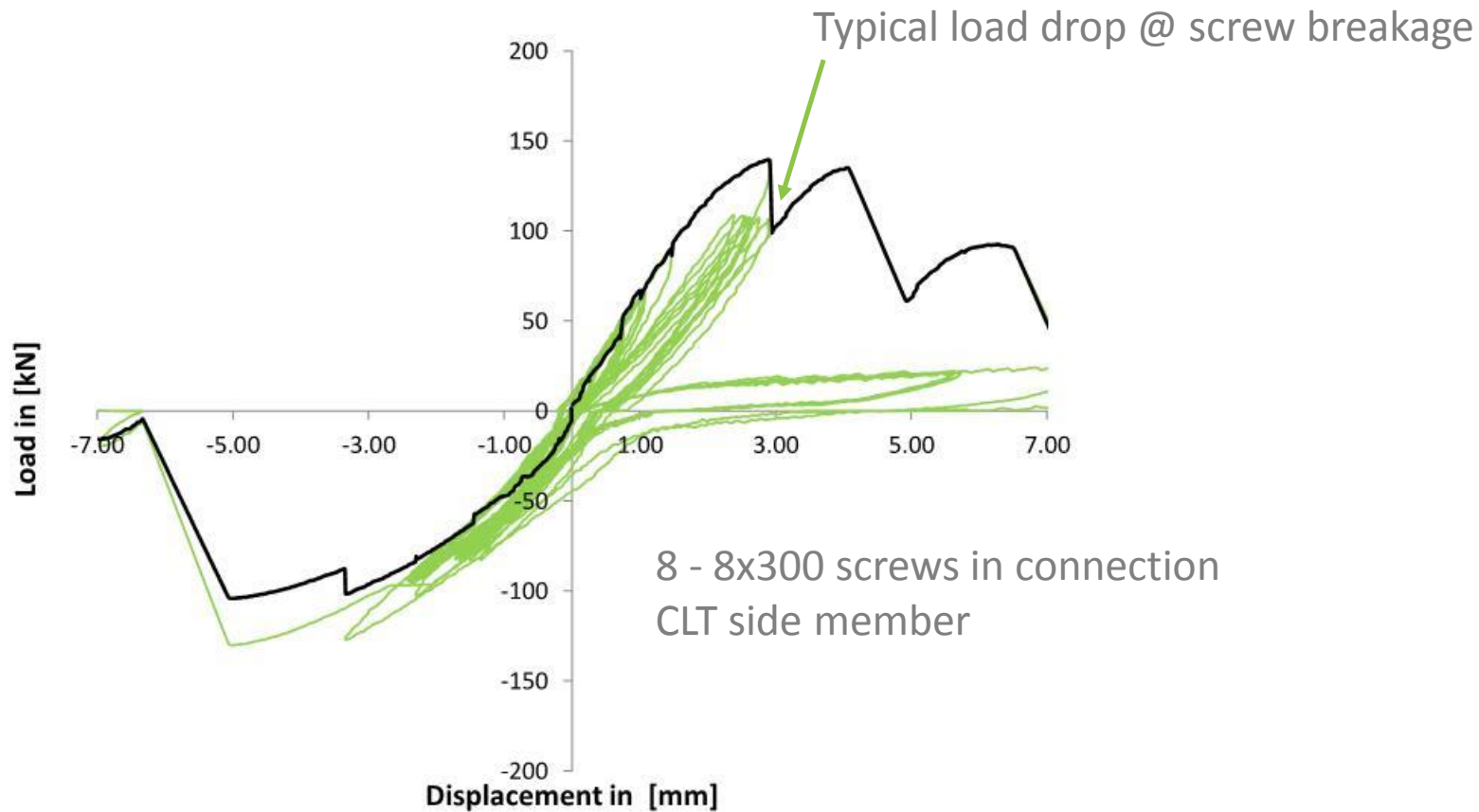
Tension and  
bending failure





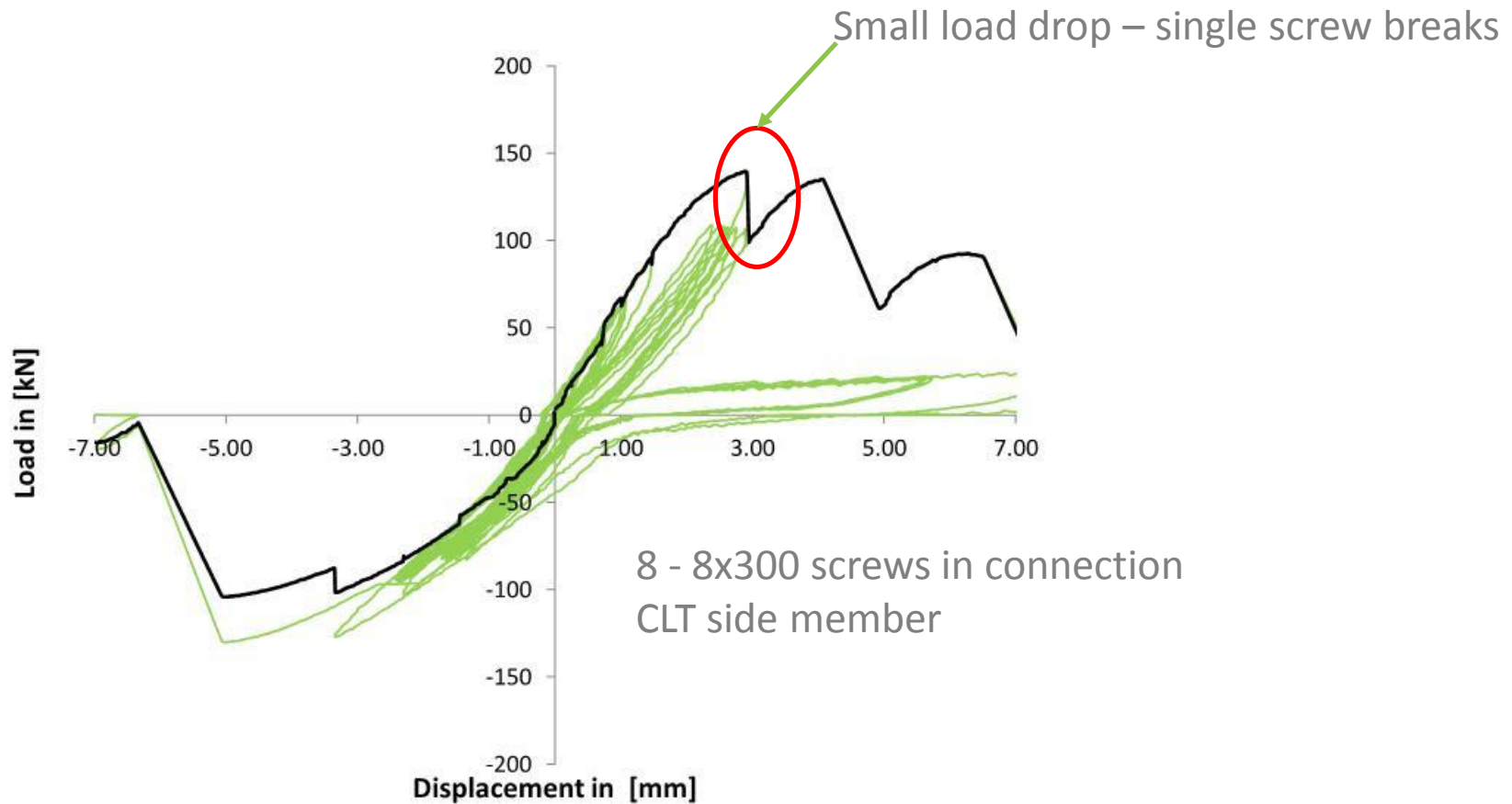
## Panel to Beam Connections

- Typical load displacement curve with screw breakage



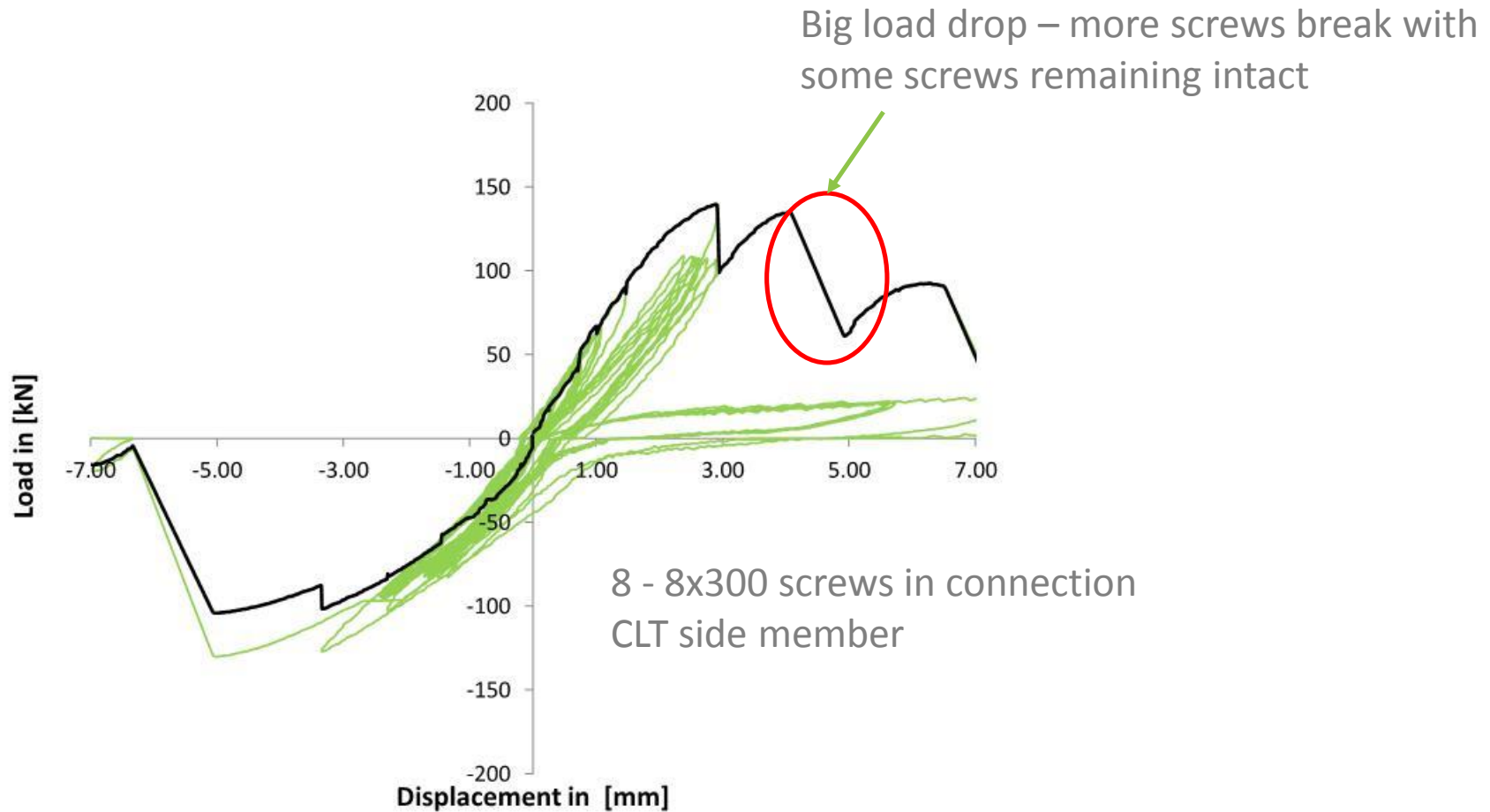
## Panel to Beam Connections

- Typical load displacement curve with screw breakage



## Panel to Beam Connections

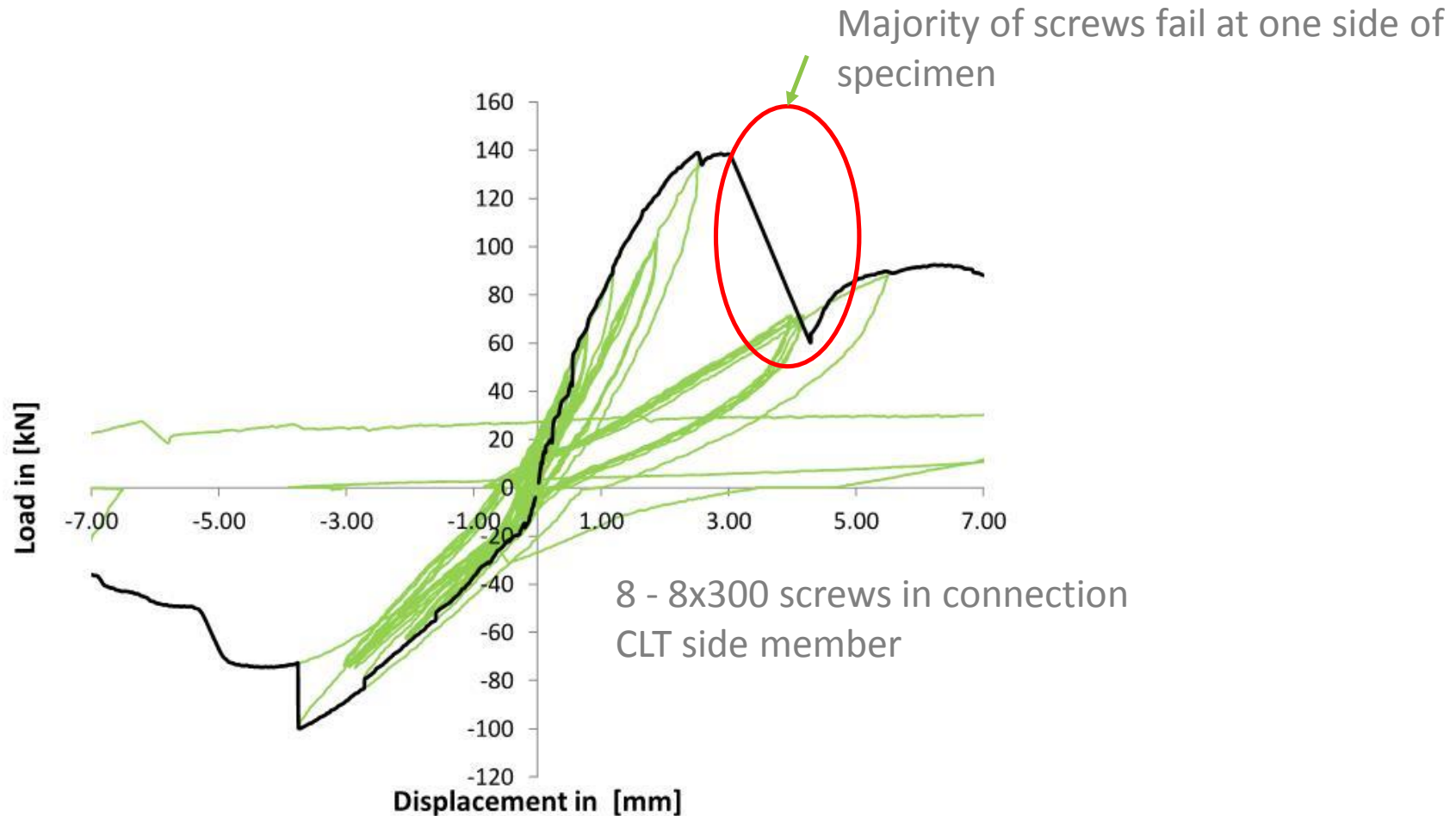
- Typical load displacement curve with screw breakage





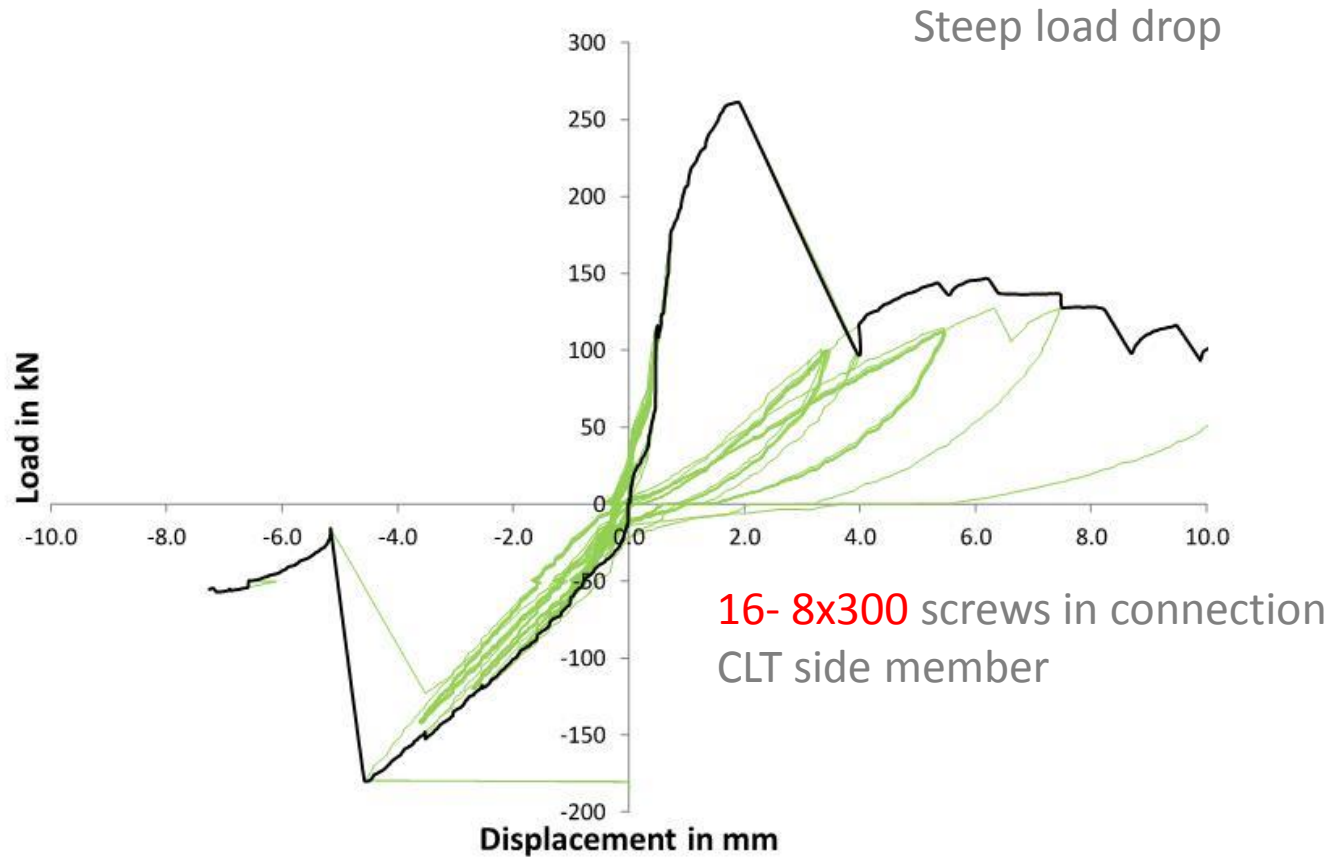
## Panel to Beam Connections

- Typical load displacement curve with screw breakage



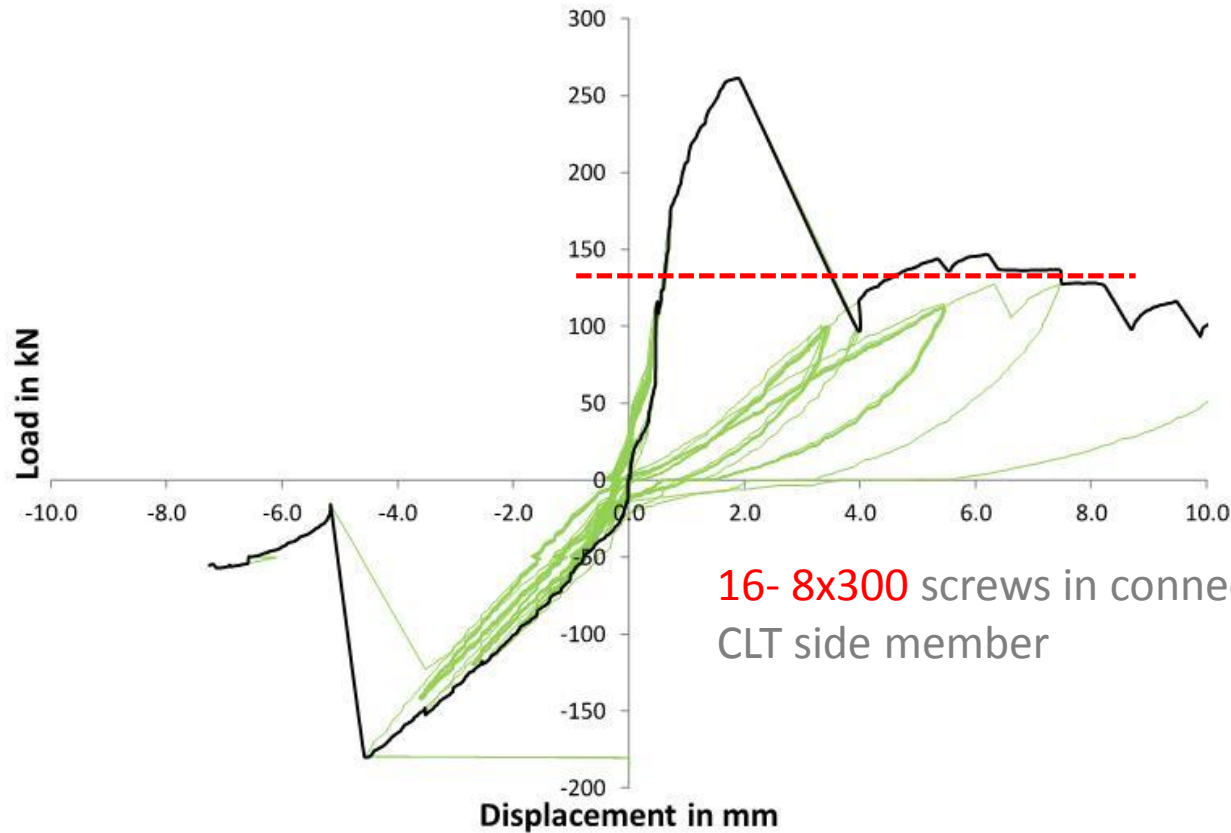
## Panel to Beam Connections

- Typical load displacement curve with screw breakage



## Panel to Beam Connections

- Typical load displacement curve with screw breakage



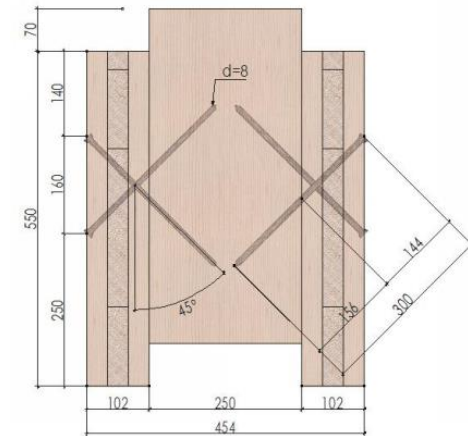
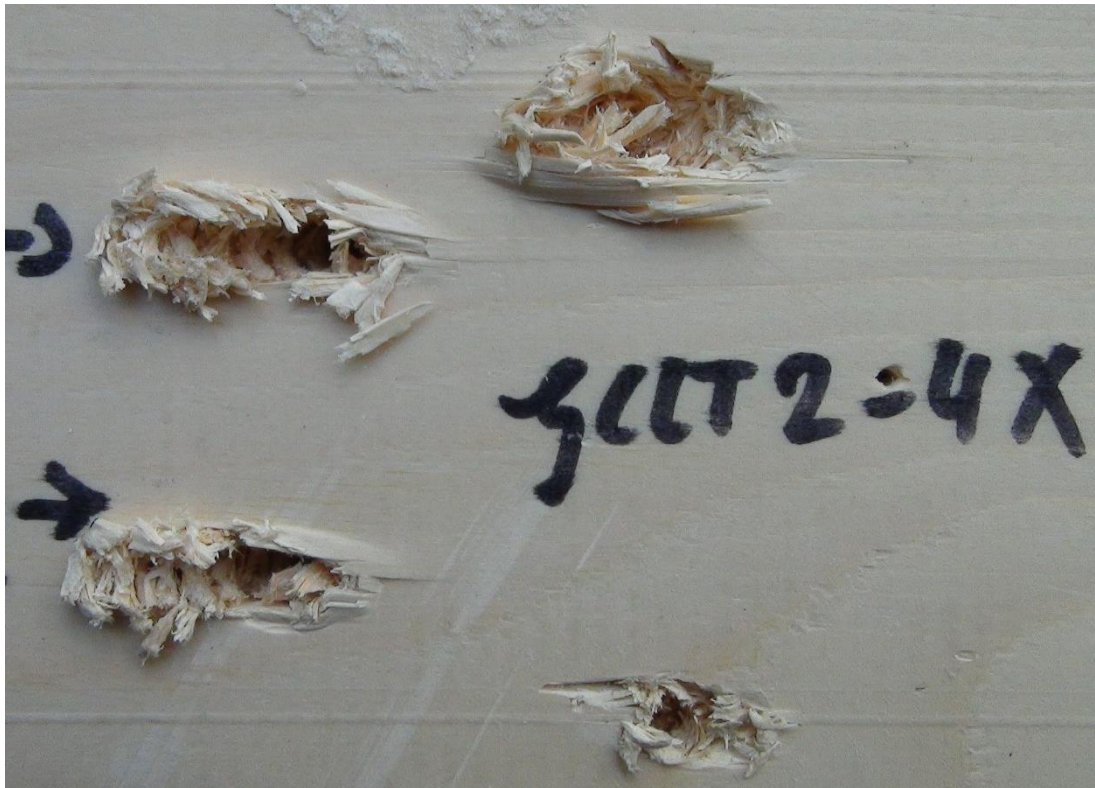
Residual load after  
failure  $\approx 130\text{kN}$

16- 8x300 screws in connection  
CLT side member

## Panel to Beam Connections

- Typical failure mode – withdrawal

Withdrawal resistance failure

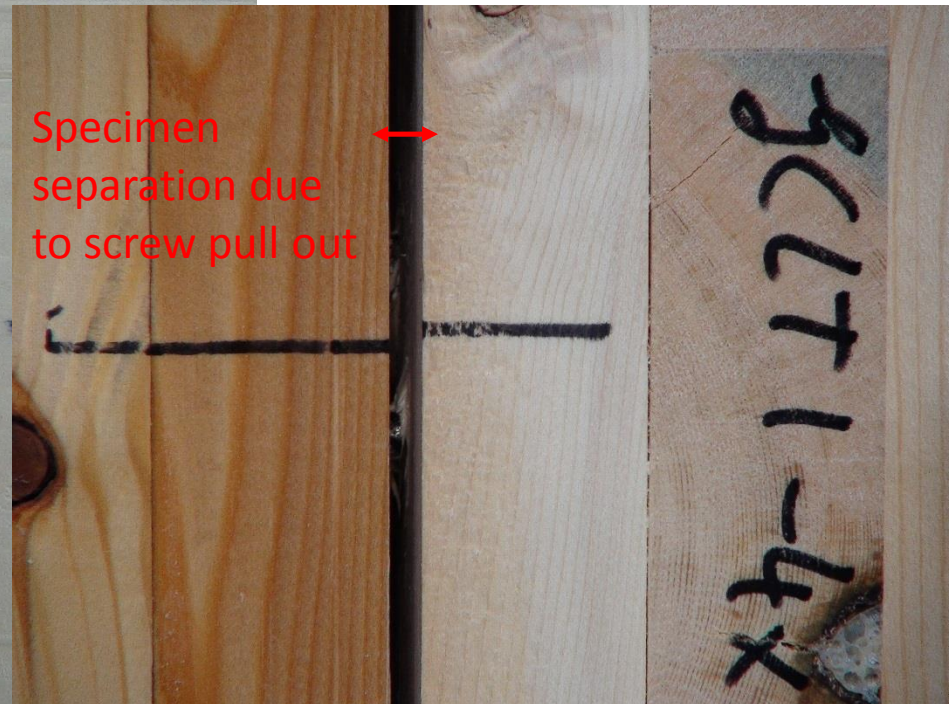
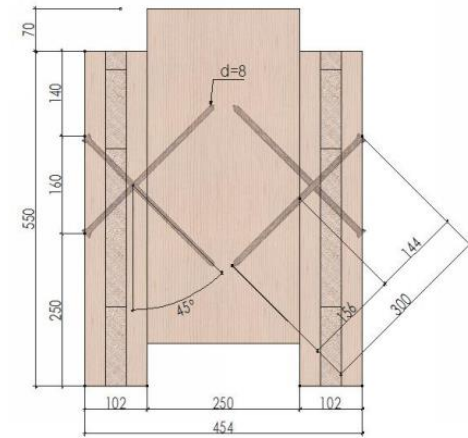




## Panel to Beam Connections

- Typical failure mode – withdrawal

Withdrawal resistance failure



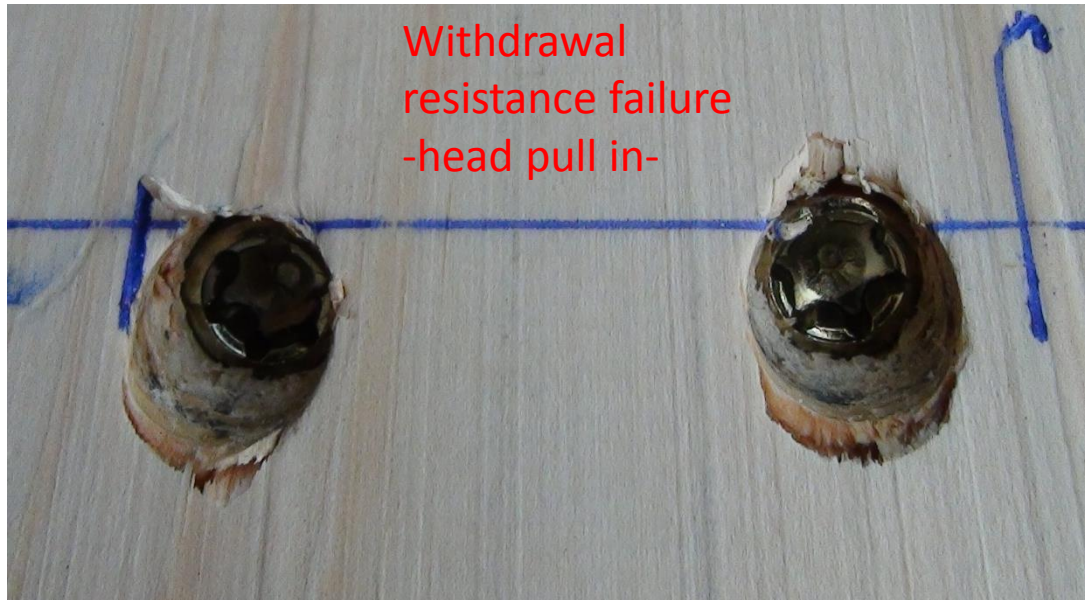
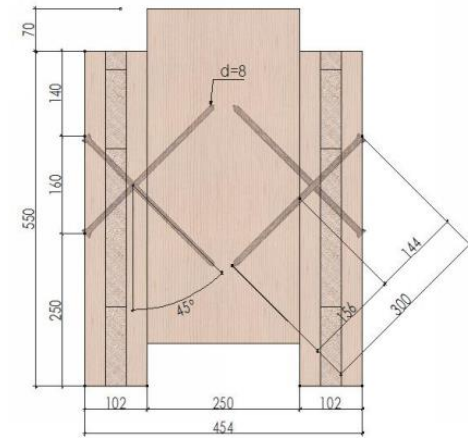


## Panel to Beam Connections

- Typical failure mode – withdrawal/push-out

Withdrawal resistance failure

Withdrawal resistance failure  
-head push out-



## Panel to Beam Connections

- Typical failure mode – withdrawal/push-out

Wood sheared off – screw is pushed out

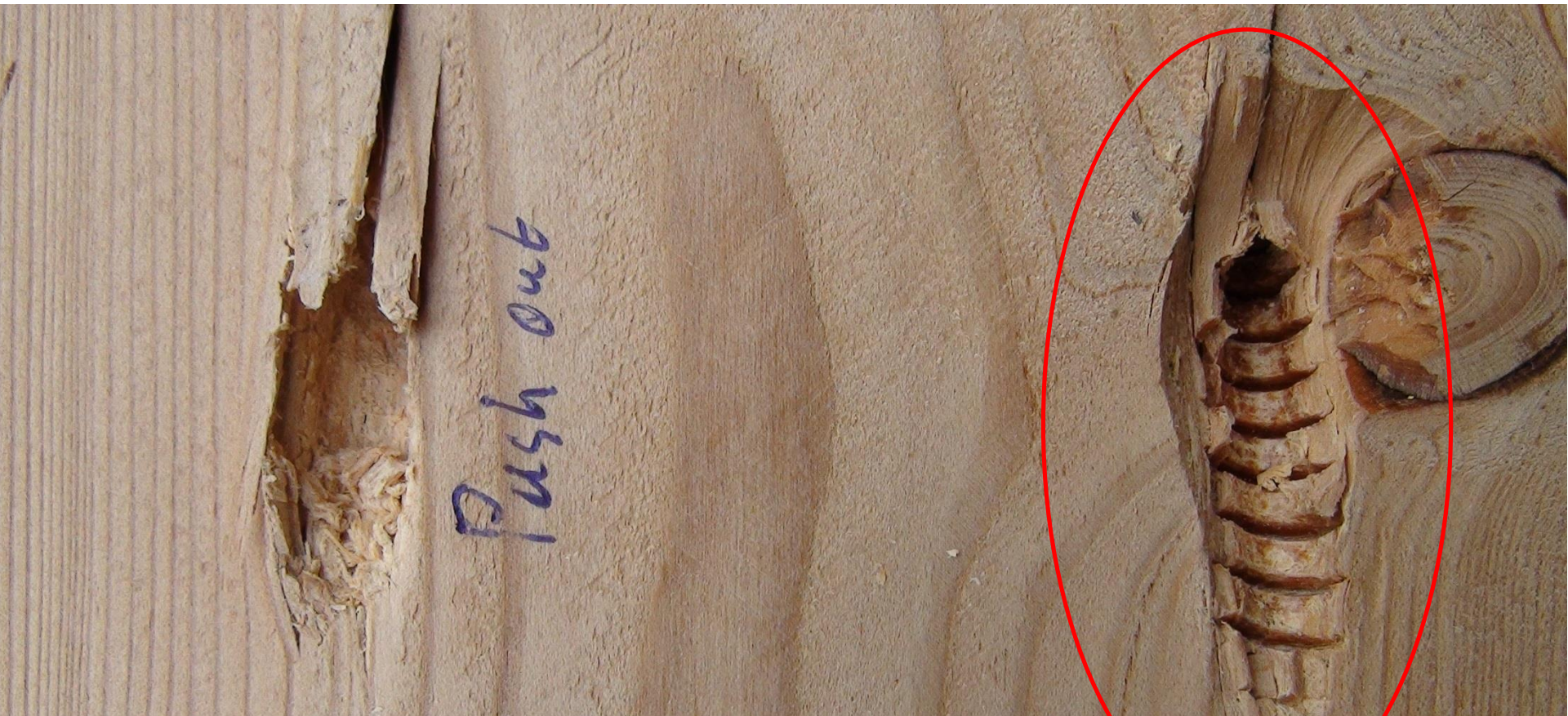




## Panel to Beam Connections

- Typical failure mode – withdrawal/push-out

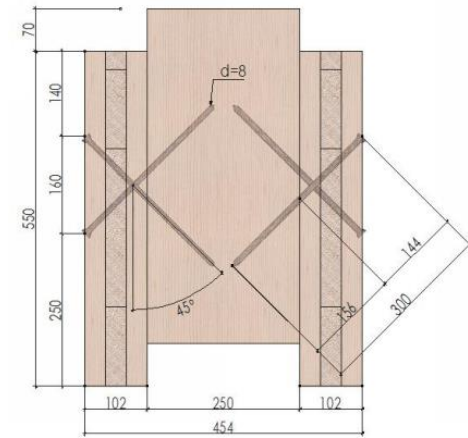
Wood not damaged – high local density at knot  
Screw did not push-out





## Panel to Beam Connections

- Typical failure mode – yielding



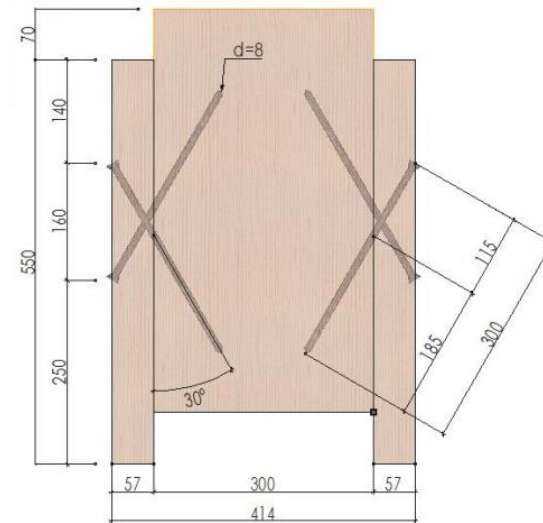
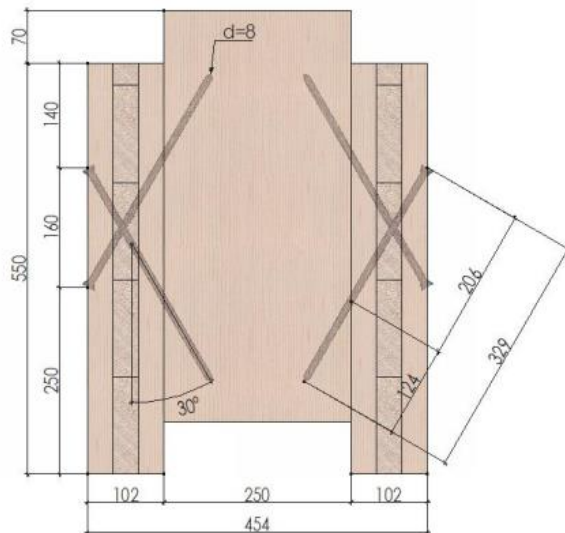
Yielding of loaded screws



# Panel to Beam Connections

Specimen	F <sub>max</sub> [kN]	Displ. F <sub>max</sub> [mm]	0.4 F <sub>max</sub> [kN]	Displ. 0.4 F <sub>max</sub> [mm]	0.7 F <sub>max</sub> [kN]	Displ. 0.7 F <sub>max</sub> [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F <sub>max</sub> [kN/mm]	Stiffness 0.7 F <sub>max</sub> [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60
GL to GL 8 - 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw



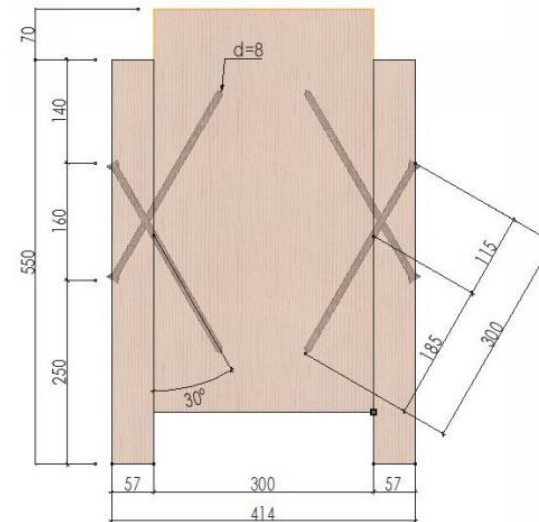
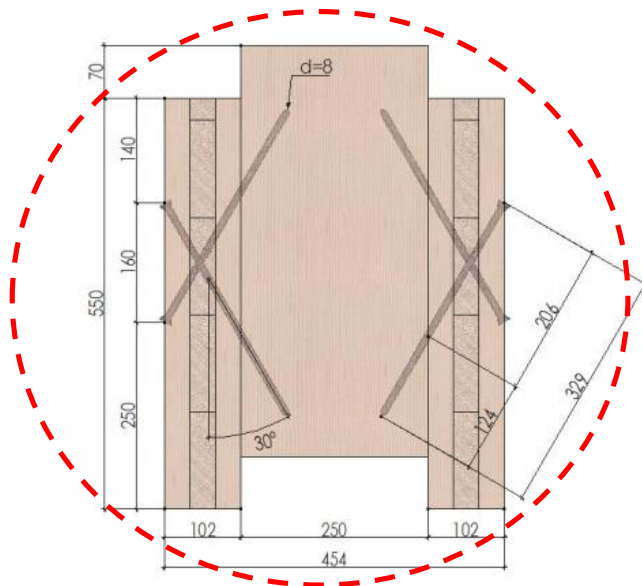


# Panel to Beam Connections

Specimen	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60
GL to GL 8 - 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

143.6kN @45° screw test = +20%

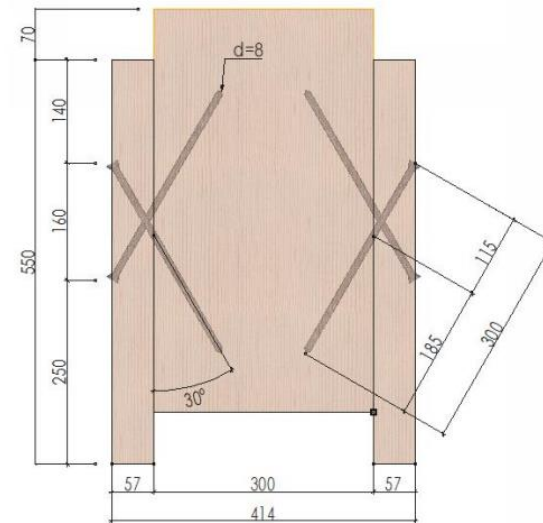
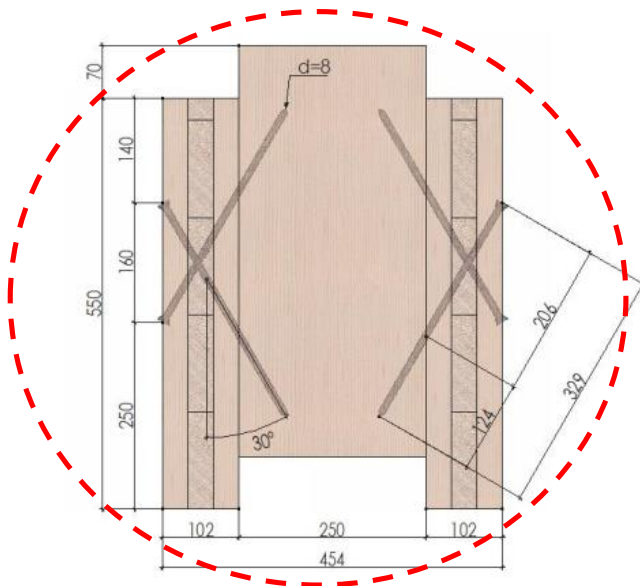


# Panel to Beam Connections

Specimen	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60
GL to GL 8 - 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

41.26kN/mm @45° screw test = +20%

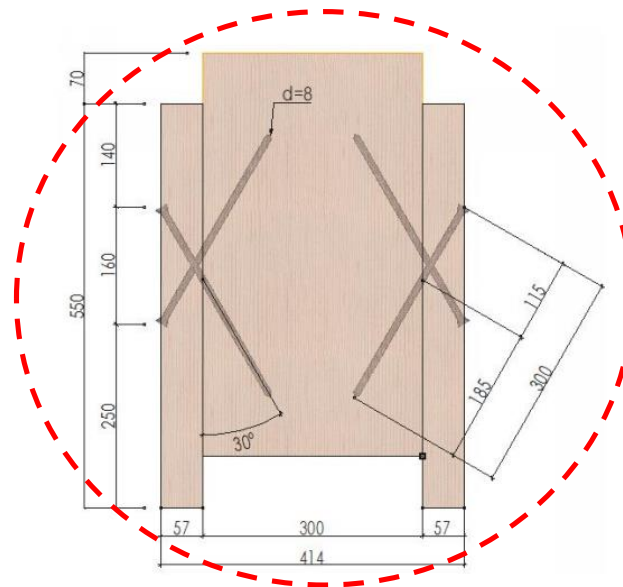
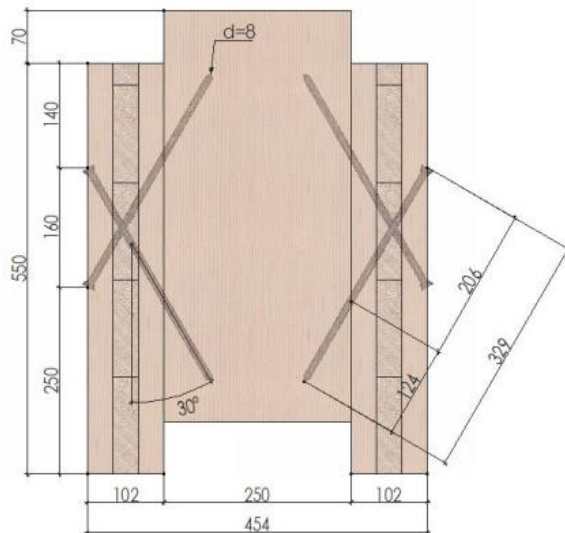


# Panel to Beam Connections

Specimen	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60
GL to GL 8 - 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

154.6kN @45° screw test = +30%

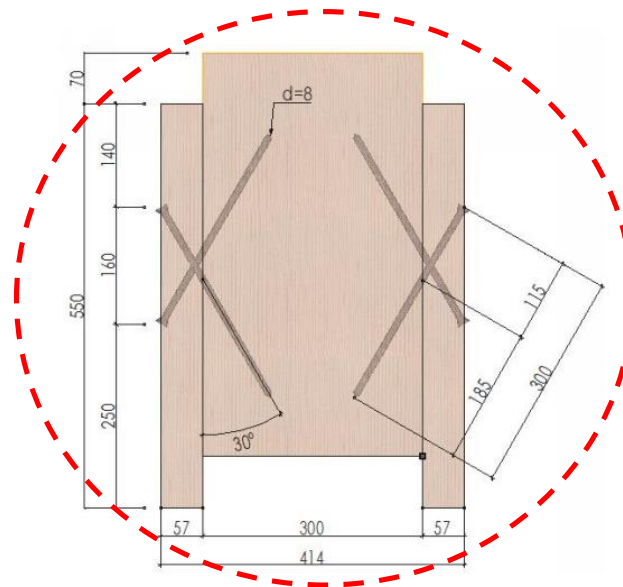
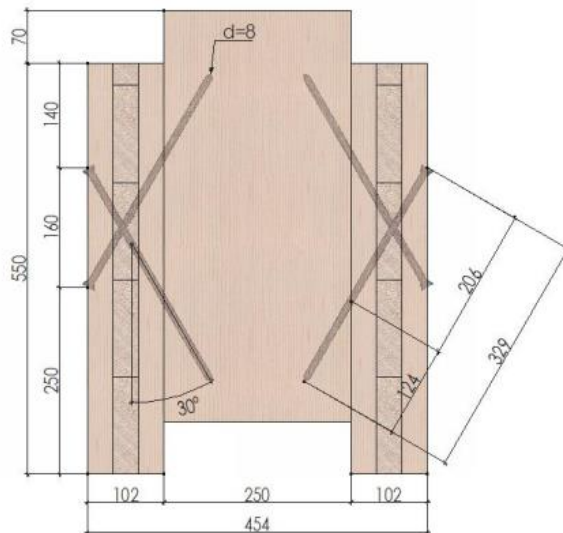


# Panel to Beam Connections

Specimen	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
CLT to GL 8 - 8x330 FT@30°	172.6	3.01	69.04	1.22	120.82	1.87	57.34	56.59	64.60
GL to GL 8 - 8x300 FT@30°	200.8	3.22	80.33	1.26	140.57	1.97	62.36	63.75	71.35

Note: Results listed in this table are average measurements out of 5 test obtained from the positive load cycle. FT= Full Thread screw

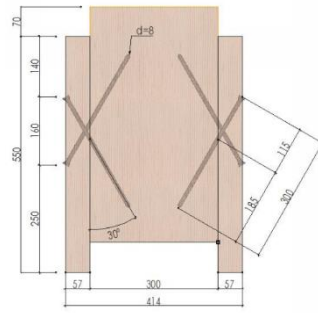
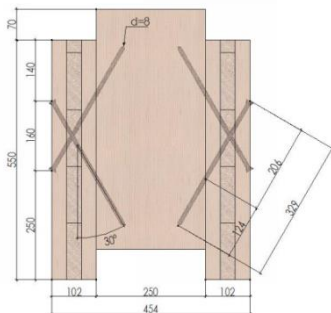
40.68kN/mm @45° screw test = +50%



# Panel to Beam Connections

Specimen	<b>Design</b> Resistance [kN]	Design Estimated stiffness [kN/mm]	TEST Resistance [kN]	TEST stiffness [kN/mm]
CLT to GL 8 - 8x300 FT@45°	44.62	47.1	143.6	37.6
CLT to GL 16 - 8x300 FT@45°	89.24	94.3	268	121.8
GL to GL 8 - 8x260 FT@45°	46.8	43	154.6	40.68
GL to GL 16 - 8x260 FT@45°	93.66	86	245	153.12
CLT to GL 8 - 8x330 FT@30°	59.15	56.3	172.6	57.3
GL to GL 8 - 8x300 FT@30°	54.56	57.7	200.8	62.36

Note: Test results listed in this table are average measurements out of 5 test obtained from the positive load cycle.  
FT= Full Thread screw. Reduction factors for dynamic loading were not considered

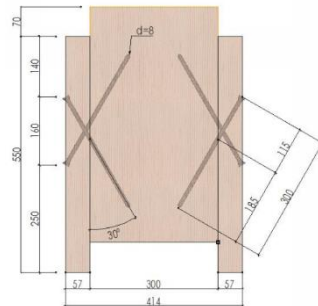
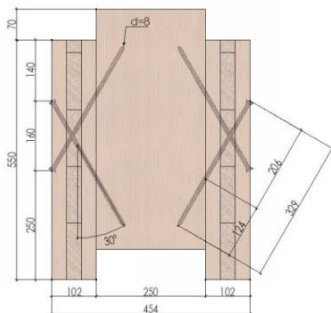




# Panel to Beam Connections

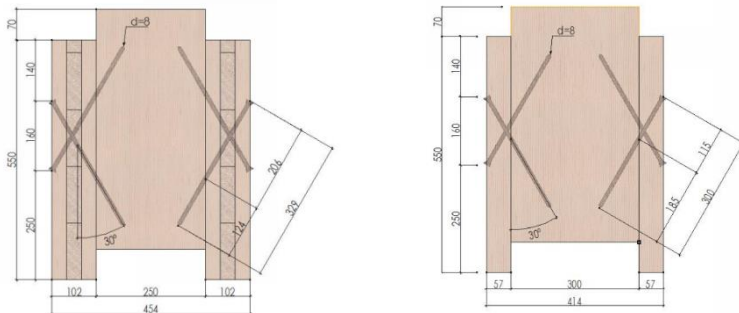
Specimen	Design Resistance [kN]	Design Estimated stiffness [kN/mm]	TEST Resistance [kN]	TEST stiffness [kN/mm]
CLT to GL 8 - 8x300 FT@45°	44.62	47.1 <sup>≈ 3</sup>	143.6	37.6
CLT to GL 16 - 8x300 FT@45°	89.24	94.3	268	121.8
GL to GL 8 - 8x260 FT@45°	46.8	43	154.6	40.68
GL to GL 16 - 8x260 FT@45°	93.66	86	245	153.12
CLT to GL 8 - 8x330 FT@30°	59.15	56.3	172.6	57.3
GL to GL 8 - 8x300 FT@30°	54.56	57.7	200.8	62.36

Note: Test results listed in this table are average measurements out of 5 test obtained from the positive load cycle.  
FT= Full Thread screw. Reduction factors for dynamic loading were not considered



More reasonable to consider the load range between 40% and 70% of recorded load?

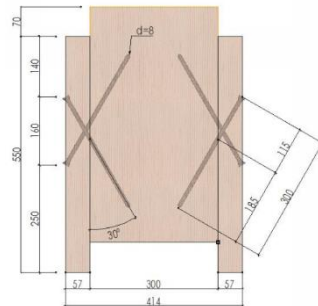
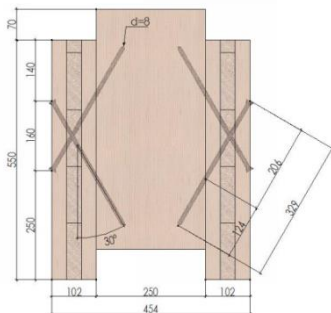
Note: Test results listed in this table are average measurements out of 5 test obtained from the positive load cycle.  
FT= Full Thread screw. Reduction factors for dynamic loading were not considered



# Panel to Beam Connections

Specimen	Design Resistance [kN]	Design Estimated stiffness [kN/mm]	TEST Resistance [kN]	TEST stiffness [kN/mm]
CLT to GL 8 - 8x300 FT@45°	44.62	47.1	143.6	37.6
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Note: Test results listed in this table are average measurements out of 5 test obtained from the positive load cycle.  
FT= Full Thread screw. Reduction factors for dynamic loading were not considered

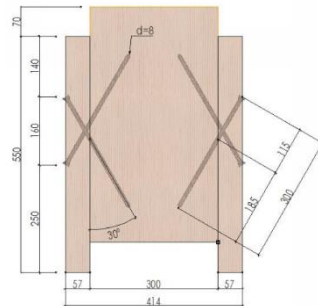
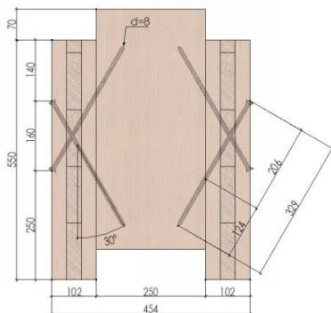


# Panel to Beam Connections

Specimen	Design Resistance [kN]	Design Estimated stiffness [kN/mm]	TEST Resistance [kN]	TEST stiffness [kN/mm]
CLT to GL 8 - 8x300 FT@45°	44.62	47.1	143.6	37.6
CLT to GL 16 - 8x300 FT@45°	89.24	94.3	268	121.8
GL to GL 8 - 8x260 FT@45°	46.8	43	154.6	40.68
GL to GL 16 - 8x260 FT@45°	93.66	86	245	153.12
CLT to GL 8 - 8x330 FT@30°	59.15	56.3	172.6	57.3
GL to GL 8 - 8x300 FT@30°	54.56	57.7	200.8	62.36

Note: Test results listed in this table are average measurements out of 5 test obtained from the positive load cycle.

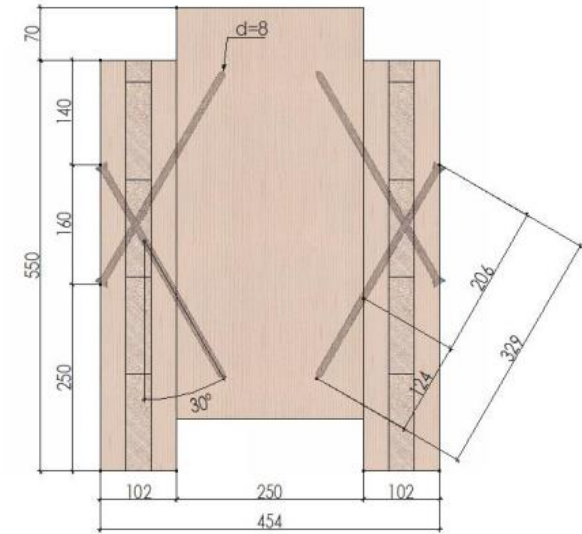
FT= Full Thread screw. **Reduction factors for dynamic loading were not considered**



**Dynamic load reduction factors were not applied to design resistance**

## Panel to Beam Connections

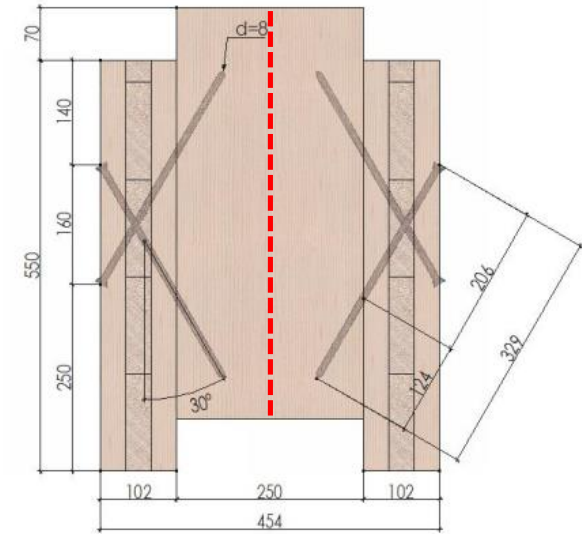
- Typical failure mode – shear failure in wood





## Panel to Beam Connections

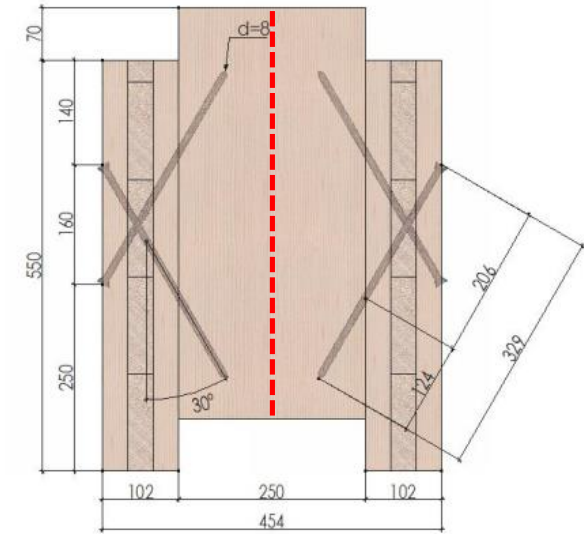
- Typical failure mode – shear failure in wood



Shear crack developed  
parallel to grain

## Panel to Beam Connections

- Typical failure mode – shear failure in wood

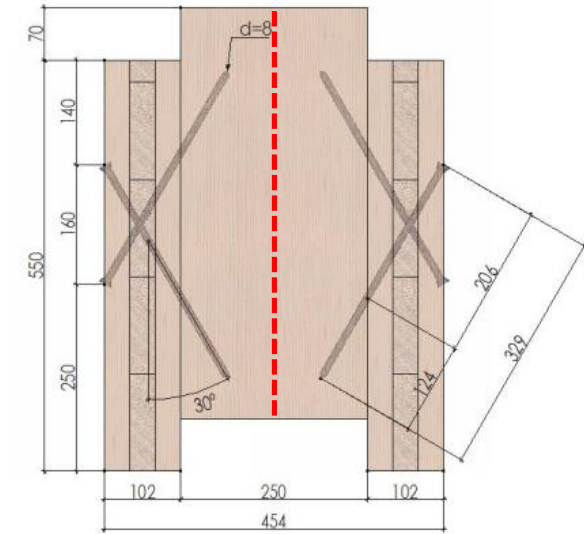
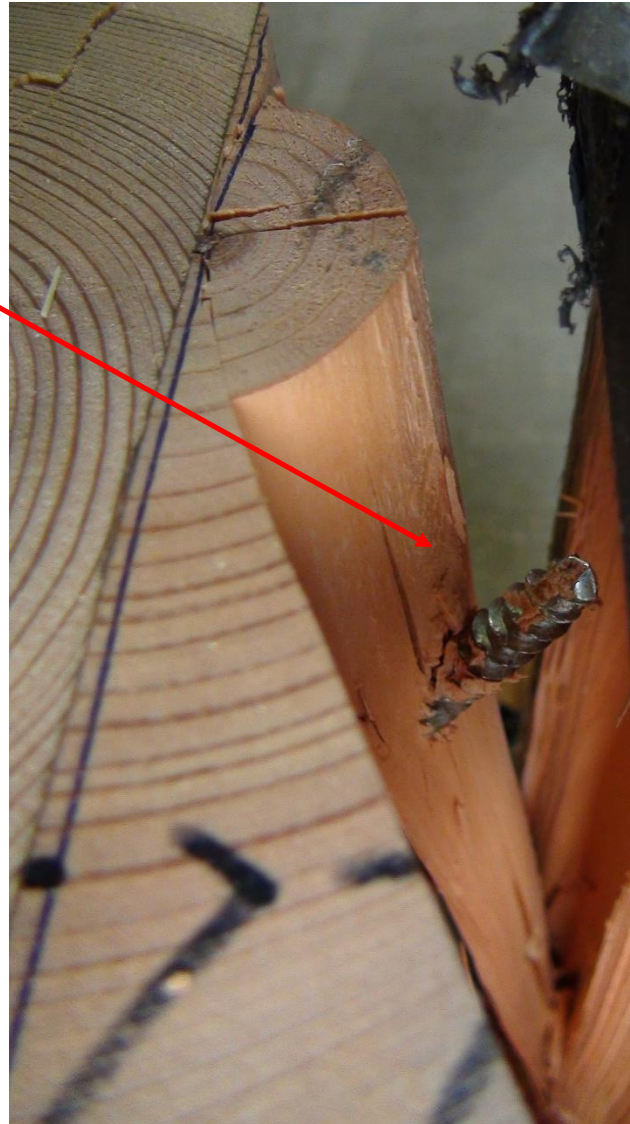


Specimen after testing



## Panel to Beam Connections

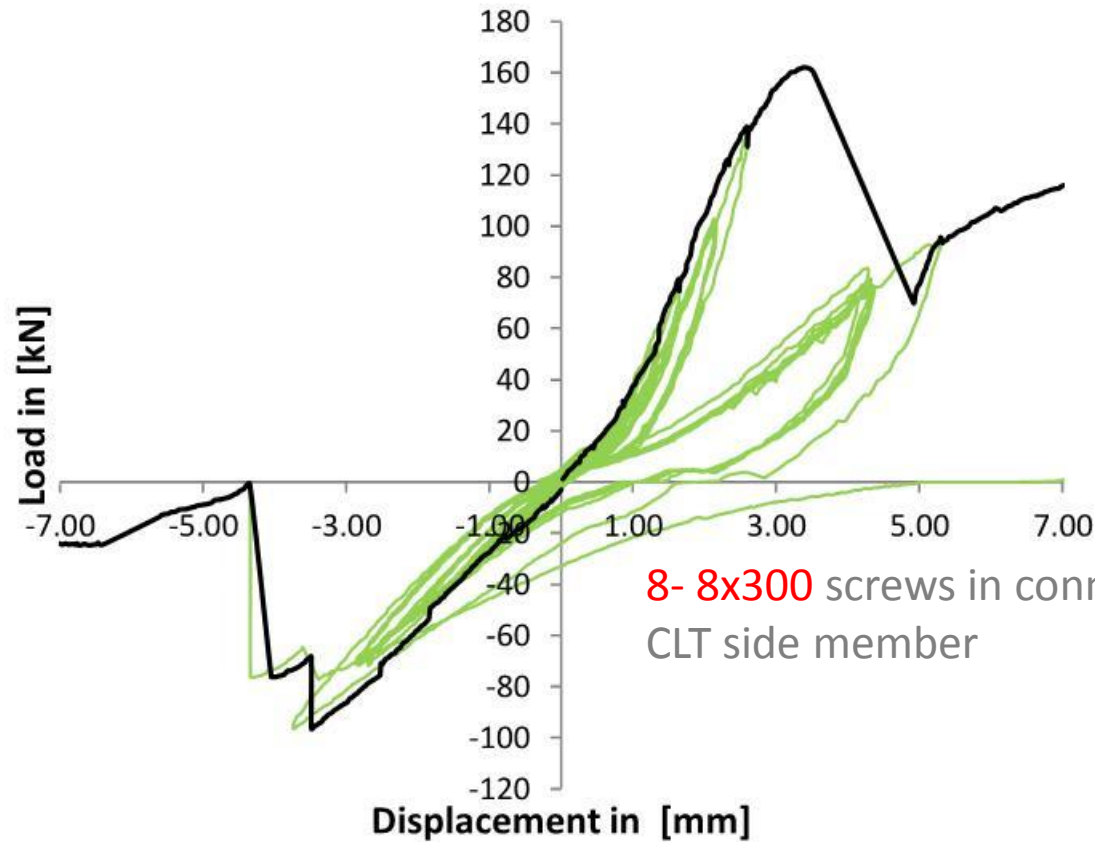
- Typical failure mode – shear failure in wood



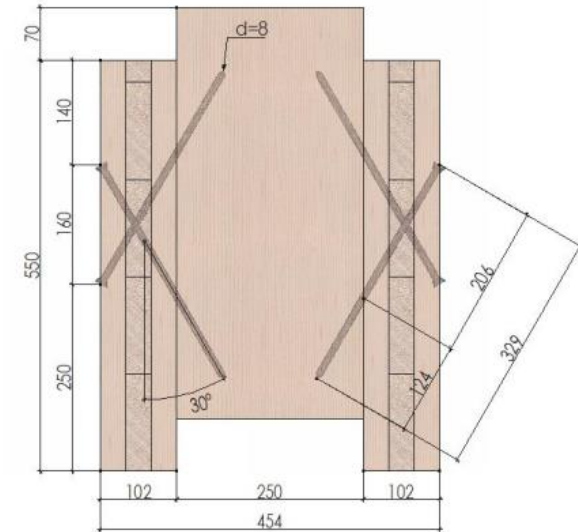
Shear failure near screw tip.  
Stresses are released into the wood.  
Complete separation of wood.  
Longitudinal to grain shear failure

## Panel to Beam Connections

- Typical load displacement curve with screw breakage



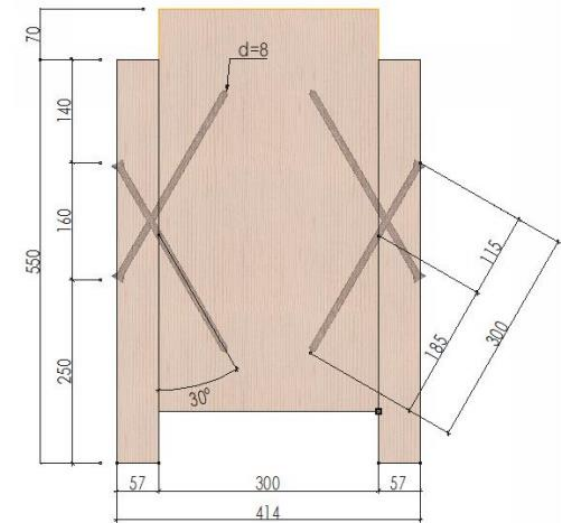
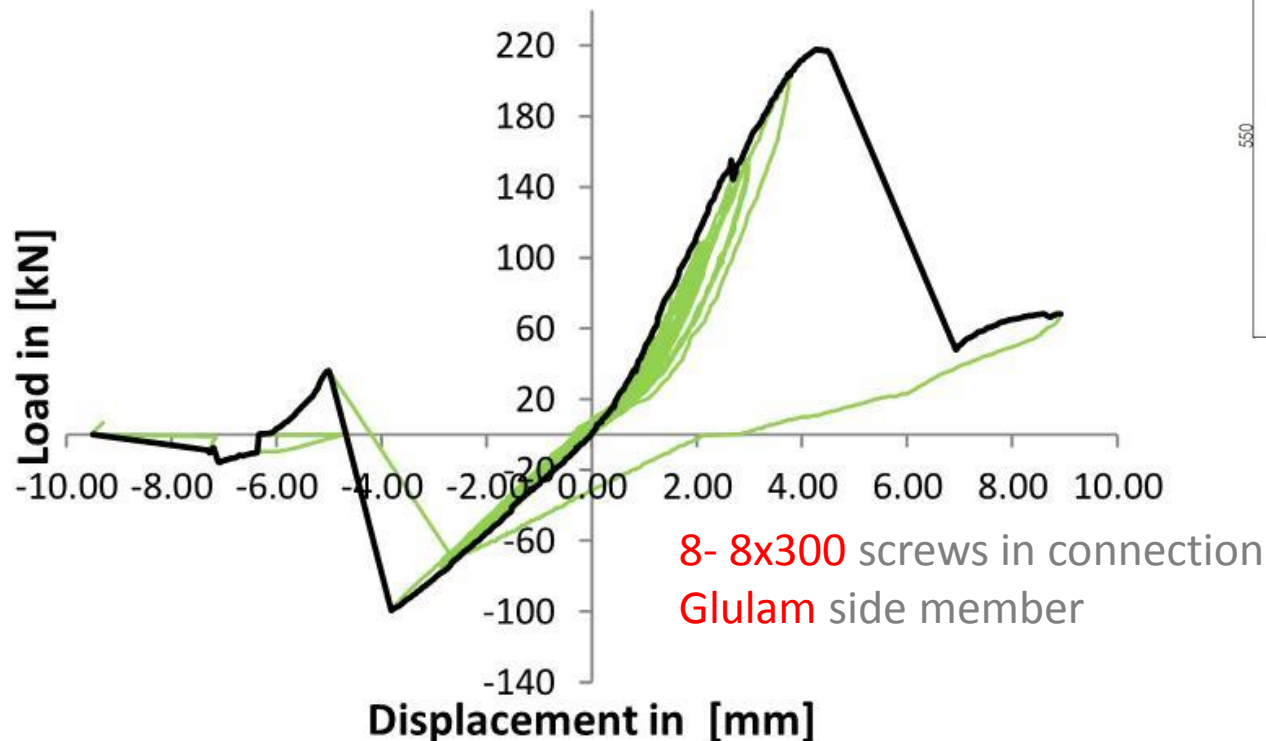
8- 8x300 screws in connection  
CLT side member



30° screws

## Panel to Beam Connections

- Typical load displacement curve with wood failure

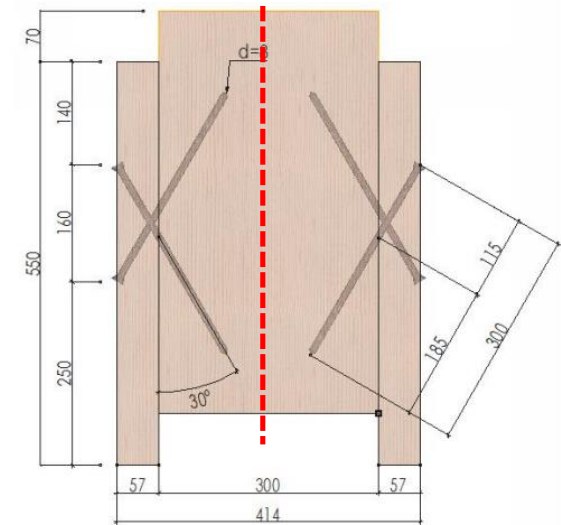
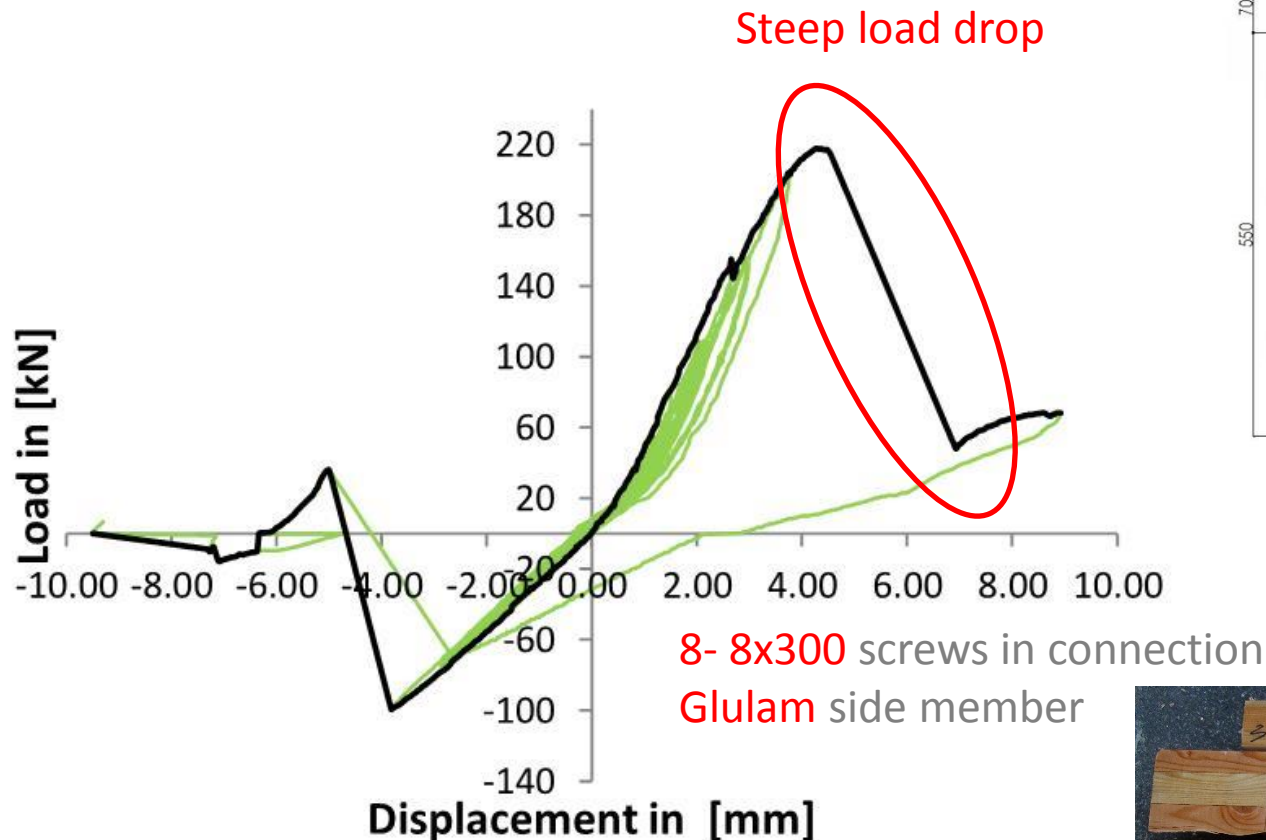


30° screws



## Panel to Beam Connections

- Typical load displacement curve with **wood failure**



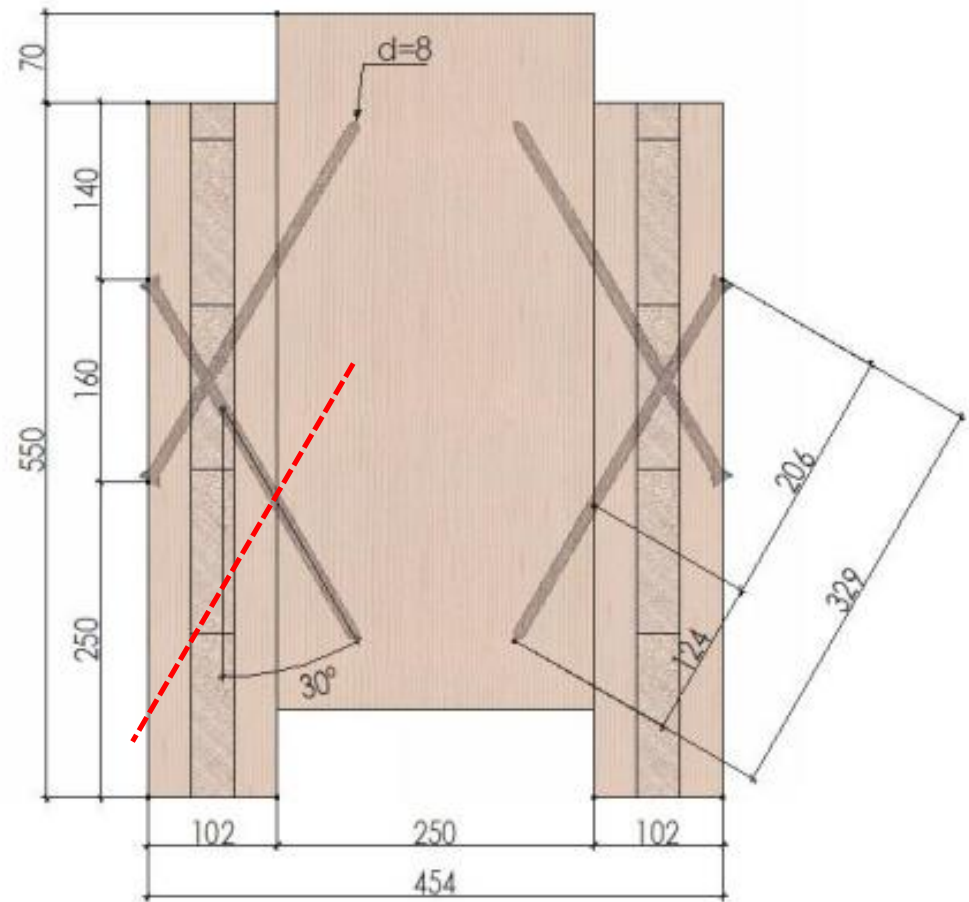
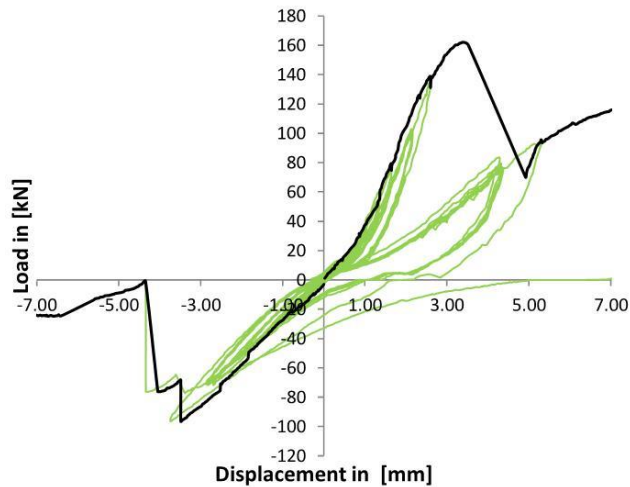
30° screws



# Panel to Beam Connections

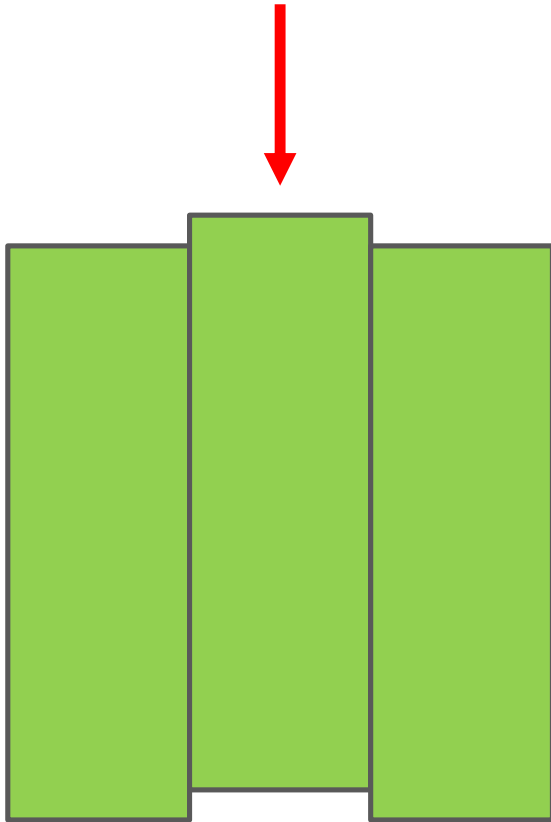
- Typical load displacement curve with screw breakage

Ideally screws intersect at shear plane



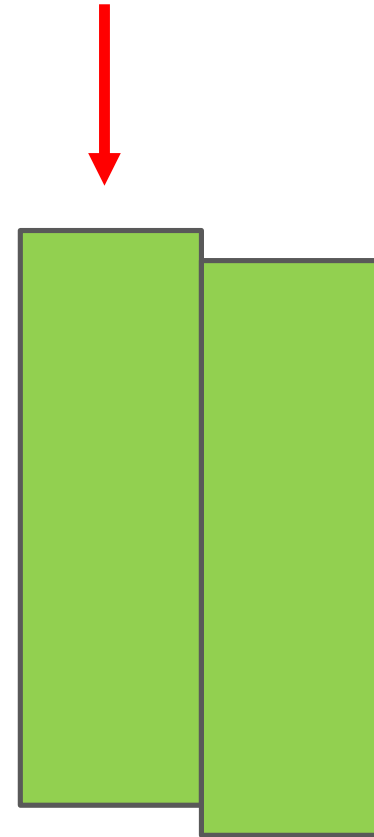
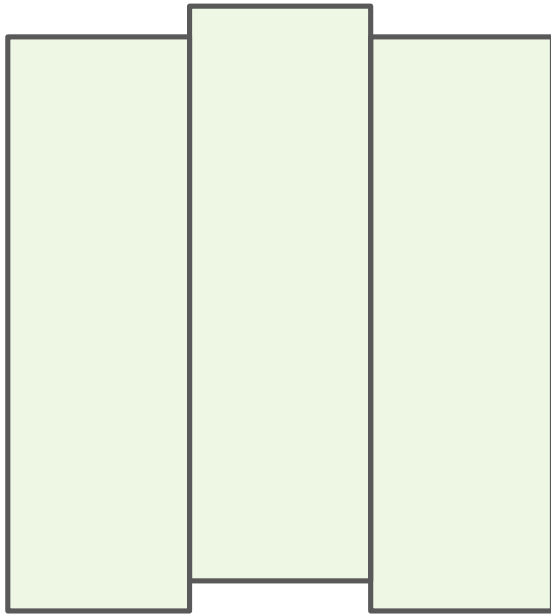
## Panel to Panel Connections

### Test series #1



## Panel to Panel Connections

### Test series #2



Connecting floor panel to floor panel or wall panel to wall panel

# Panel to Panel Connections (3 Panels)

## • Test Series

Series	Joint type	CLT layers	Plywood thickness	STS length	STS rows	STS per row	STS spacing	STS action
		-	(")	mm	#	#	x*d	-
SS_3p_3ply_1R_8S	Surface Spline	3ply	3/4	80	1	5	8	Shear
SS_3p_3ply_2R_8S		3ply	3/4	80	2	5	8	Shear
SS_3p_5ply_1R_8S		5ply	1	100	1	5	8	Shear
SS_3p_5ply_2R_8S		5ply	1	100	2	5	8	Shear
LJ_3p_3ply_1R_8S	Lap Joint	3ply	-	90	1	5	8	Shear
LJ_3p_5ply_1R_8S		5ply	-	160	1	5	8	Shear
LJ_3p_3ply_2R_45		3ply	-	220	2	4	8	Withdr.
LJ_3p_5ply_2R_45		5ply	-	240	2	3	8	Withdr.
BJ_3p_3ply_2R_8S	Butt Joint	3ply	-	180	2	4	-	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

3p=3 pieces or panels

nR=n row of screws per each side of shear planes (n=1 and 2)

8S=Spacing of the screws is 8 times the diameter of the screw

45=Angle between the screw axis and the CLT plane



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Series	Joint type	CLT layers	Plywood thickness	STS length	STS rows	STS per row	STS spacing	STS action
		-	(")	mm	#	#	x*d	-
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SS_3p_5ply_2R_8S		5ply	1	100	2	5	8	Shear
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## Panel to Panel Connections (3 Panels)

- Spacing, end, and edge distances (mm)

Series No.	$a_1$	$a_1 T$	$a_1 C$	$a_2$	$a_2 T$	$a_2 C$
SS_3p_3ply_1R_8S	64	56	56	-	55	55
SS_3p_3ply_2R_8S	64	56	56	50	30	30
SS_3p_5ply_1R_8S	64	56	56		30	30
SS_3p_5ply_1R_8S	64	56	56	50	30	30
LJ_3p_3ply_1R_8S	64	72	72	-	40	40
LJ_3p_5ply_1R_8S	64	72	72	-	40	40
LJ_3p_3ply_2R_45	80	60	60	25	30	25
LJ_3p_5ply_2R_45	80	60	60	25	30	25
BJ_3p_3ply_2R_8S	See figure	35	35	-	53	53
Min requirement	$5d = 40$	$6d = 48$	$6d = 48$	$2.5d = 20$	$2.5d = 20$	$2.5d = 20$

## Panel to Panel Connections (3 Panels)

- Spacing, end, and edge distances (mm)

Series No.	$a_1$	$a_1 T$	$a_1 C$	$a_2$	$a_2 T$	$a_2 C$
SS_3p_3ply_1R_8S	64	56	56	-	55	55
SS_3p_3ply_2R_8S	64	56	56	50	30	30
SS_3p_5ply_1R_8S	64	56	56		30	30
SS_3p_5ply_1R_8S	64	56	56	50	30	30
LJ_3p_3ply_1R_8S	64	72	72	-	40	40
LJ_3p_5ply_1R_8S	64	72	72	-	40	40
LJ_3p_3ply_2R_45	80	60	60	25	30	25
LJ_3p_5ply_2R_45	80	60	60	25	30	25
BJ_3p_3ply_2R_8S	See figure	35	35	-	53	53
Min requirement	$5d = 40$	$6d = 48$	$6d = 48$	$2.5d = 20$	$2.5d = 20$	$2.5d = 20$

Fasteners in CLT with small spacing

## Panel to Panel Connections (3 Panels)

- Spacing, end, and edge distances (mm)

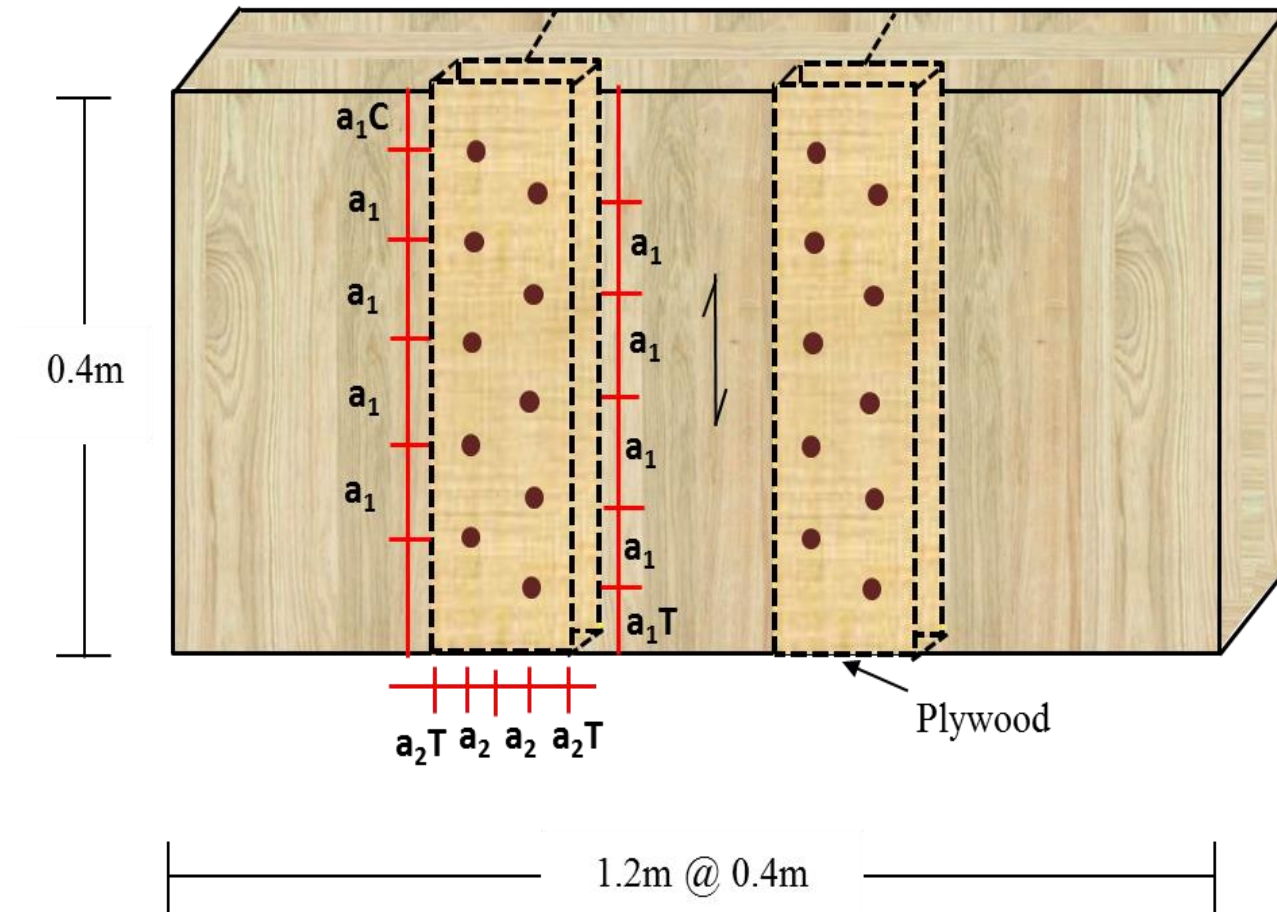
Series No.	$a_1$	$a_1 T$	$a_1 C$	$a_2$	$a_2 T$	$a_2 C$
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SS_3p_5ply_1R_8S	64	56	56		30	30
SS_3p_5ply_1R_8S	64	56	56	50	30	30
LJ_3p_3ply_1R_8S	64	72	72	-	40	40
LJ_3p_5ply_1R_8S	64	72	72	-	40	40
LJ_3p_3ply_2R_45	80	60	60	25	30	25
LJ_3p_5ply_2R_45	80	60	60	25	30	25
BJ_3p_3ply_2R_8S	See figure	35	35	-	53	53
Min requirement	$5d = 40$	$6d = 48$	$6d = 48$	$2.5d = 20$	$2.5d = 20$	$2.5d = 20$

**!Pay attention when connecting panel to beam!**

**Spacing requirements differ in timber and GL and typically govern**

## Panel to Panel Connections (3 Panels)

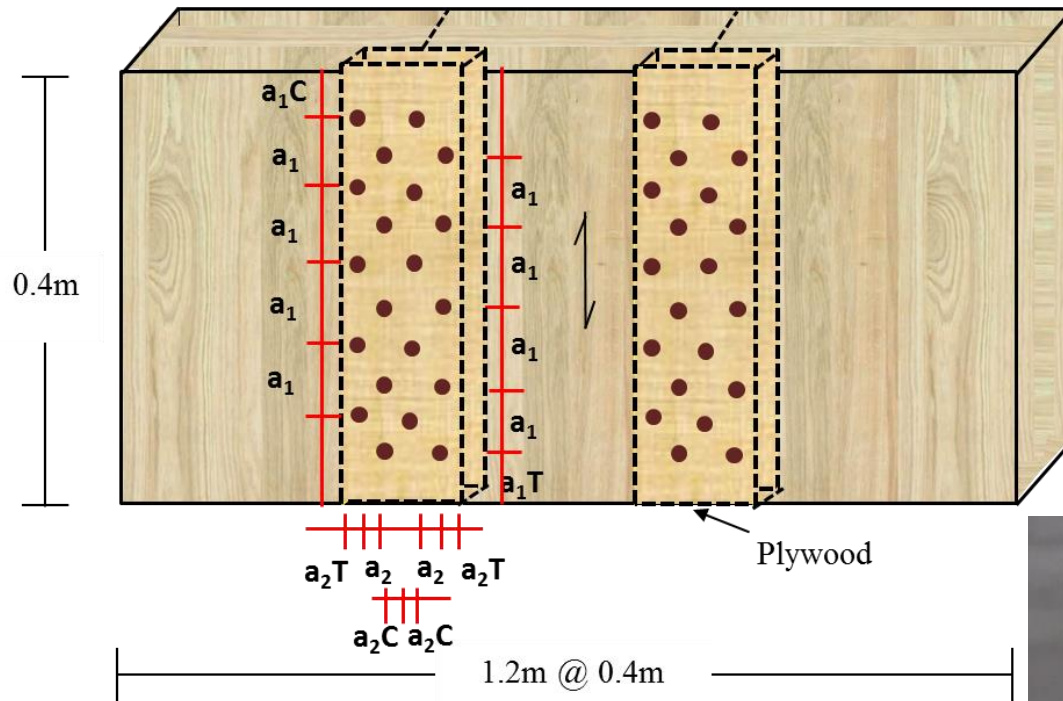
- Surface Spline Joints with one row of STS





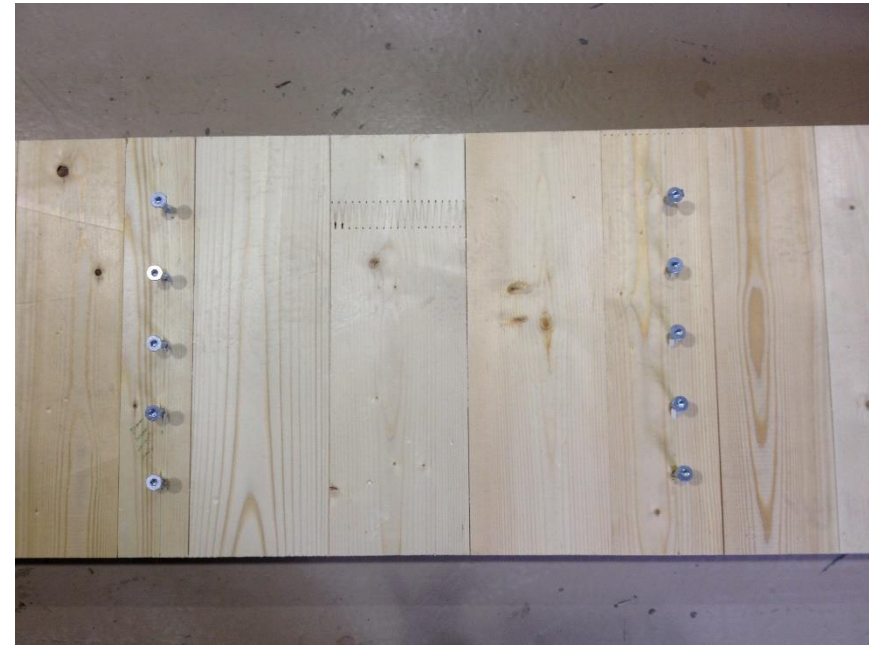
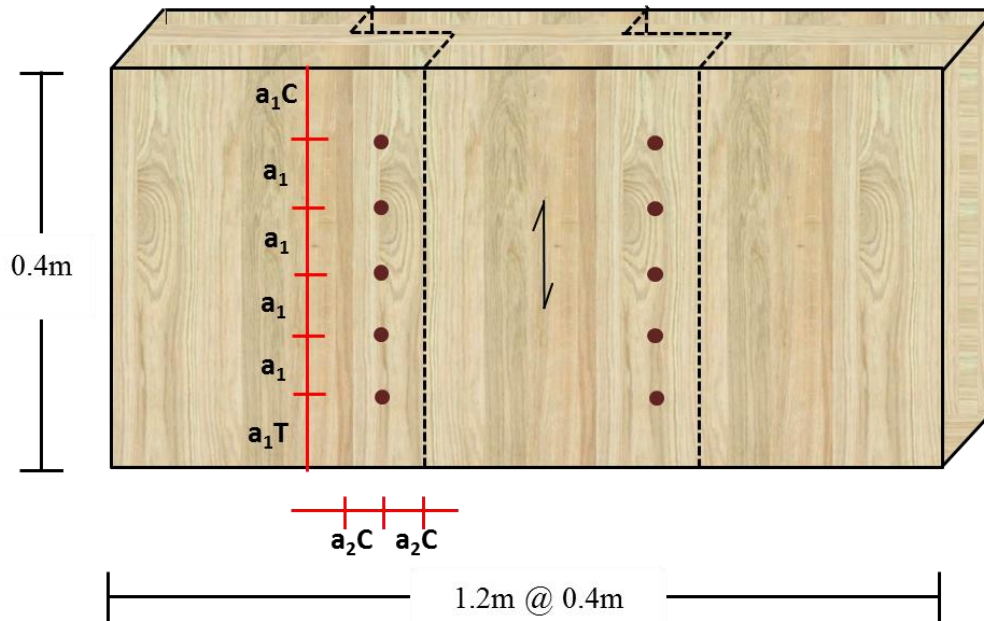
## Panel to Panel Connections (3 Panels)

- Surface Spline Joints with two rows of STS

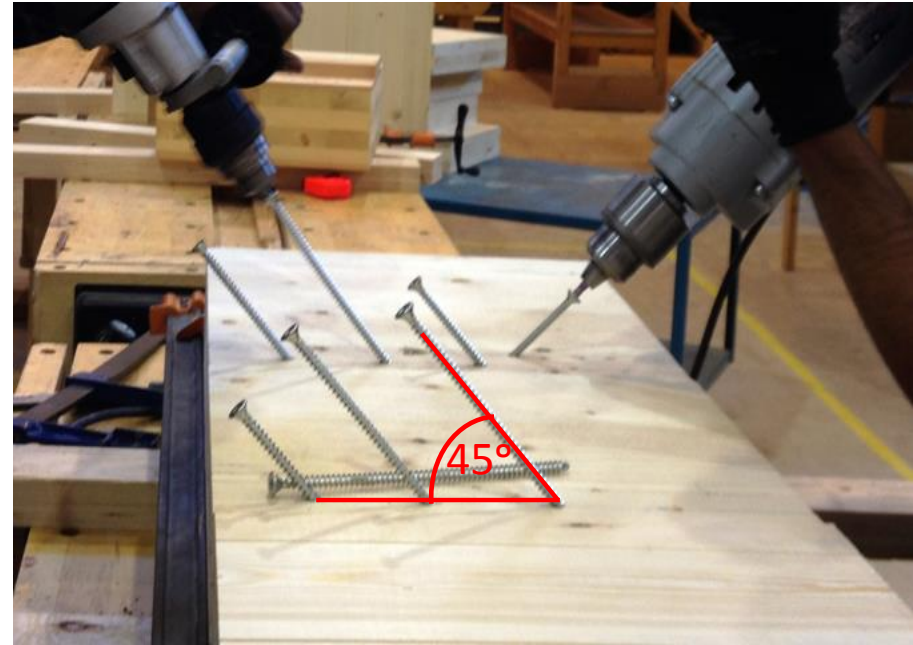
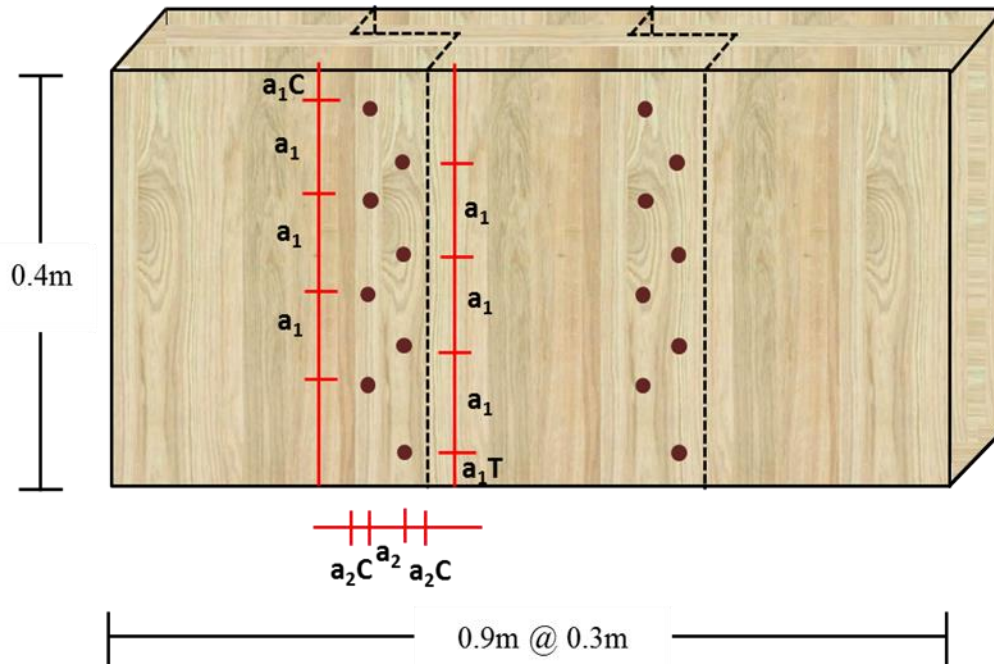


## Panel to Panel Connections (3 Panels)

- Half Lap Joints with one row of STS



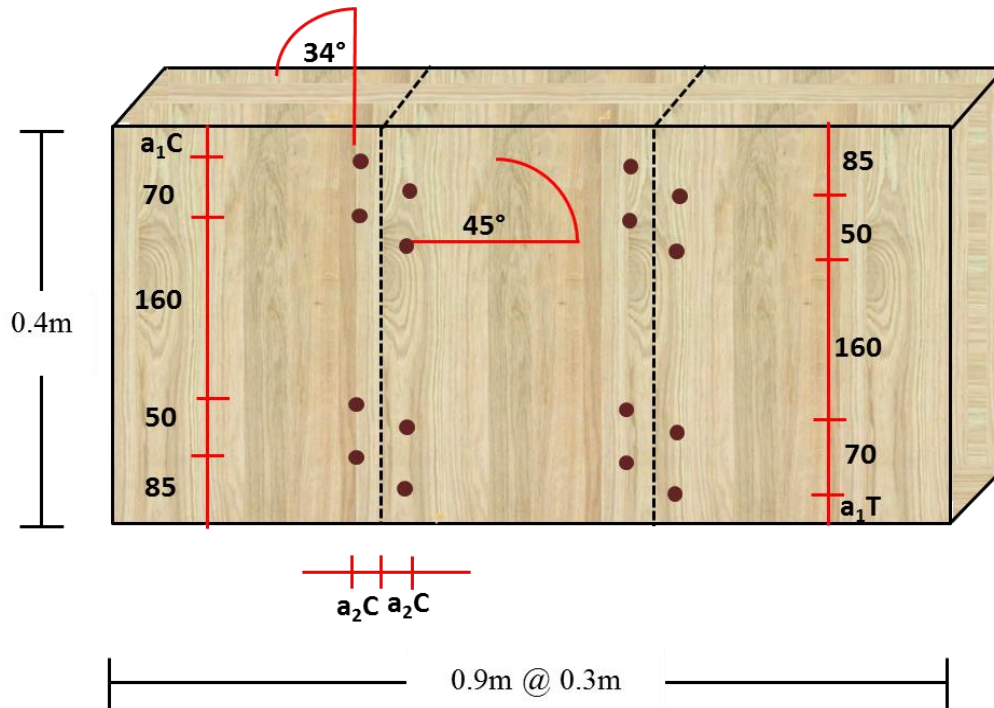
- Half-lap Joints with STS in withdrawal –one row each direction



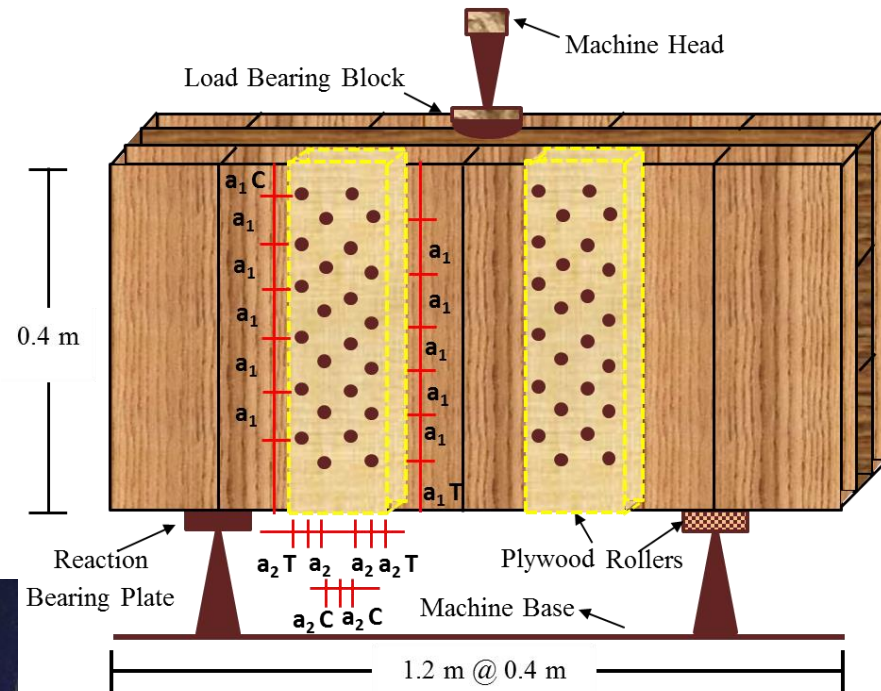


# Panel to Panel Connections (3 Panels)

- Butt Joints



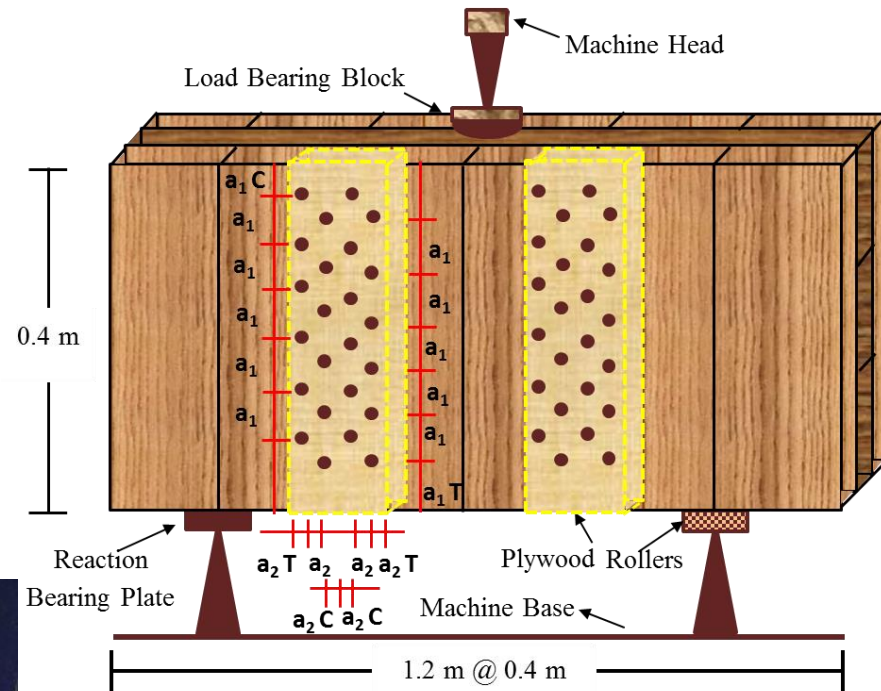
- Test set up in CEME
  - Actuator loading from top
  - Displacement control
  - Failure is assumed when the actuator load falls below 80% of recorded peak load
  - Data taken: Actuator load and displacement





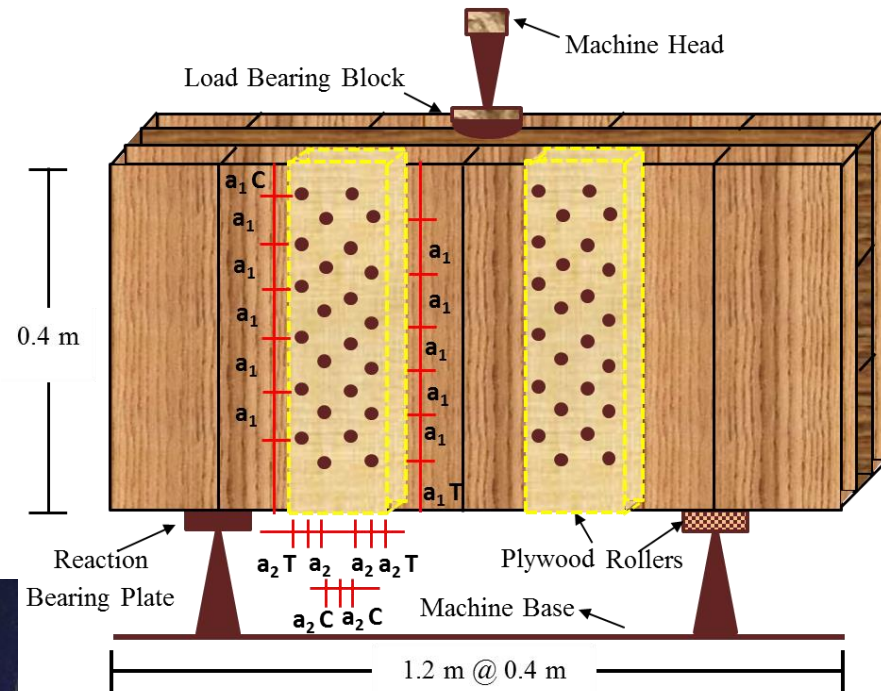
## Panel to Panel Connections (3 Panels)

- Test set up in CEME
  - Actuator loading from top
  - **Displacement control**
  - Failure is assumed when the actuator load falls below 80% of recorded peak load
  - Data taken: Actuator load and displacement



## Panel to Panel Connections (3 Panels)

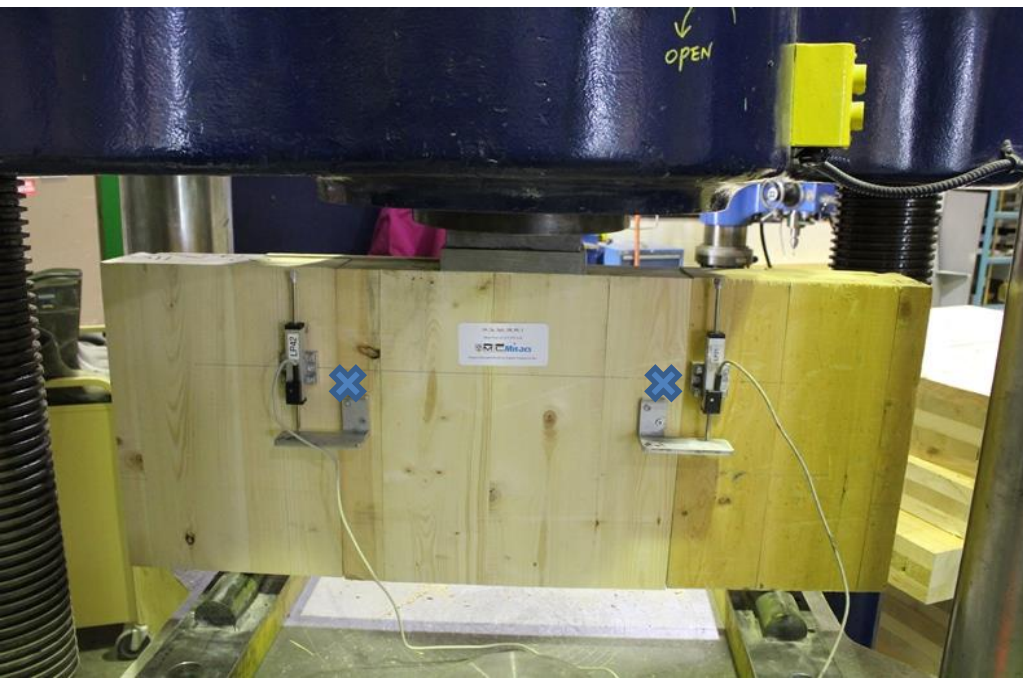
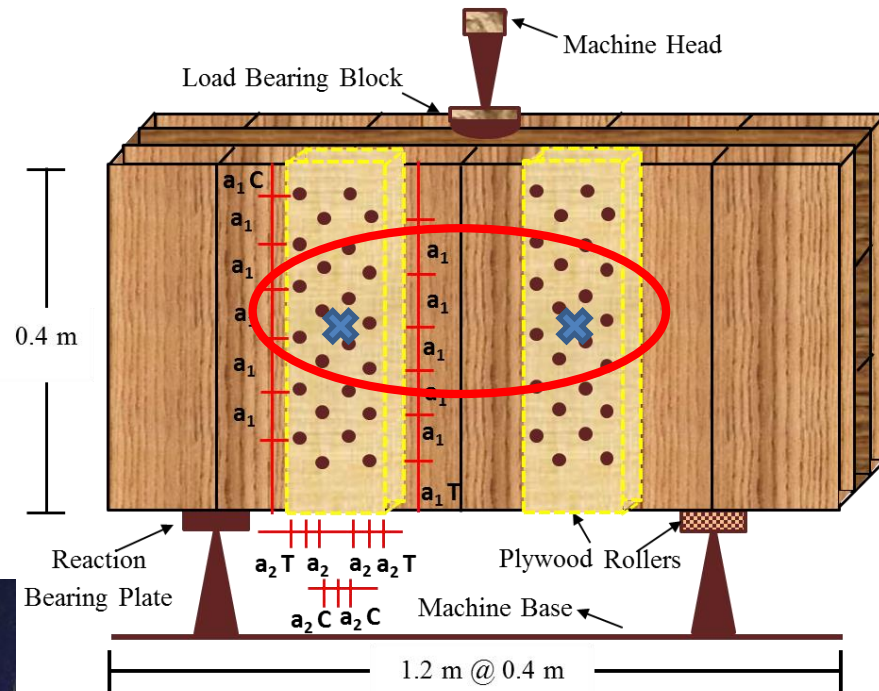
- Test set up in CEME
  - Actuator loading from top
  - Displacement control
  - Failure is assumed when the actuator load falls below 80% of recorded peak load
  - Data taken: Actuator load and displacement





## Panel to Panel Connections (3 Panels)

- Test set up in CEME
  - Actuator loading from top
  - Displacement control
  - Failure is assumed when the actuator load falls below 80% of recorded peak load
  - **Data taken: Actuator load and displacement**



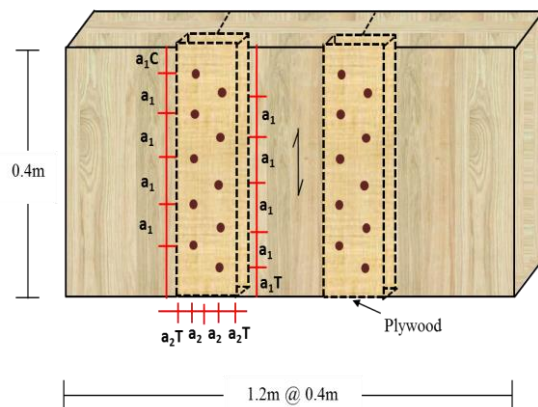
# Panel to Panel Connections (3 Panels)

## • Results for 3-ply

Series	Fmax* [kN]	F* at 5mm disp. [kN]	Yield load $F_Y^*$ (kN)	Displ. at Fmax $\Delta_{max}$ (mm)	Displ. at yield $\Delta_Y$ (mm)	Ductility $\mu$ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



# Panel to Panel Connections (3 Panels)

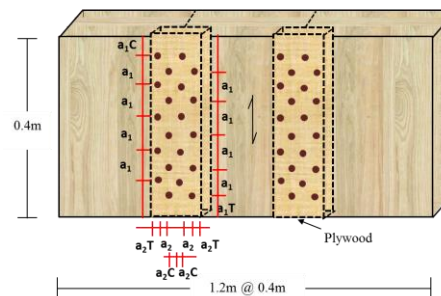
## • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

Load decrease – group factor impact?





# Panel to Panel Connections (3 Panels)

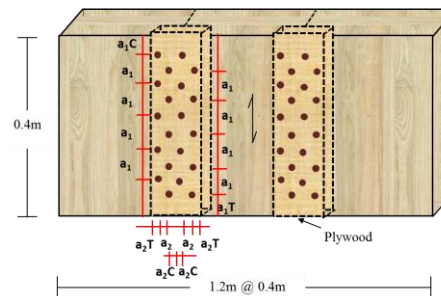
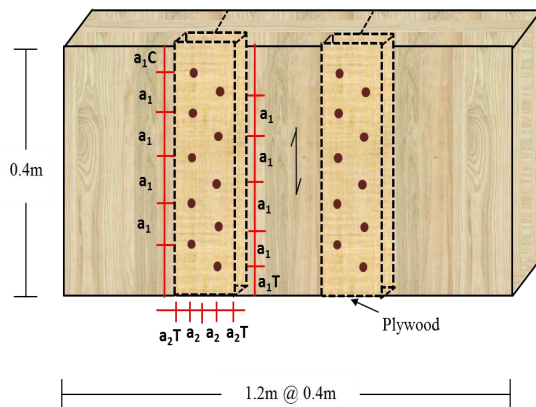
## • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

Load decrease – group factor impact?  
but  
connection stiffer



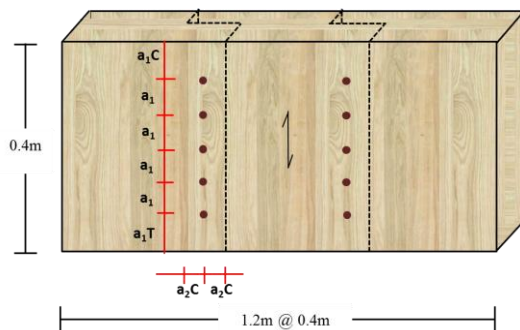
# Panel to Panel Connections (3 Panels)

- Results for 3-ply

Series	Fmax* [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at Fmax Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



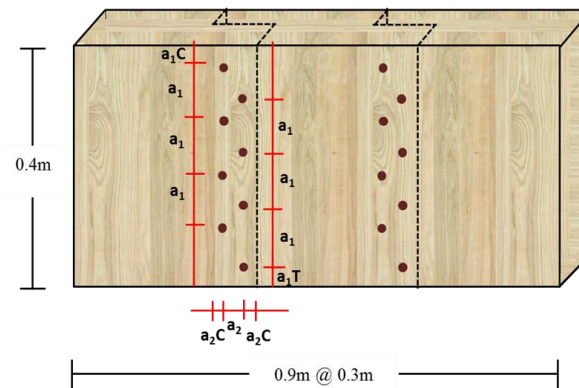
# Panel to Panel Connections (3 Panels)

## • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



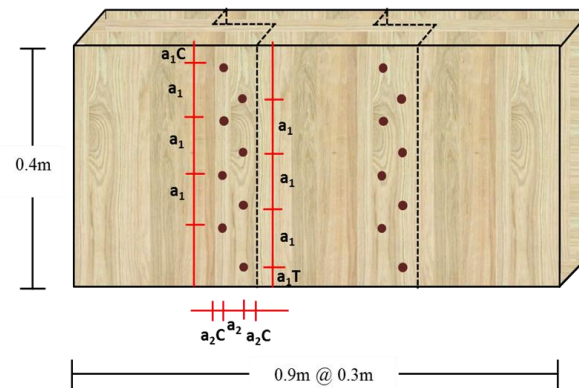
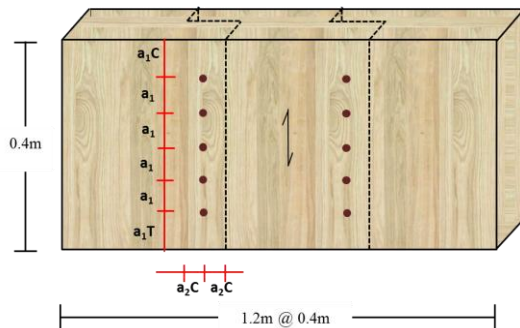
## Panel to Panel Connections (3 Panels)

### • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



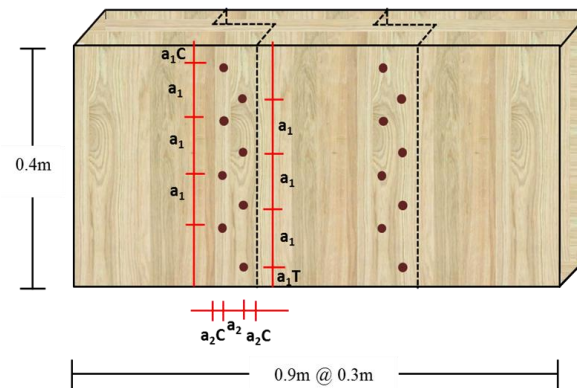
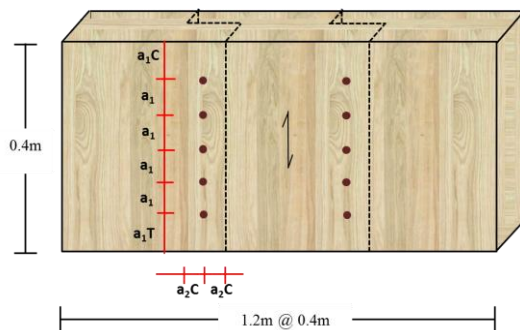
# Panel to Panel Connections (3 Panels)

## • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws





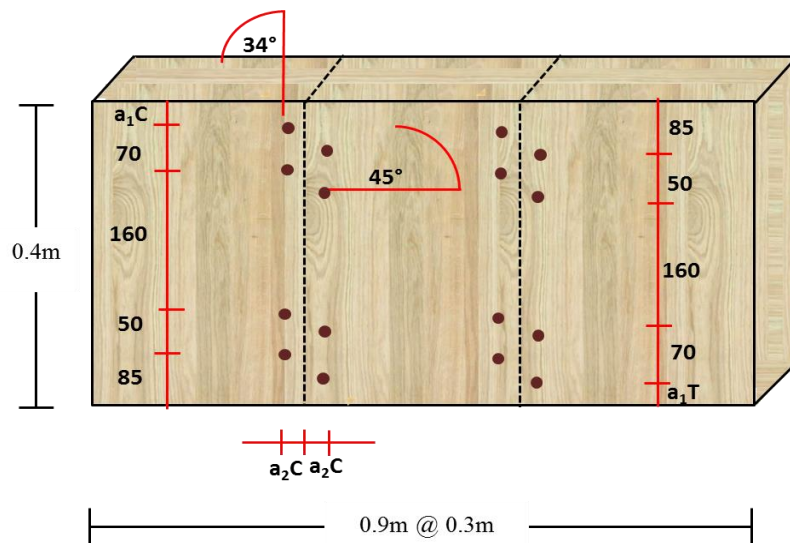
# Panel to Panel Connections (3 Panels)

## Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



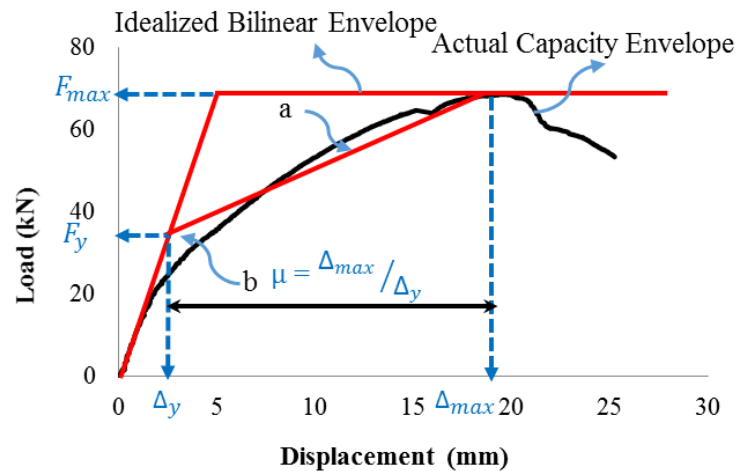
# Panel to Panel Connections (3 Panels)

## • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



Ductility evaluation of tension screw connections with FEMA 356 may not be suitable?

## Panel to Panel Connections (3 Panels)

- Results for 5-ply

Series	Fmax* [kN]	F* at 5mm disp. [kN]	Yield load $F_Y$ * (kN)	Displ. at Fmax $\Delta_{max}$ (mm)	Displ. @ yield $\Delta_y$ (mm)	Ductility $\mu$ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

# Panel to Panel Connections (3 Panels)

## • Results for 5-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

## • Results for 3-ply

≈ 30% difference

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

## Panel to Panel Connections (3 Panels)

### • Results for 5-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

### • Results for 3-ply

≈ 50% difference

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws



## Panel to Panel Connections (3 Panels)

### • Results for 5-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

### • Results for 3-ply

≈ capacity doubles

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

## Panel to Panel Connections (3 Panels)

### • Results for 5-ply

1" thick plywood

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

### • Results for 3-ply

Fastener yielding and crushing of plywood limits capacity

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

## Panel to Panel Connections (3 Panels)

### • Results for 5-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

Pull out resistance limits capacity

### • Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

## Panel to Panel Connections (3 Panels)

- Results for 5-ply

Series	Fmax* [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at Fmax Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_5ply_1R_8S	6.2	2.7	3.6	47.7	8.6	5.7
SS_3p_5ply_2R_8S	4.6	1.7	2.8	33.0	7.0	4.9
LJ_3p_5ply_1R_8S	21.4	10.5	14.3	43.3	8.3	5.4
LJ_3p_5ply_2R_45	19.7	-	17.0	3.0	1.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

\* values are per pair of screws

Overall small displacement

- Results for 3-ply

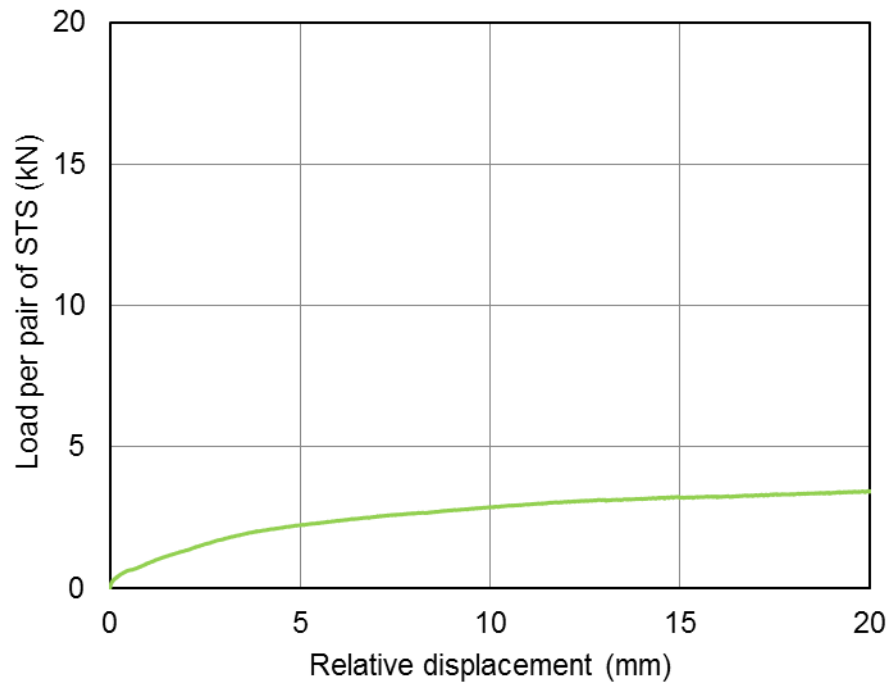
Series	Fmax* [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at Fmax Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_3p_3ply_1R_8S	4.1	2.7	2.7	34.2	4.9	7.0
SS_3p_3ply_2R_8S	3.4	2.9	2.0	22.3	3.7	6.1
LJ_3p_3ply_1R_8S	10.3	6.1	6.4	23.5	5.1	5.5
LJ_3p_3ply_2R_45	10.8	-	8.8	2.6	0.8	4.2
BJ_3p_3ply_2R_8S	11.9	-	10.6	1.8	0.4	4.9

Note: Results listed in this table are average measurements out of 6 tests.

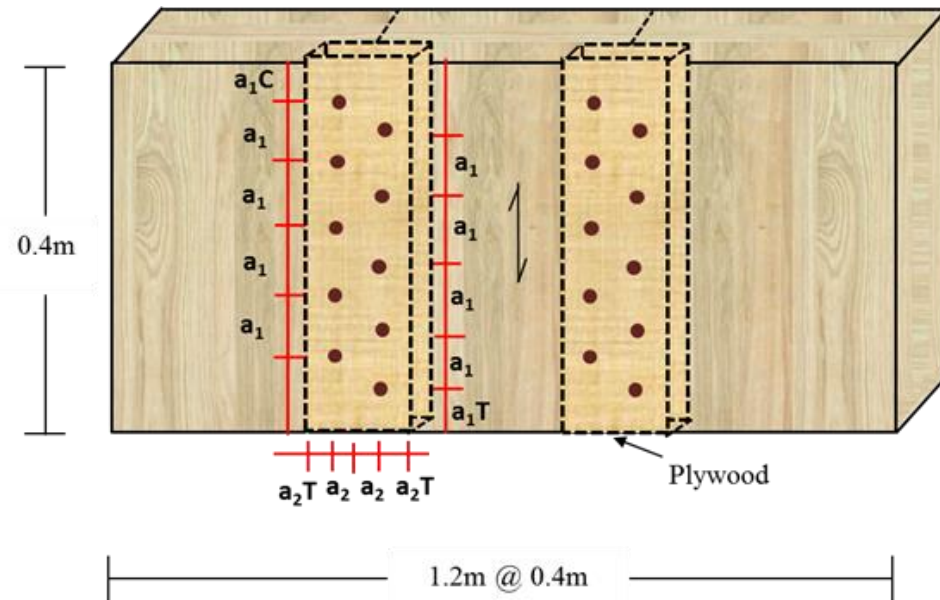
\* values are per pair of screws

## Panel to Panel Connections (3 Panels)

- Load-Displacement Curves



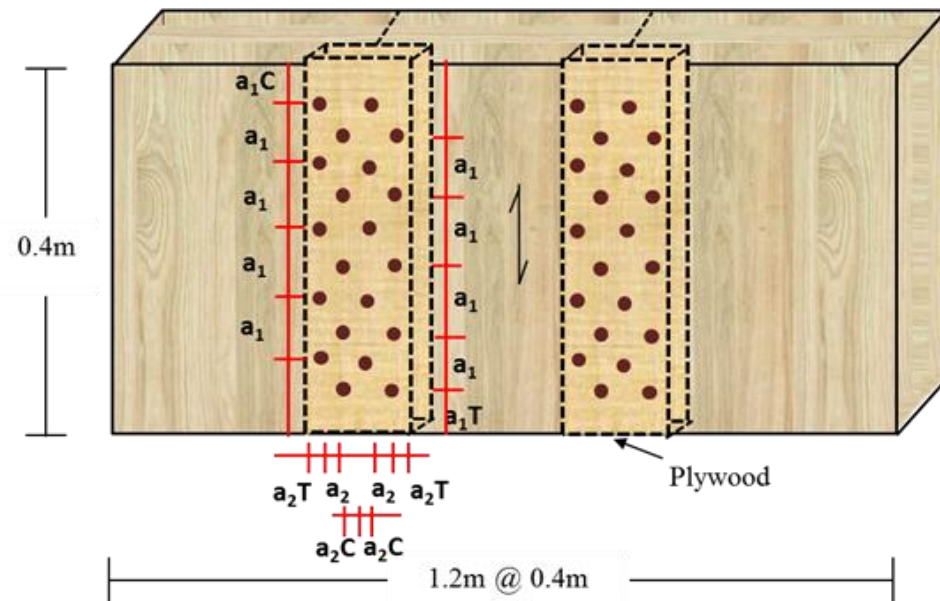
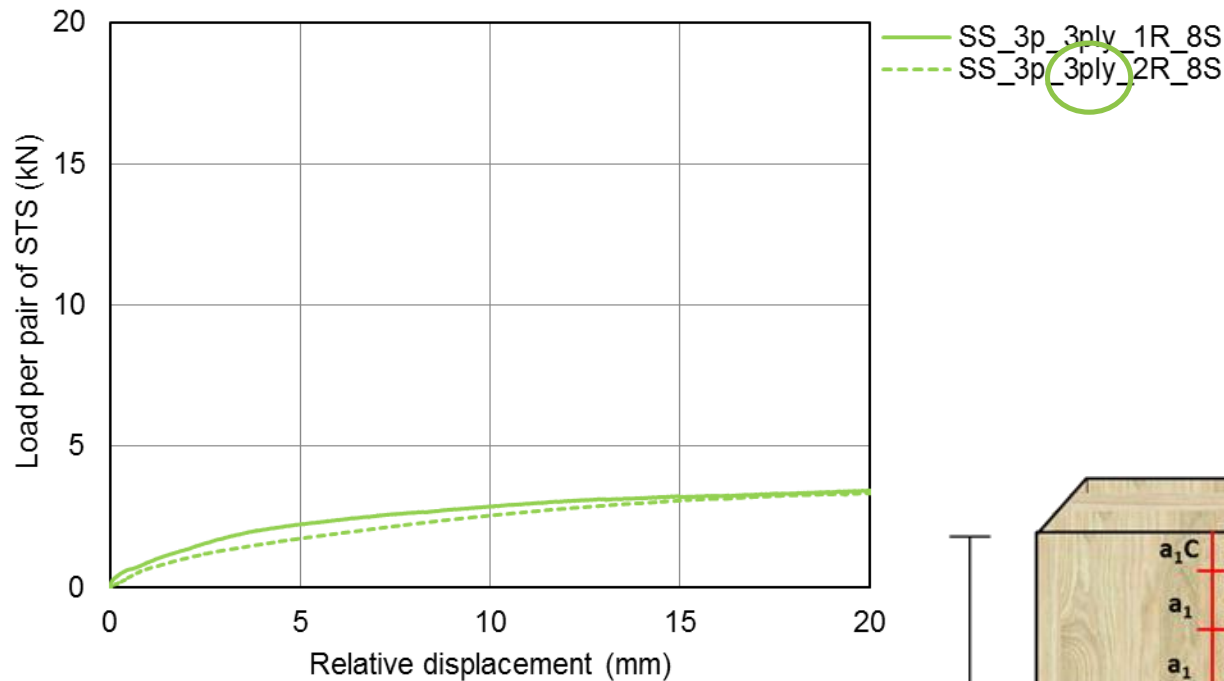
SS\_3p\_3ply\_1R\_8S





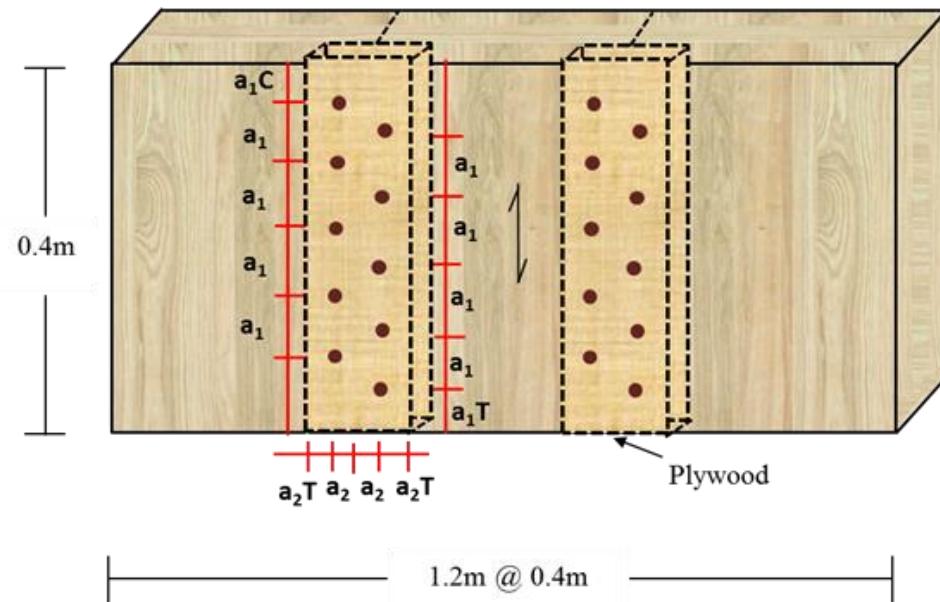
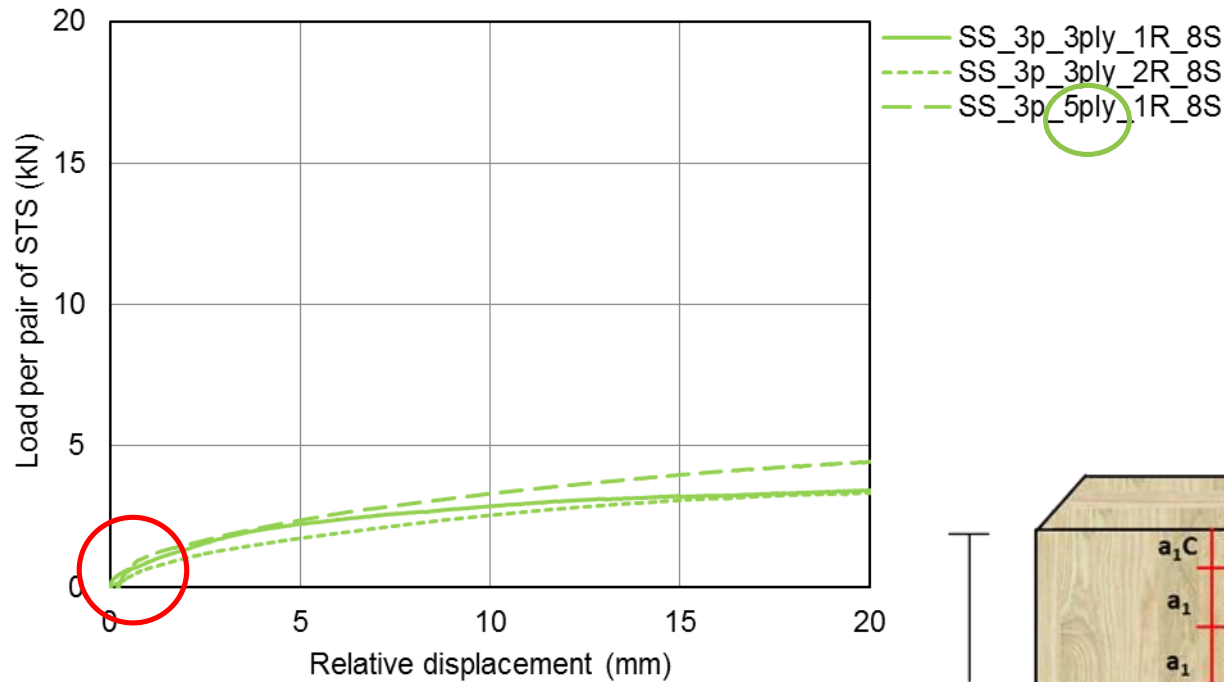
# Panel to Panel Connections (3 Panels)

## Load-Displacement Curves



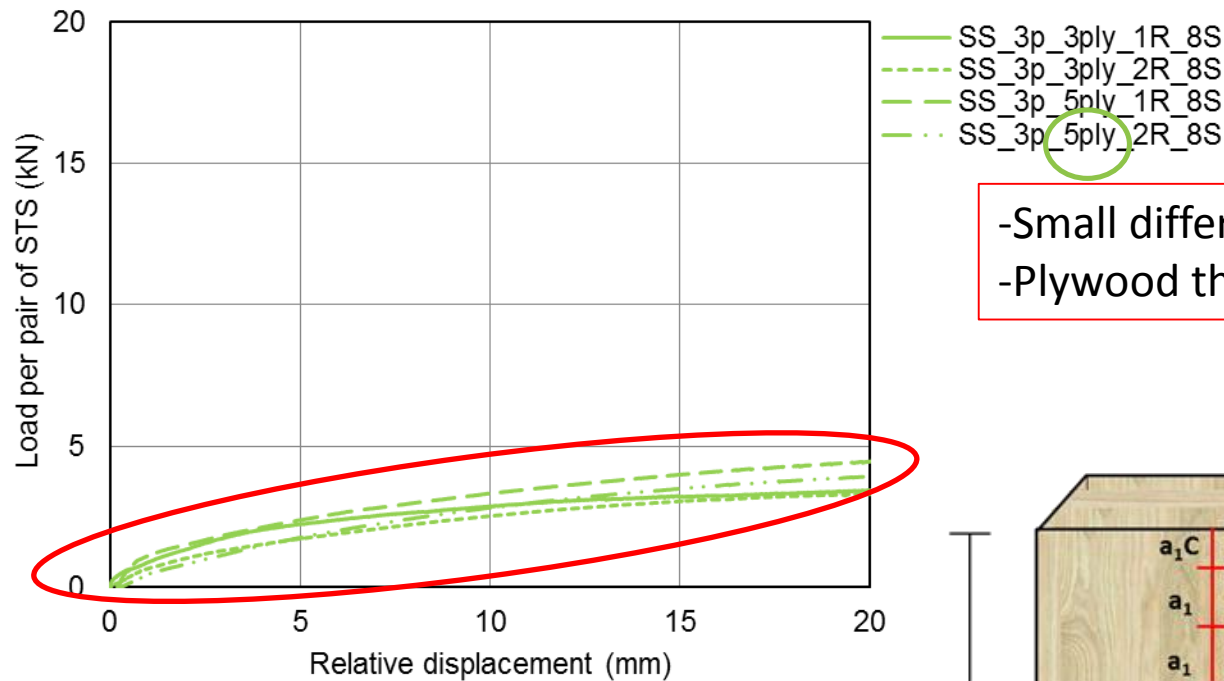
## Panel to Panel Connections (3 Panels)

- Load-Displacement Curves

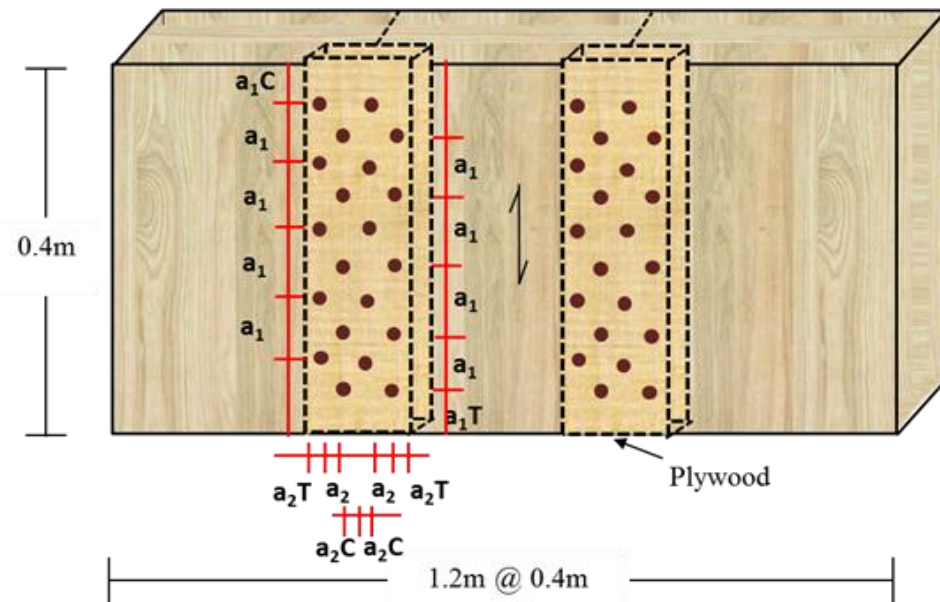


# Panel to Panel Connections (3 Panels)

## • Load-Displacement Curves

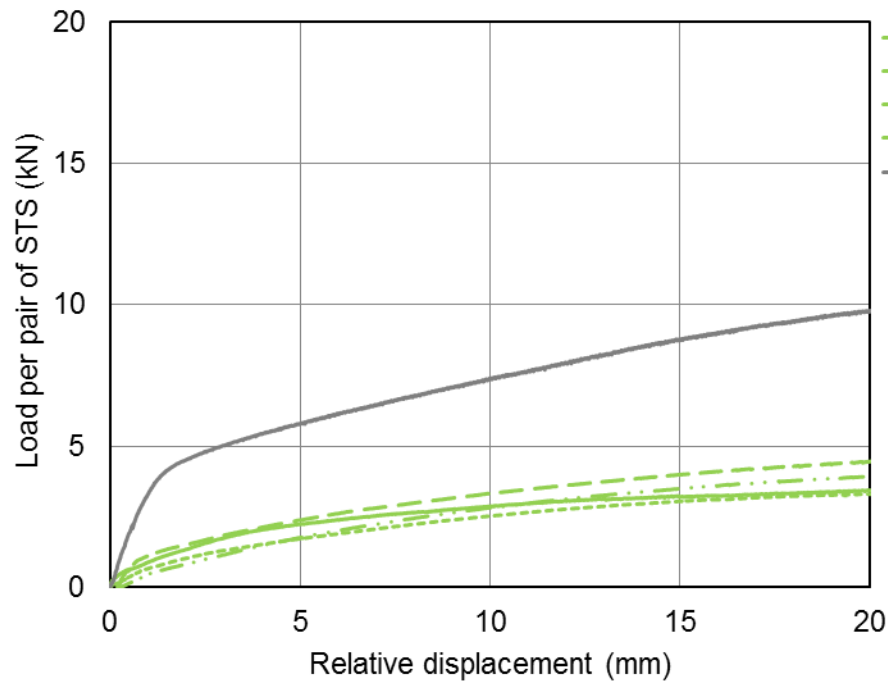


- Small differences
- Plywood thickness controls

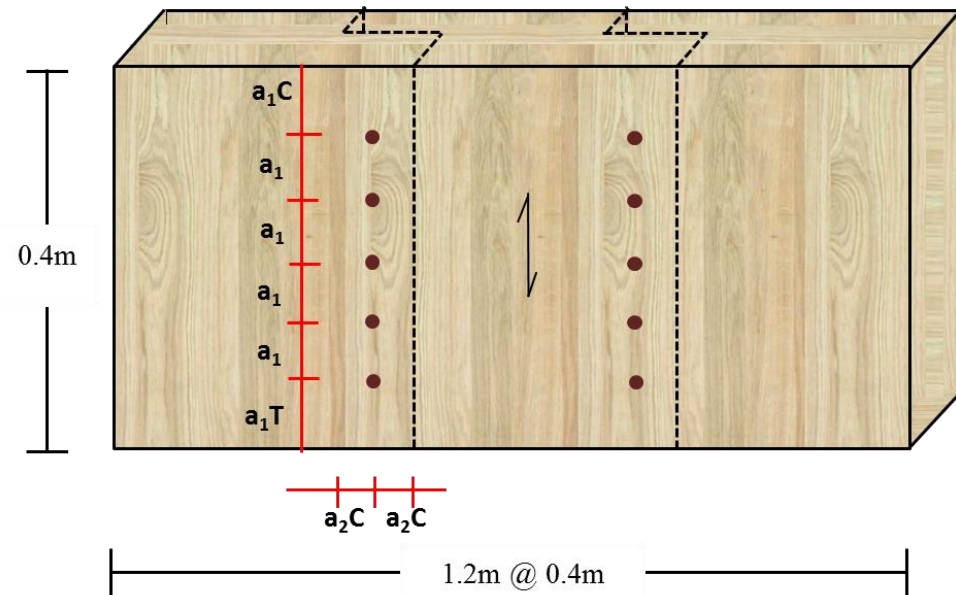


# Panel to Panel Connections (3 Panels)

- Load-Displacement Curves

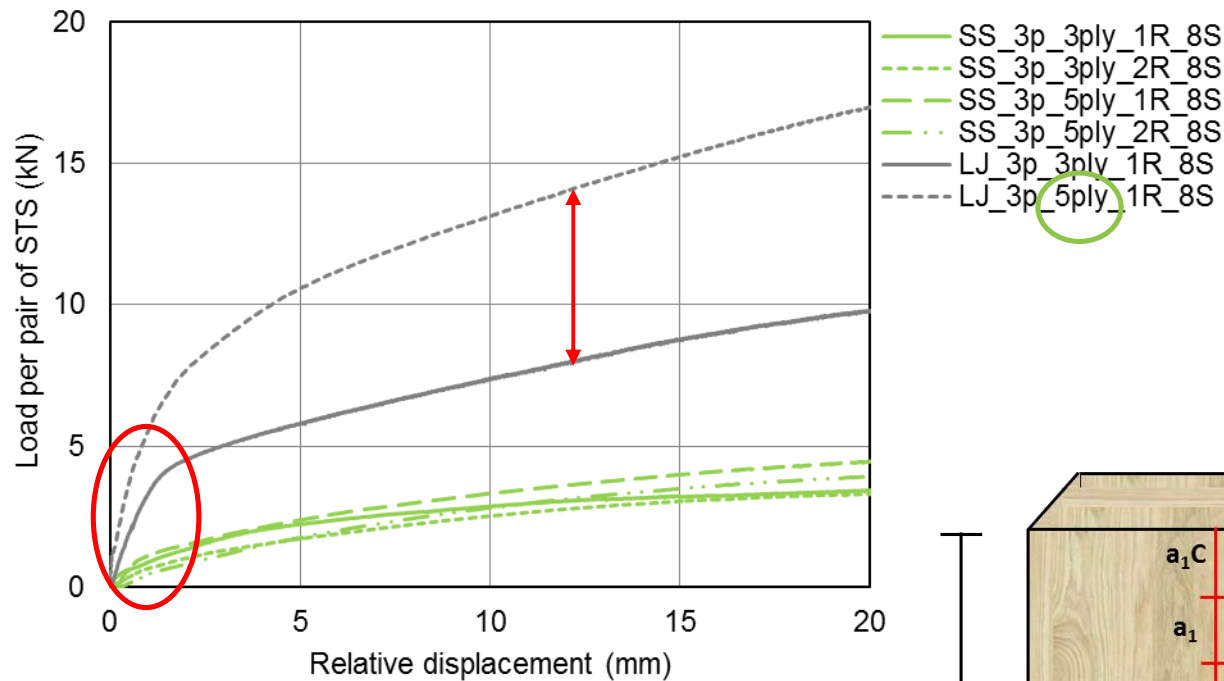


- Deeper embedment
- Fastener can reach yield strength

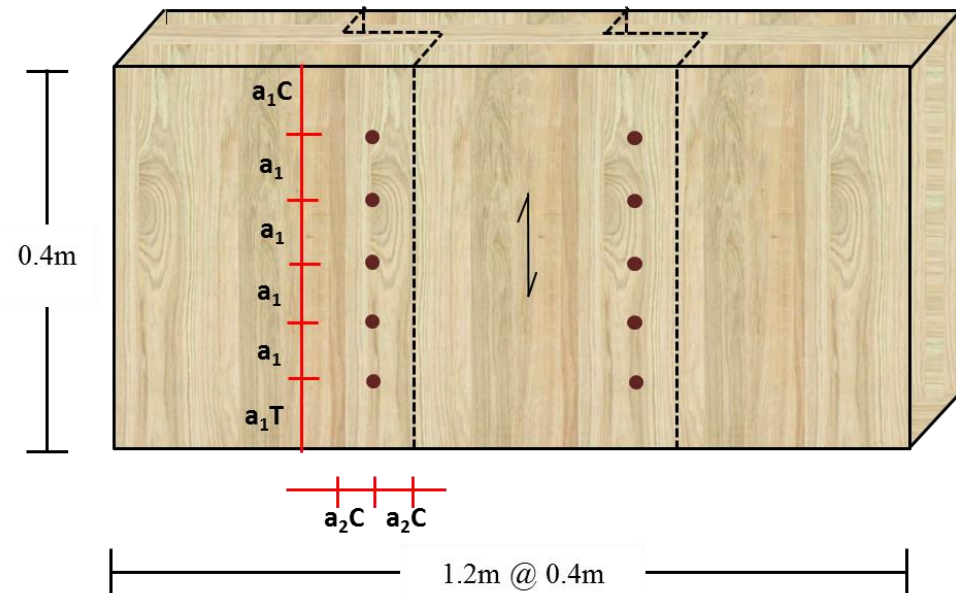


# Panel to Panel Connections (3 Panels)

## • Load-Displacement Curves



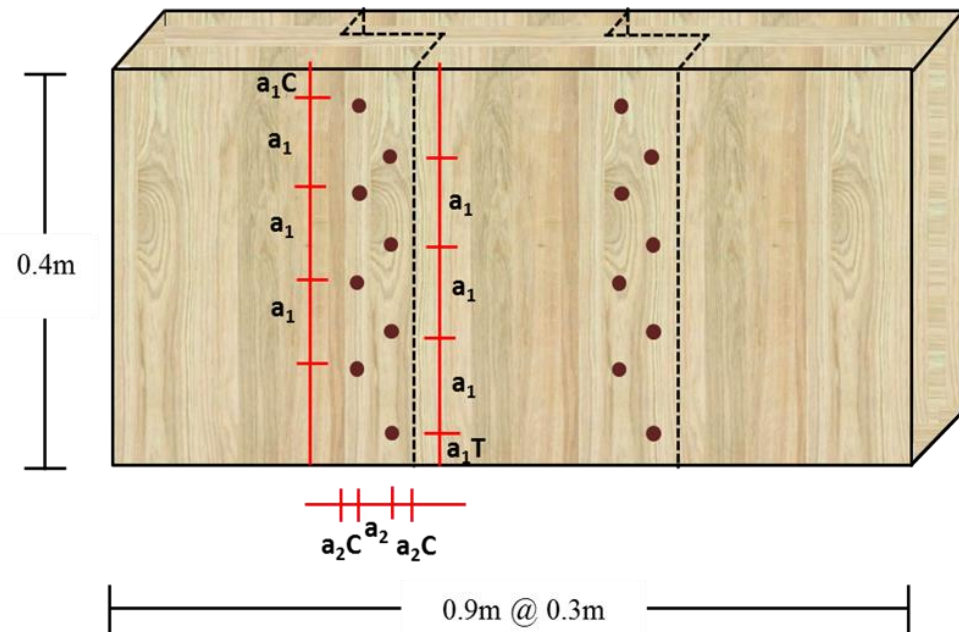
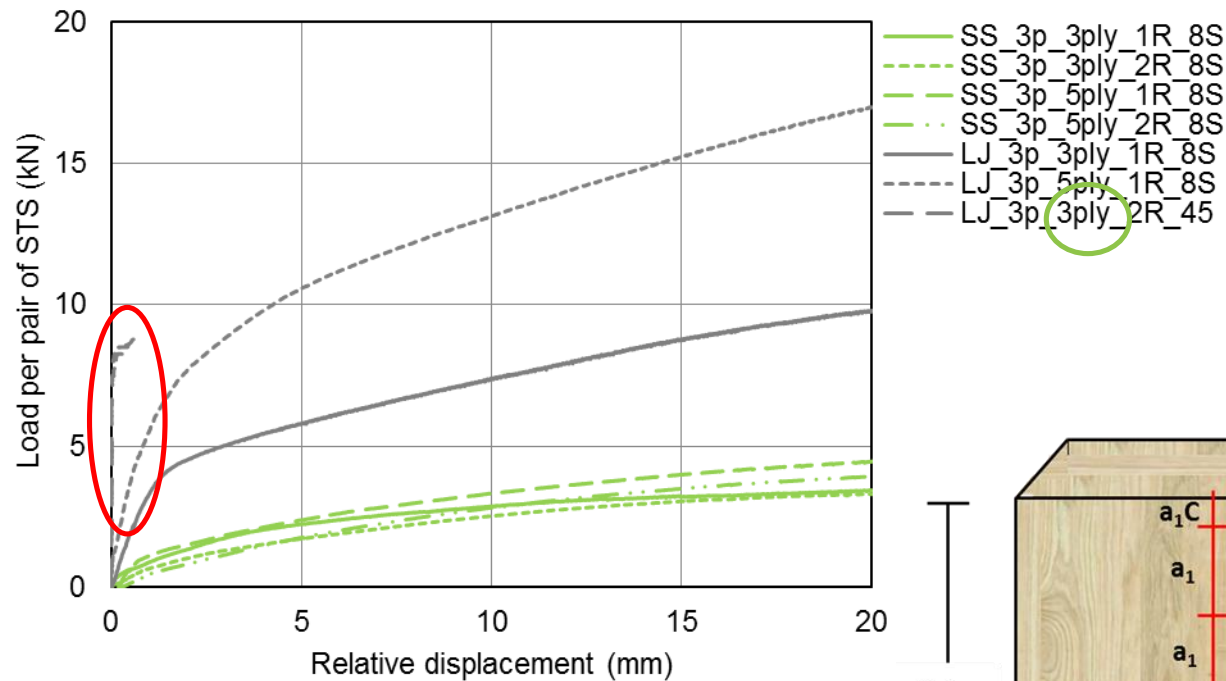
Parallel to grain loading in shear plane for 5-Ply half lap joint





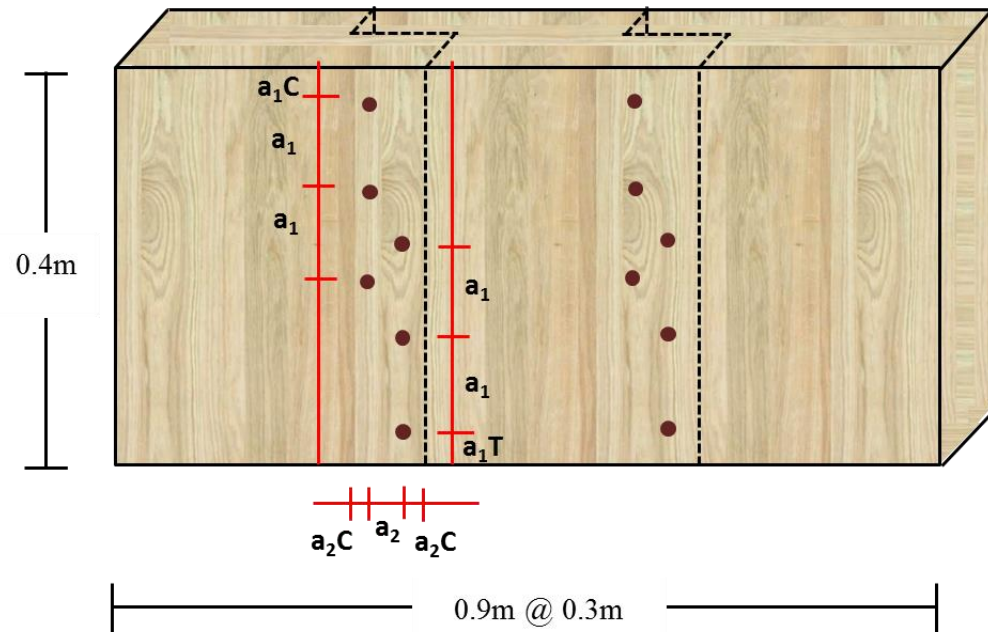
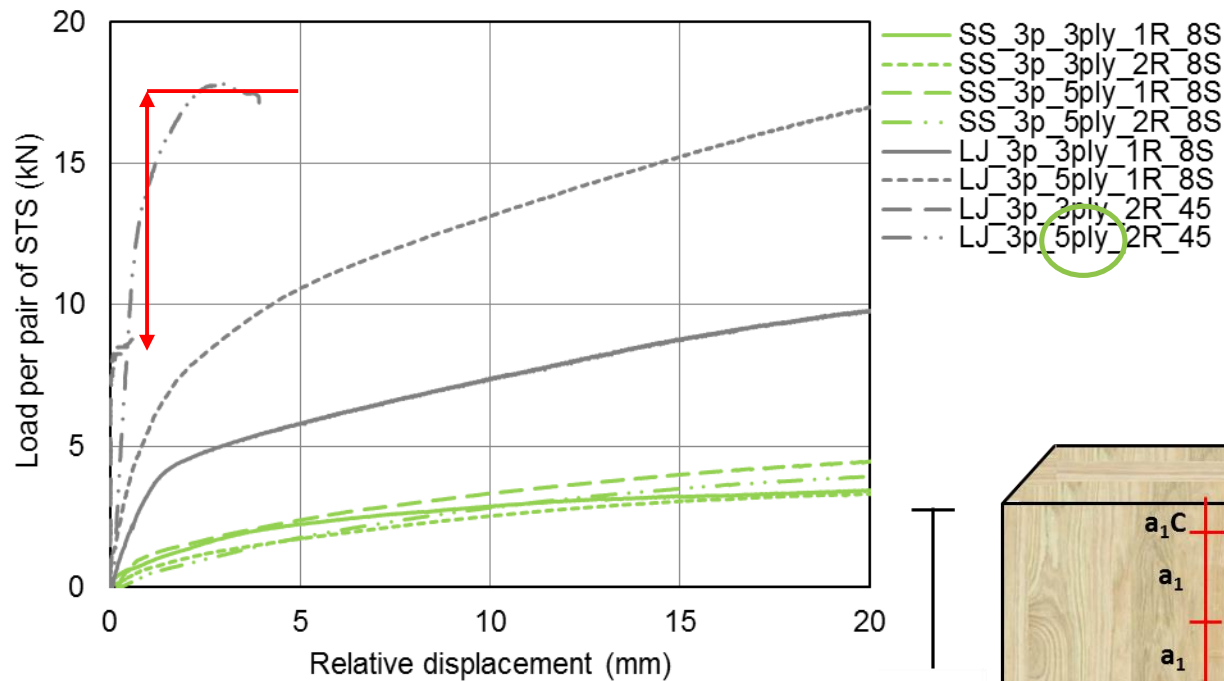
# Panel to Panel Connections (3 Panels)

## Load-Displacement Curves



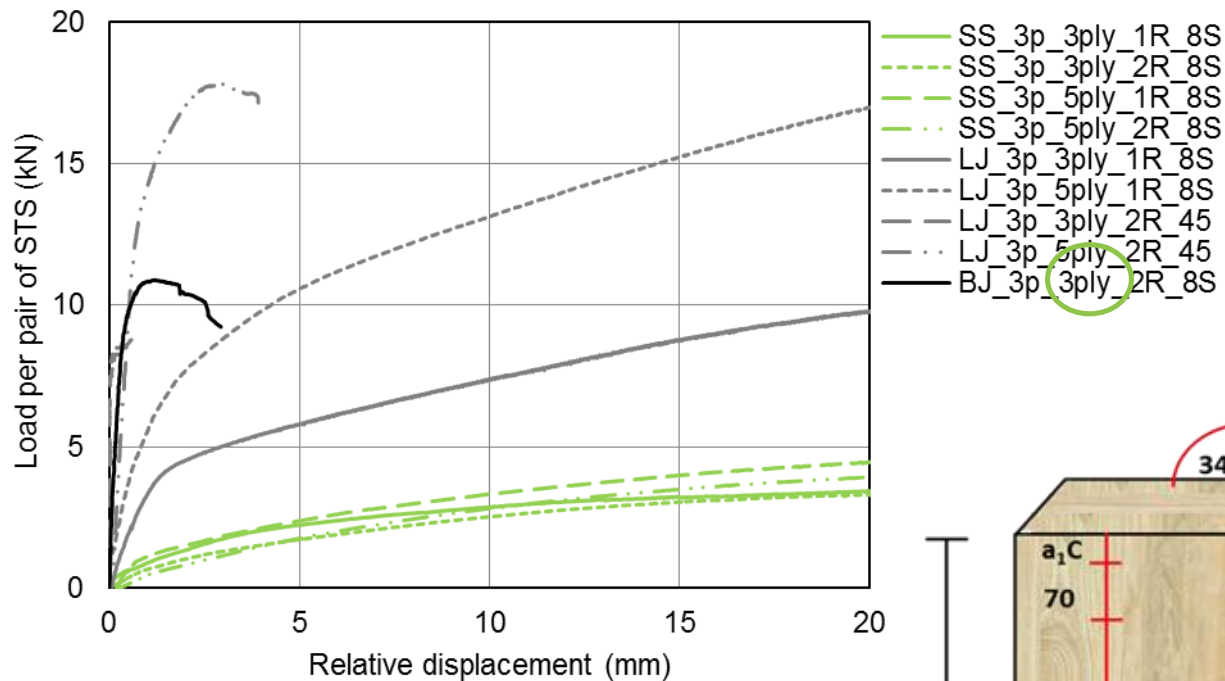
# Panel to Panel Connections (3 Panels)

## Load-Displacement Curves

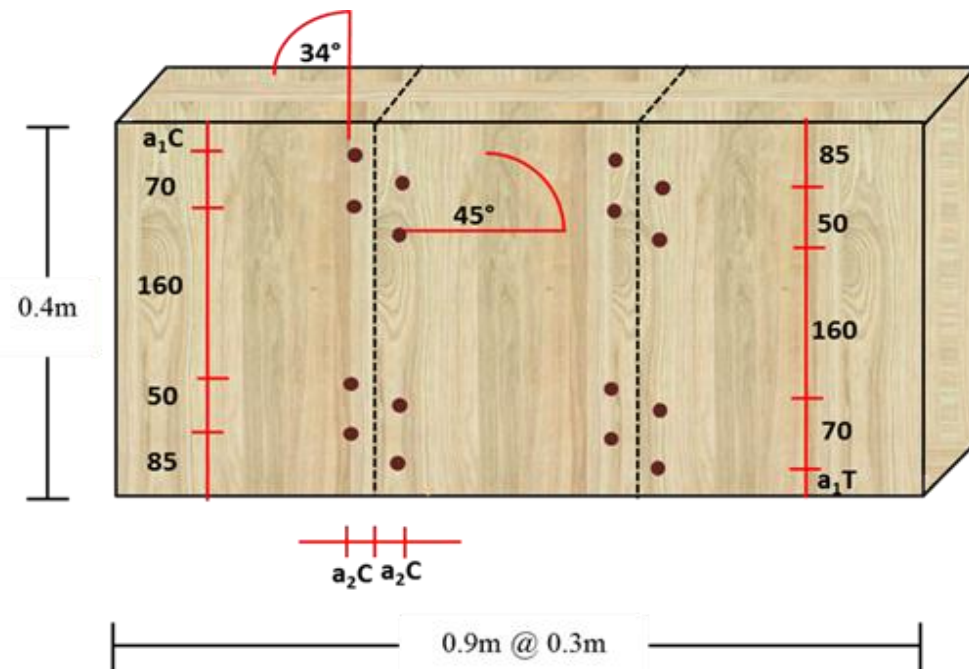


# Panel to Panel Connections (3 Panels)

## Load-Displacement Curves



Intermediate performance  
compared to lap joint but  
less machining required



## Panel to Panel Connections (3 Panels)

- Test statistics

Series	STS per shear plane [#]	Fmax [kN]	Displ. F max [mm]	0.4 Fmax [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
SS_3p_3ply_1R_8S	10	20.35	34.20	8.14	3.30	14.25	9.00	0.60	2.47	1.58
SS_3p_3ply_2R_8S	20	34.10	22.30	13.64	3.00	23.87	8.70	1.53	4.55	2.74
SS_3p_5ply_1R_8S	10	30.80	47.70	12.32	6.40	21.56	18.60	0.65	1.93	1.16
SS_3p_5ply_2R_8S	20	45.95	33.00	18.38	4.80	32.17	12.20	1.39	3.83	2.64
LJ_3p_3ply_1R_8S	5	25.65	23.50	10.26	1.30	17.96	8.70	1.09	7.89	2.06
LJ_3p_5ply_1R_8S	5	53.40	43.30	21.36	2.60	37.38	12.50	1.23	8.22	2.99
LJ_3p_3ply_2R_45	8	43.40	2.60	17.36	0.03	30.38	0.32	16.69	578.67	94.94
LJ_3p_5ply_2R_45	6	59.15	3.00	23.66	0.11	41.41	0.74	19.72	215.09	55.95
BJ_3p_3ply_2R_8S	8	47.40	1.80	18.96	0.10	33.18	0.20	26.33	189.60	165.90

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners

# Panel to Panel Connections (3 Panels)

- Test statistics

Series	STS per shear plane [#]	Design Resistance [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness [kN/mm]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	1.73	4.48	20.35	34.20	0.60	2.63
SS_3p_3ply_2R_8S	20	15.49	1.73	8.96	34.10	22.30	1.53	2.20
SS_3p_5ply_1R_8S	10	9.79	1.75	5.60	30.80	47.70	0.65	3.15
SS_3p_5ply_2R_8S	20	19.57	1.75	11.19	45.95	33.00	1.39	2.35
LJ_3p_3ply_1R_8S	5	2.78	2.13	1.31	25.65	23.50	1.09	9.22
LJ_3p_5ply_1R_8S	5	7.13	2.49	2.86	53.40	43.30	1.23	7.49
LJ_3p_3ply_2R_45	8	19.62	0.63	31.16	43.40	2.60	16.69	2.21
LJ_3p_5ply_2R_45	6	24.60	0.84	29.27	59.15	3.00	19.72	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners



## Panel to Panel Connections (3 Panels)

- Test statistics

Series	STS per shear plane [#]	Design Resistance [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness [kN/mm]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	1.73	4.48	20.35	34.20	0.60	2.63
SS_3p_3ply_2R_8S	20	15.49	1.73	8.96	34.10	22.30	1.53	2.20
SS_3p_5ply_1R_8S	10	9.79	1.75	5.60	30.80	47.70	0.65	3.15
SS_3p_5ply_2R_8S	20	19.57	1.75	11.19	45.95	33.00	1.39	2.35
LJ_3p_3ply_1R_8S	5	2.78	2.13	1.31	25.65	23.50	1.09	9.22
LJ_3p_5ply_1R_8S	5	7.13	2.49	2.86	53.40	43.30	1.23	7.49
LJ_3p_3ply_2R_45	8	19.62	0.63	31.16	43.40	2.60	16.69	2.21
LJ_3p_5ply_2R_45	6	24.60	0.84	29.27	59.15	3.00	19.72	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners

## Panel to Panel Connections (3 Panels)

- Test statistics

Series	STS per shear plane [#]	Design Resistance [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness [kN/mm]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	1.73	4.48	20.35	34.20	0.60	2.63
SS_3p_3ply_2R_8S	20	15.49	1.73	8.96	34.10	22.30	1.53	2.20
SS_3p_5ply_1R_8S	10	9.79	1.75	5.60	30.80	47.70	0.65	3.15
SS_3p_5ply_2R_8S	20	19.57	1.75	11.19	45.95	33.00	1.39	2.35
LJ_3p_3ply_1R_8S	5	2.78	2.13	1.31	25.65	23.50	1.09	9.22
LJ_3p_5ply_1R_8S	5	7.13	2.49	2.86	53.40	43.30	1.23	7.49
LJ_3p_3ply_2R_45	8	19.62	0.63	31.16	43.40	2.60	16.69	2.21
LJ_3p_5ply_2R_45	6	24.60	0.84	29.27	59.15	3.00	19.72	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners

# Panel to Panel Connections (3 Panels)

- Test statistics

Series	STS per shear plane [#]	Design Resistance [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness [kN/mm]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	1.73	4.48	20.35	34.20	0.60	2.63
SS_3p_3ply_2R_8S	20	15.49	1.73	8.96	34.10	22.30	1.53	2.20
SS_3p_5ply_1R_8S	10	9.79	1.75	5.60	30.80	47.70	0.65	3.15
SS_3p_5ply_2R_8S	20	19.57	1.75	11.19	45.95	33.00	1.39	2.35
LJ_3p_3ply_1R_8S	5	2.78	2.13	1.31	25.65	23.50	1.09	9.22
LJ_3p_5ply_1R_8S	5	7.13	2.49	2.86	53.40	43.30	1.23	7.49
LJ_3p_3ply_2R_45	8	19.62	0.63	31.16	43.40	2.60	16.69	2.21
LJ_3p_5ply_2R_45	6	24.60	0.84	29.27	59.15	3.00	19.72	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners

# Panel to Panel Connections (3 Panels)

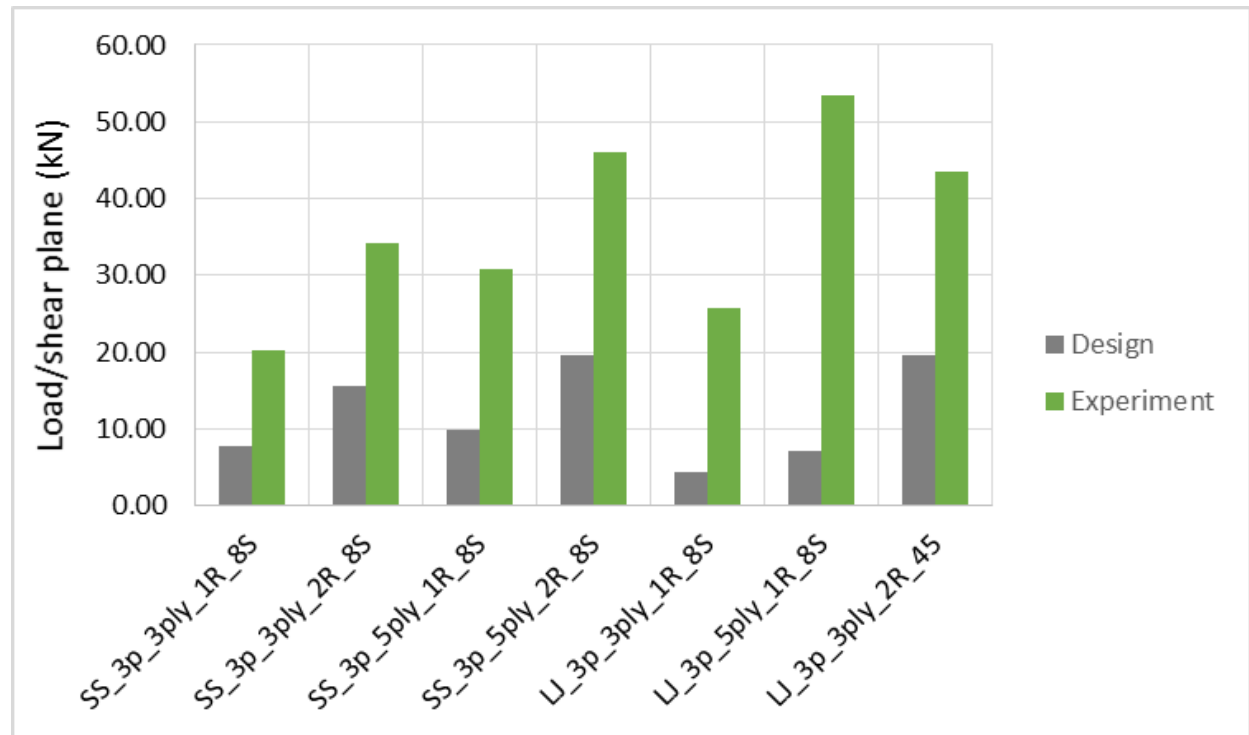
- Test statistics

Series	STS per shear plane [#]	Design Resistance [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness [kN/mm]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	1.73	4.48	20.35	34.20	0.60	2.63
SS_3p_3ply_2R_8S	20	15.49	1.73	8.96	34.10	22.30	1.53	2.20
SS_3p_5ply_1R_8S	10	9.79	1.75	5.60	30.80	47.70	0.65	3.15
SS_3p_5ply_2R_8S	20	19.57	1.75	11.19	45.95	33.00	1.39	2.35
LJ_3p_3ply_1R_8S	5	2.78	2.13	1.31	25.65	23.50	1.09	9.22
LJ_3p_5ply_1R_8S	5	7.13	2.49	2.86	53.40	43.30	1.23	7.49
LJ_3p_3ply_2R_45	8	19.62	0.63	31.16	43.40	2.60	16.69	2.21
LJ_3p_5ply_2R_45	6	24.60	0.84	29.27	59.15	3.00	19.72	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners

Rotation of specimen may impact displacement

# Panel to Panel Connections (3 Panels)



Series	STS per shear plane [#]	Design Resistance [kN]	Test Fmax [kN]	Overstrength
SS_3p_3ply_1R_8S	10	7.75	20.35	2.63
SS_3p_3ply_2R_8S	20	15.49	34.10	2.20
SS_3p_5ply_1R_8S	10	9.79	30.80	3.15
SS_3p_5ply_2R_8S	20	19.57	45.95	2.35
LJ_3p_3ply_1R_8S	5	2.78	25.65	9.22
LJ_3p_5ply_1R_8S	5	7.13	53.40	7.49
LJ_3p_3ply_2R_45	8	19.62	43.40	2.21
LJ_3p_5ply_2R_45	6	24.60	59.15	2.40

Note: Results listed in this table are average measurements out of 6 tests.  
All the values are per shear plane utilising the indicated number of fasteners



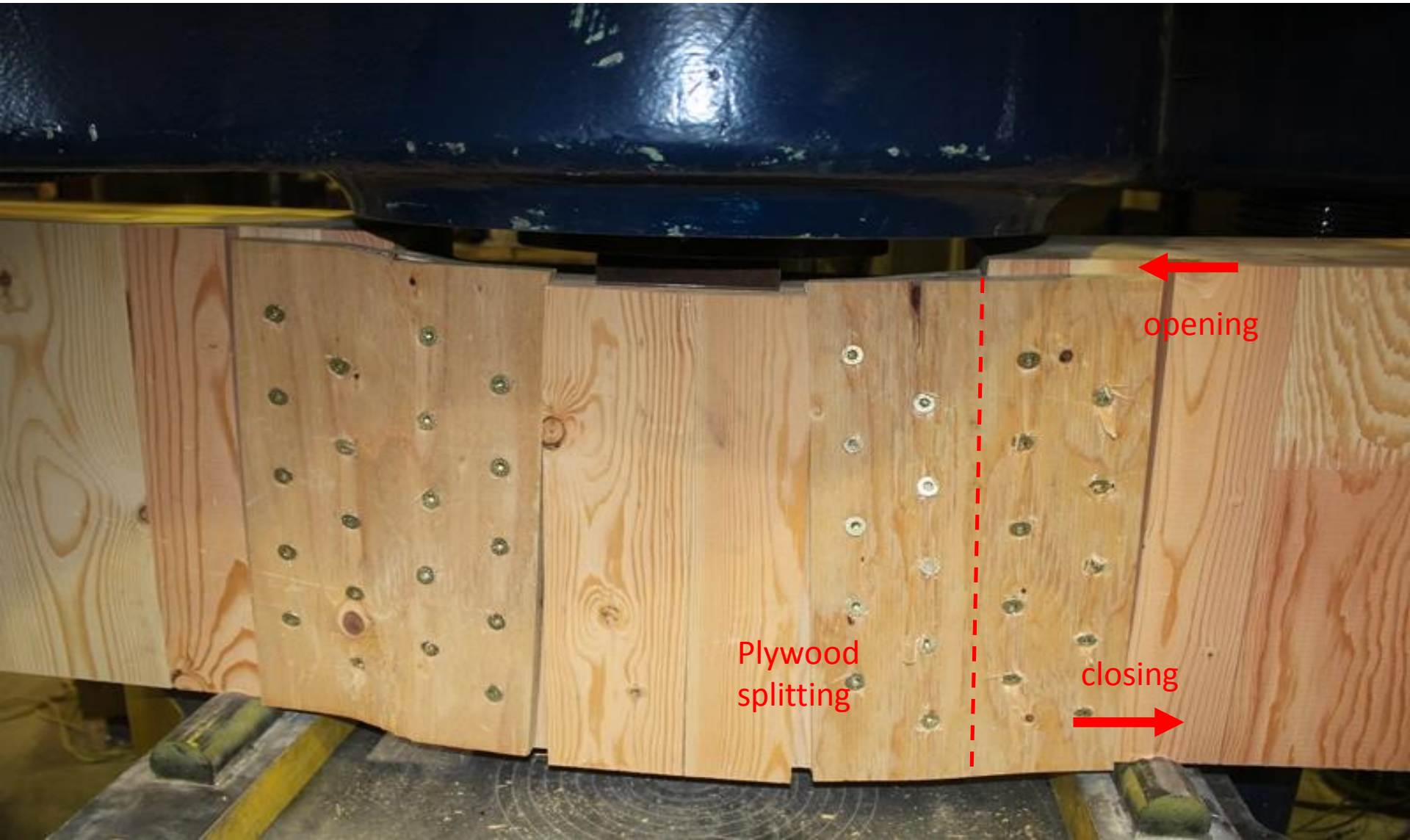
## Panel to Panel Connections (3 Panels)

- Pure shear (Lap-joint)



## Panel to Panel Connections (3 Panels)

- Bending (Surface Spline)





## Panel to Panel Connections (3 Panels)

- Screw Yielding (Surface Spline )



## Panel to Panel Connections (3 Panels)

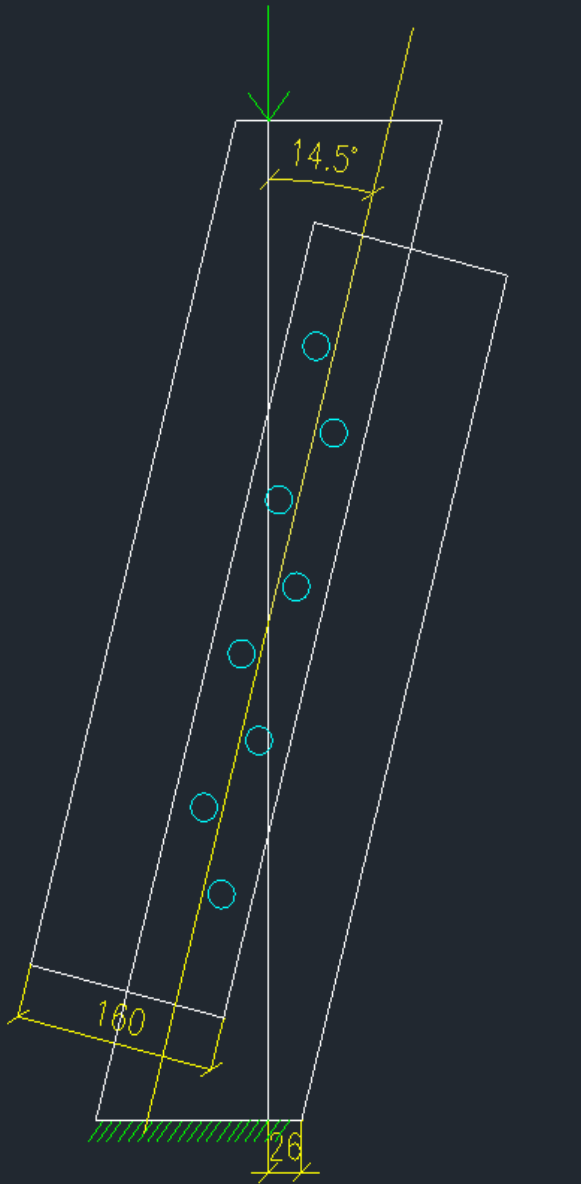
- Screw Yielding and Breakage (Lap-Joint)





## Panel to Panel Connections (2 Panels)

- 2 Panels



Brandner et al. 2013





# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain



# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/46	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

# Panel to Panel Connections (2 Panels)

## • Test Series

Label	Type	Screw [mm]	Angle [°]	Replicates	STS rows	STS action
SS_2p_3ply_1R_90	Surface Spline	80	90	6	2	Shear
SS_2p_3ply_1R_90_NF		80	90	3	2	Shear
SS_2p_5ply_1R_90		100	90	6	2	Shear
LJ_2p_3ply_1R_90	Lap Joint	90	90	6	1	Shear
LJ_2p_3ply_1R_90_NF		90	90	3	1	Shear
LJ_2p_5ply_1R_90		160	90	6	1	Shear
LJ_2p_3ply_1R_45		140	45	6	2	Withdr.
LJ_2p_3ply_1R_45_NF		140	45	3	2	Withdr.
LJ_2p_5ply_1R_45		220	45	6	2	Withdr.
LJ_2p_3ply_1R_45-90		90 + 140	90 + 45	6	2	Shear+Withdr.
LJ_2p_3ply_1R_45-90_NF		90 + 140	90 + 45	3	2	Shear+Withdr.
LJ_2p_5ply_1R_45-90		160 + 220	90 + 45	6	2	Shear+Withdr.
BJ_2p_3ply_1R_33/45	Butt Joint	180	33/45	6	2	Withdr.
BJ_2p_3ply_1R_33/45_NF		180	33/45	3	2	Withdr.

SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint

2p=2 pieces or panels

1R=1 row of screws per each side of shear planes

NF=No Friction

45=Angle between the screw axis and the CLT grain

## Panel to Panel Connections (2 Panels)

- Surface Spline Joints with one row of STS each member





## Panel to Panel Connections (2 Panels)

- Half-lap Joints with STS in shear



Friction



No  
Friction



## Panel to Panel Connections (2 Panels)

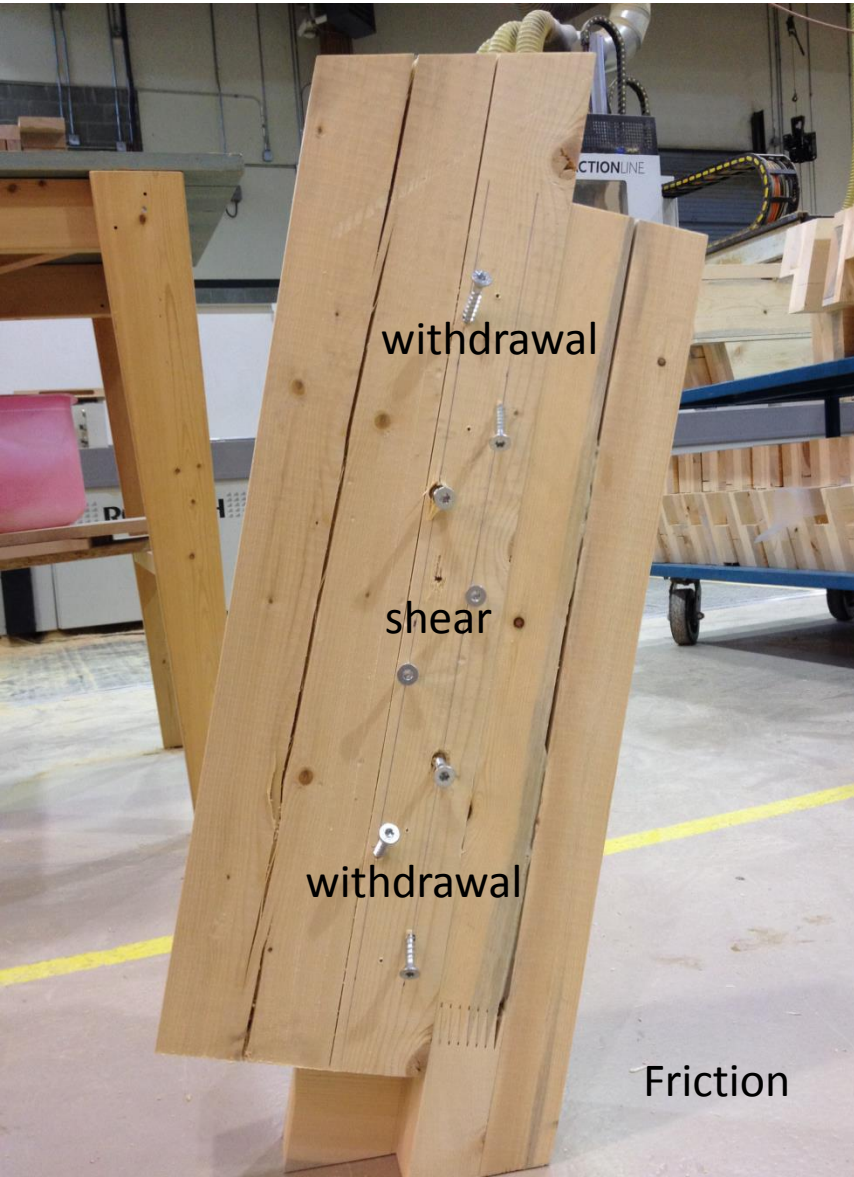
- Half-lap Joints with STS in withdrawal





## Panel to Panel Connections (2 Panels)

- Half-lap Joints with STS in shear and withdrawal





## Panel to Panel Connections (2 Panels)

- Butt Joints



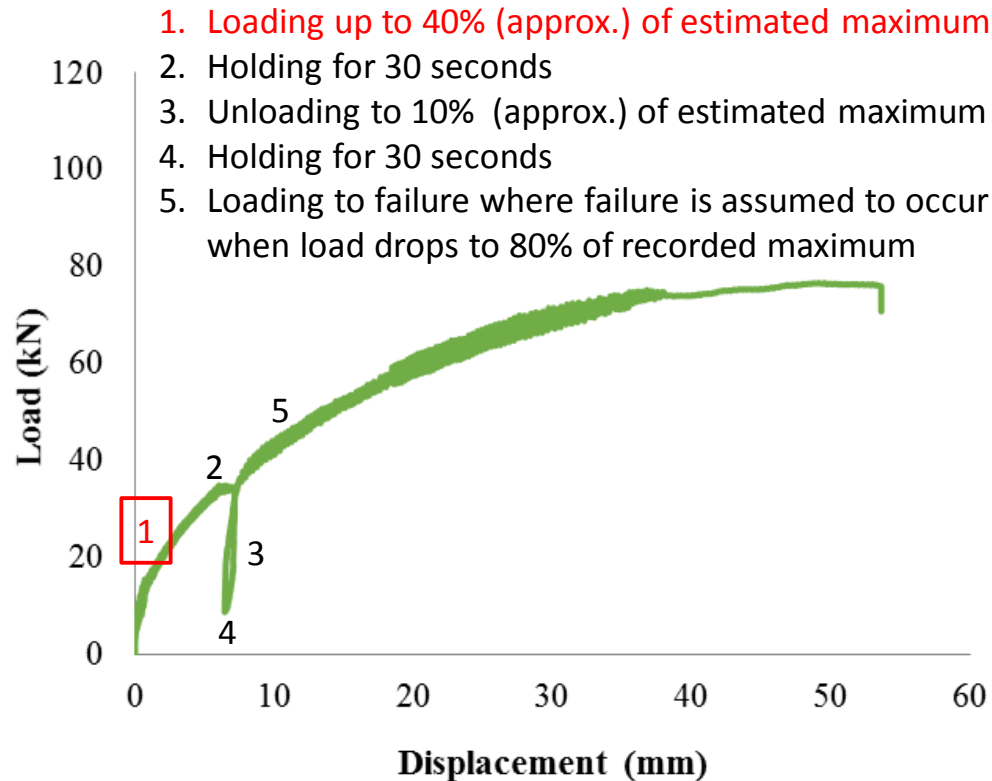
Friction



No  
Friction

## Panel to Panel Connections (2 Panels)

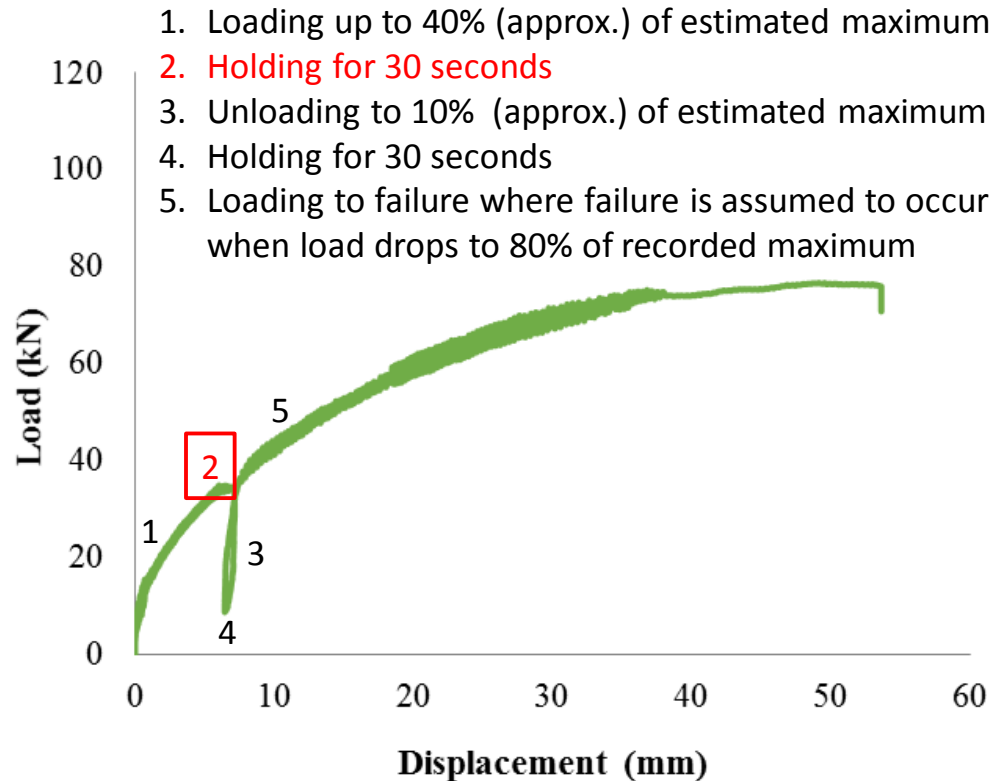
- Test set DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min





## Panel to Panel Connections (2 Panels)

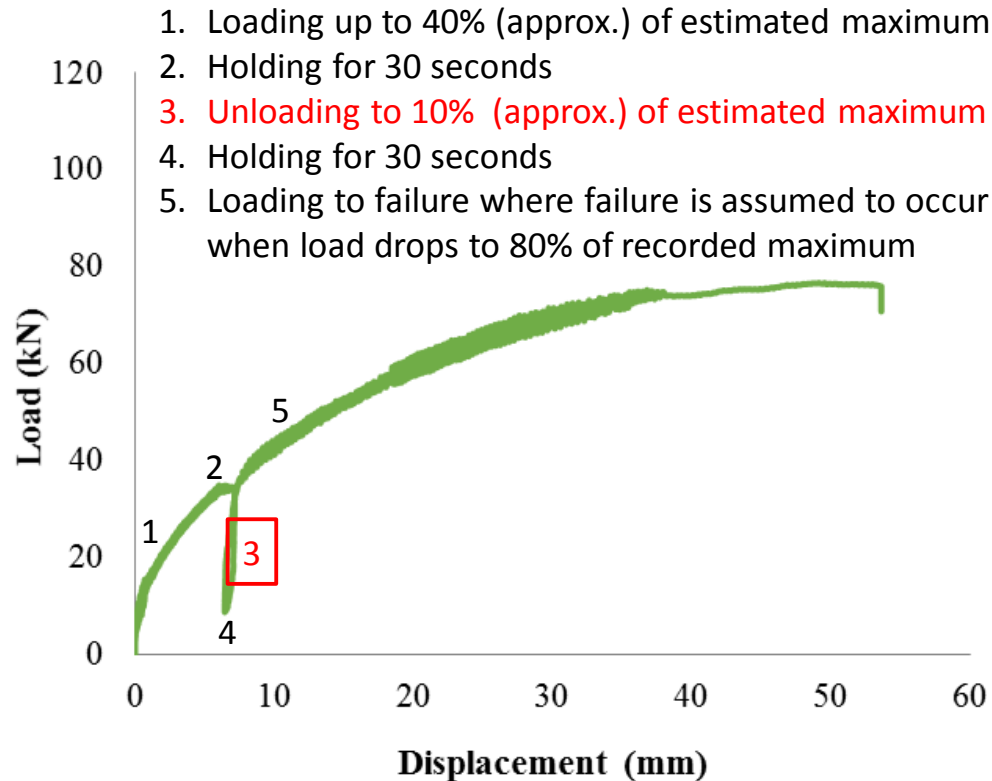
- Test set DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min





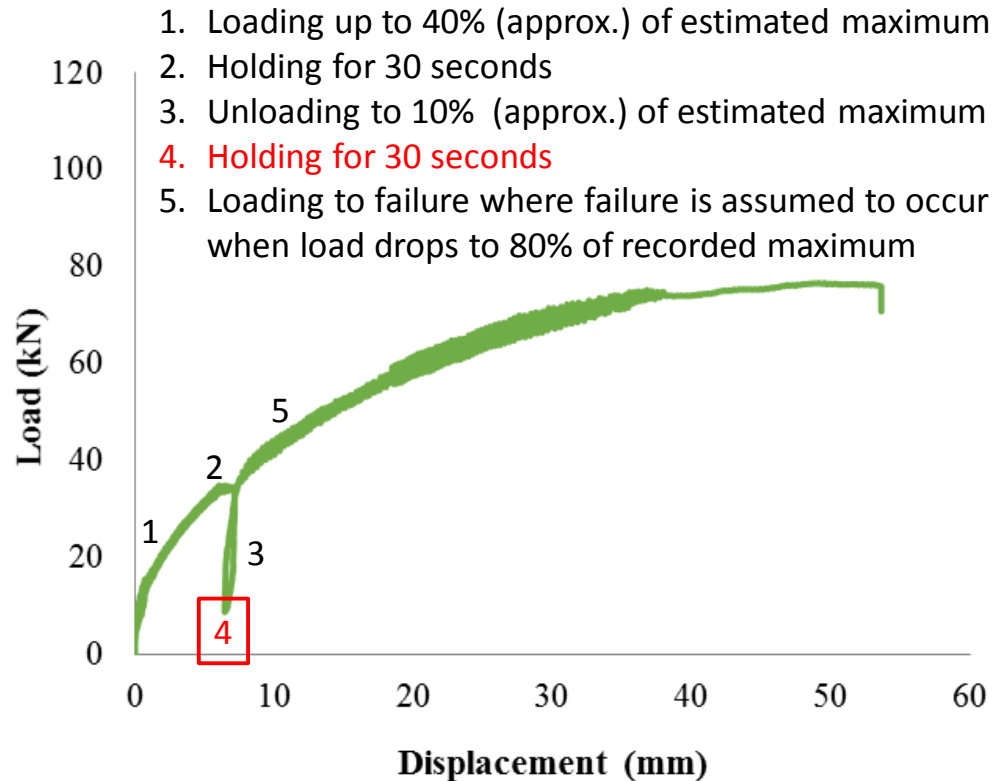
## Panel to Panel Connections (2 Panels)

- Test set DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min



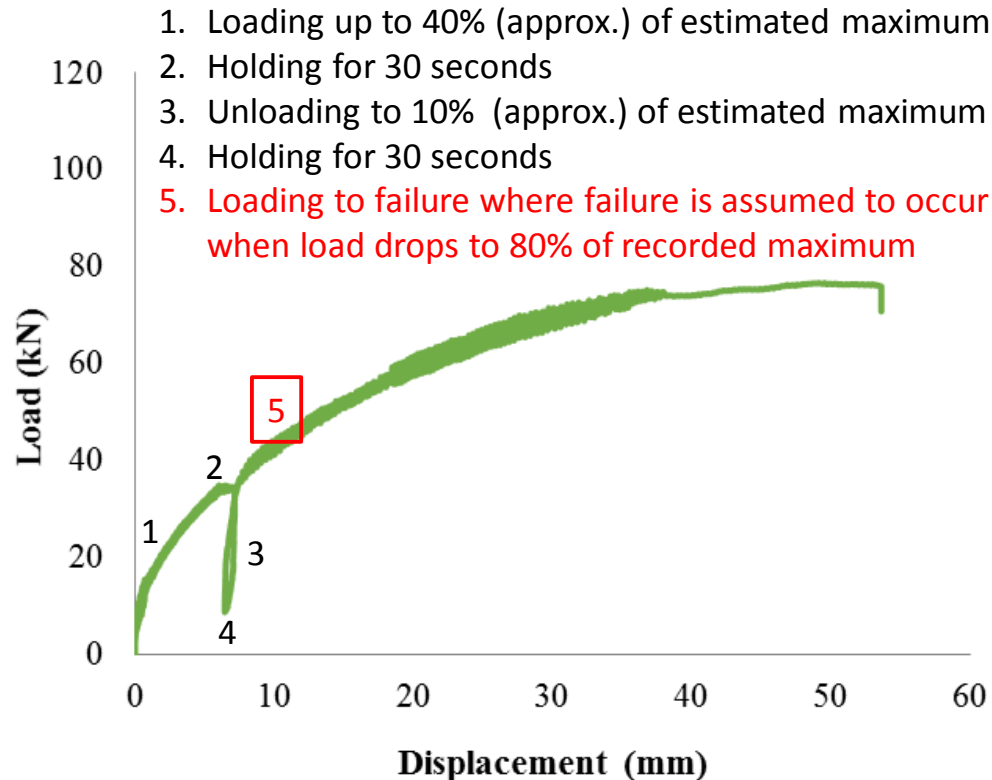
## Panel to Panel Connections (2 Panels)

- Test set DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min



## Panel to Panel Connections (2 Panels)

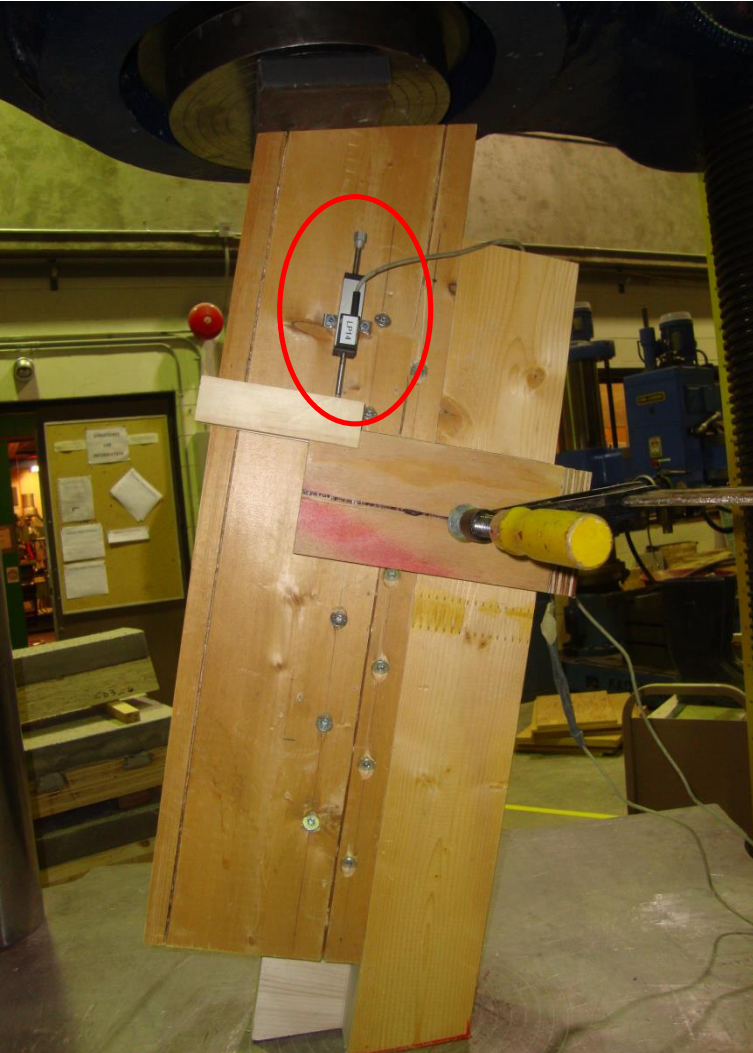
- Test set DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min





## Panel to Panel Connections (2 Panels)

- Transducer locations



## Panel to Panel Connections (2 Panels)

- Surface Spline Joints with one row of STS





## Panel to Panel Connections (2 Panels)

- Surface Spline Joints with one row of STS



## Panel to Panel Connections (2 Panels)

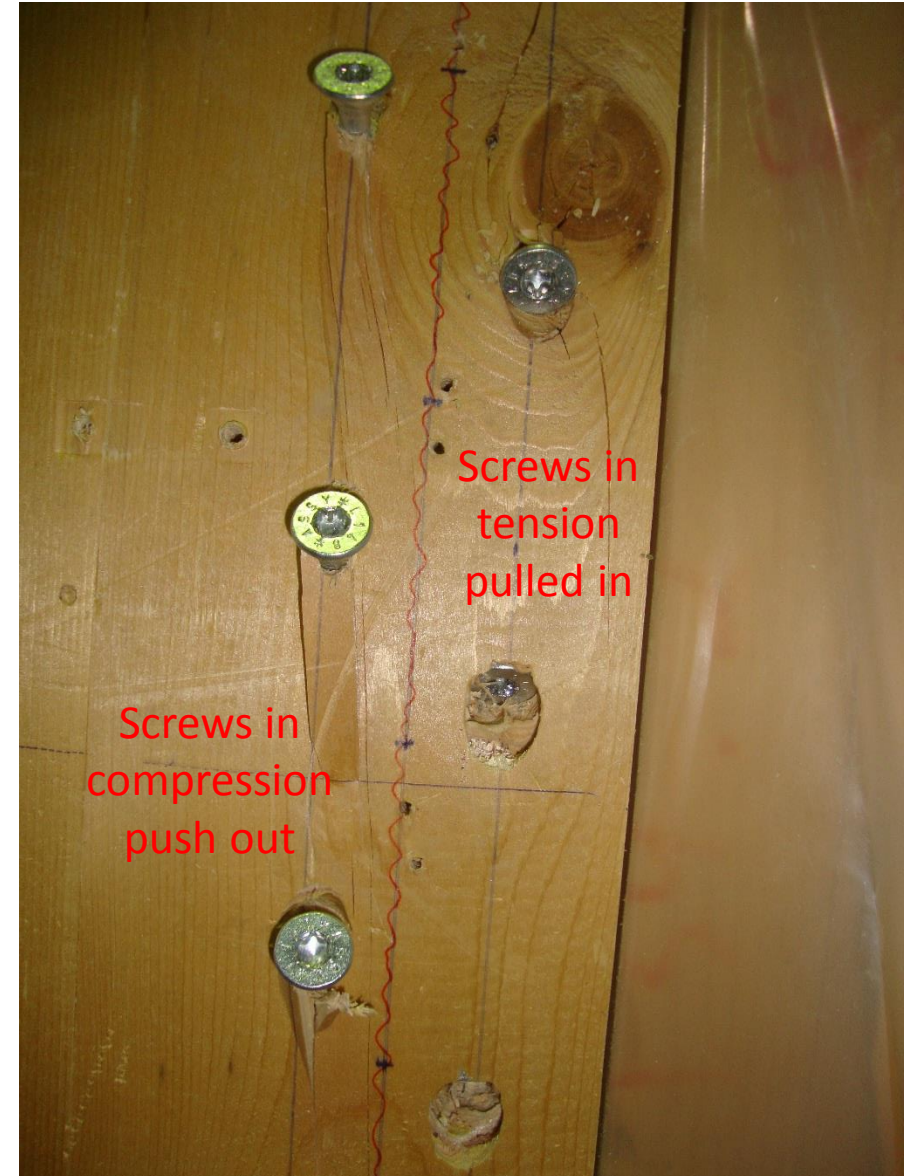
- Half-lap Joints with STS in shear





## Panel to Panel Connections (2 Panels)

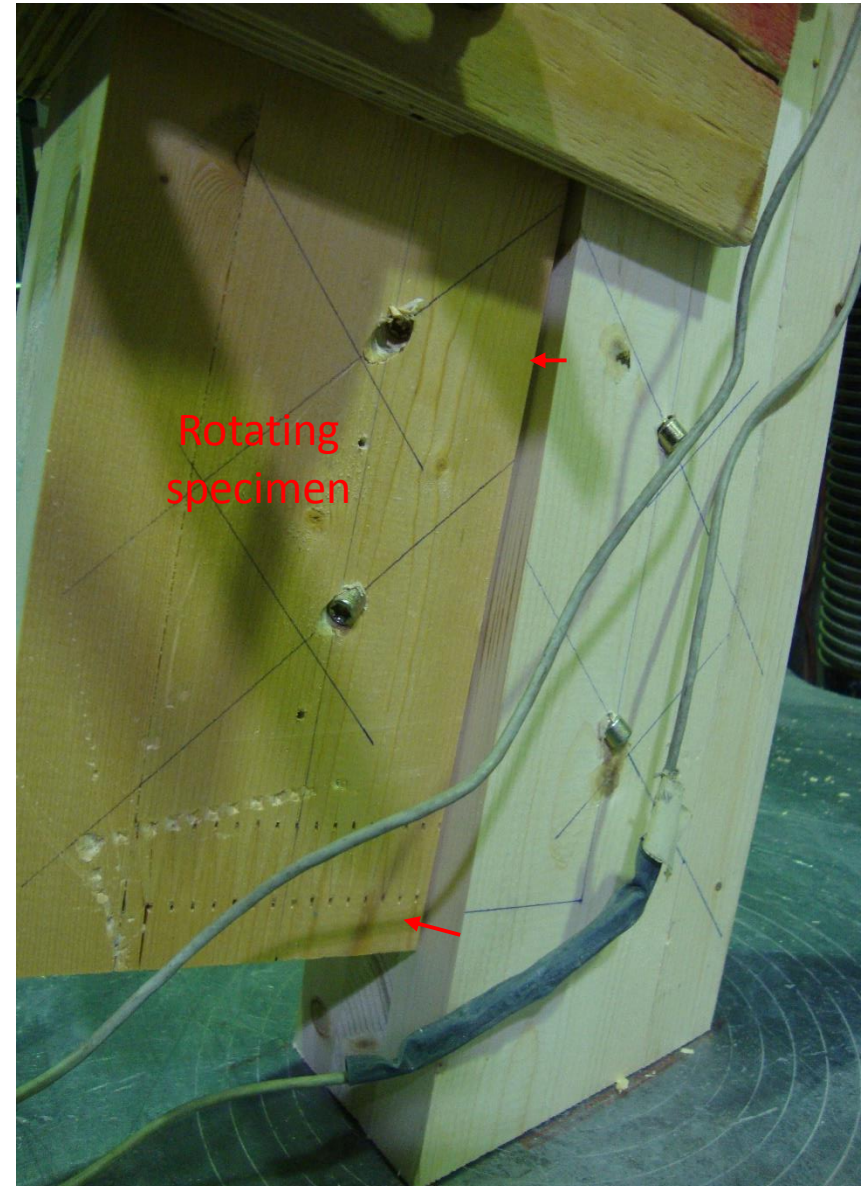
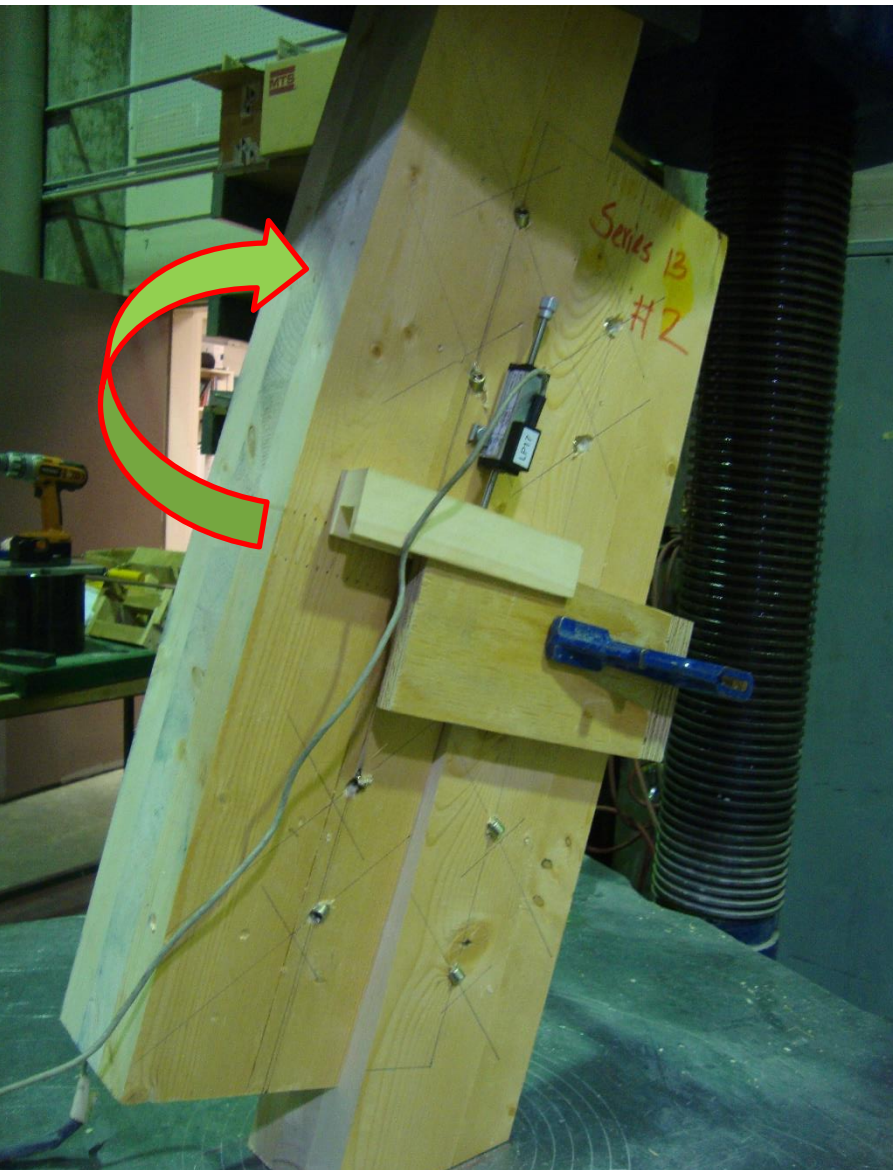
- Half-lap Joints with STS in withdrawal





## Panel to Panel Connections (2 Panels)

- Butt Joints



## Panel to Panel Connections (2 Panels)

- Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>Y</sub> (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	6.3	2.5	4.5	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	6.2	2.5	4.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	13.5	5.8	8.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	13.6	6.0	8.3	30.5	8.5	3.6
LJ_2p_3ply_1R_45	14.1	11.2	12.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	14.0	11.0	10.8	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	15.7	14.0	11.5	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	14.2	12.5	12.0	6.3	3.1	2.1

Note: Results listed in this table are average measurements out of 6 specimen (labeled NF) and 3 (for any other specimen).

\*All values per pair of screws

NF= specimen with anti friction membrane in shear plane



## Panel to Panel Connections (2 Panels)

- Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>y</sub> (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	6.3	2.5	4.5	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	6.2	2.5	4.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	13.5	5.8	8.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	13.6	6.0	8.3	30.5	8.5	3.6
LJ_2p_3ply_1R_45	14.1	11.2	12.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	14.0	11.0	10.8	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	15.7	14.0	11.5	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	14.2	12.5	12.0	6.3	3.1	2.1

Note: Results listed in this table are average measurements out of 6 specimen (labeled NF) and 3 (for any other specimen).

\*All values per pair of screws

NF= specimen with anti friction membrane in shear plane

## Panel to Panel Connections (2 Panels)

- Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>Y</sub> (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	6.3	2.5	4.5	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	6.2	2.5	4.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	13.5	5.8	8.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	13.6	6.0	8.3	30.5	8.5	3.6
LJ_2p_3ply_1R_45	14.1	11.2	12.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	14.0	11.0	10.8	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	15.7	14.0	11.5	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	14.2	12.5	12.0	6.3	3.1	2.1

Note: Results listed in this table are average measurements out of 6 specimen (labeled NF) and 3 (for any other specimen).

\*All values per pair of screws

NF= specimen with anti friction membrane in shear plane

## Panel to Panel Connections (2 Panels)

- Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. @ yield Δ <sub>Y</sub> (mm)	Ductility μ (-)
SS_2p_3ply_1R_90	6.3	2.5	4.5	47.6	12.1	4.0
SS_2p_3ply_1R_90_NF	6.2	2.5	4.3	54.0	11.7	4.7
LJ_2p_3ply_1R_90	13.5	5.8	8.7	26.5	9.8	2.7
LJ_2p_3ply_1R_90_NF	13.6	6.0	8.3	30.5	8.5	3.6
LJ_2p_3ply_1R_45	14.1	11.2	12.0	5.4	1.5	3.5
LJ_2p_3ply_1R_45_NF	14.0	11.0	10.8	5.7	1.8	3.0
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0	19.5	2.4	8.1
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5	7.8	2.0	4.3
BJ_2p_3ply_1R_33/45	15.7	14.0	11.5	5.8	2.0	2.9
BJ_2p_3ply_1R_33/45_NF	14.2	12.5	12.0	6.3	3.1	2.1

Note: Results listed in this table are average measurements out of 6 specimen (labeled NF) and 3 (for any other specimen).

\*All values per pair of screws

NF= specimen with anti friction membrane in shear plane

## Panel to Panel Connections (2 Panels)

- Results for 5-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)	Displ. at F <sub>max</sub> Δ <sub>max</sub> (mm)	Displ. at yield Δ <sub>Y</sub> (mm)	Ductility μ (-)
SS_2p_5ply_1R_90	10.6	3.6	7.0	56.3	12.0	4.3
LJ_2p_5ply_1R_90	21.4	8.4	14.8	54.7	11.8	4.7
LJ_2p_5ply_1R_45	25.3	23.0	19.2	4.4	1.8	2.6
LJ_2p_5ply_1R_45-90	18.0	16.6	15.4	3.0	2.5	2.5

Note: Results listed in this table are average measurements out of 6 tests.

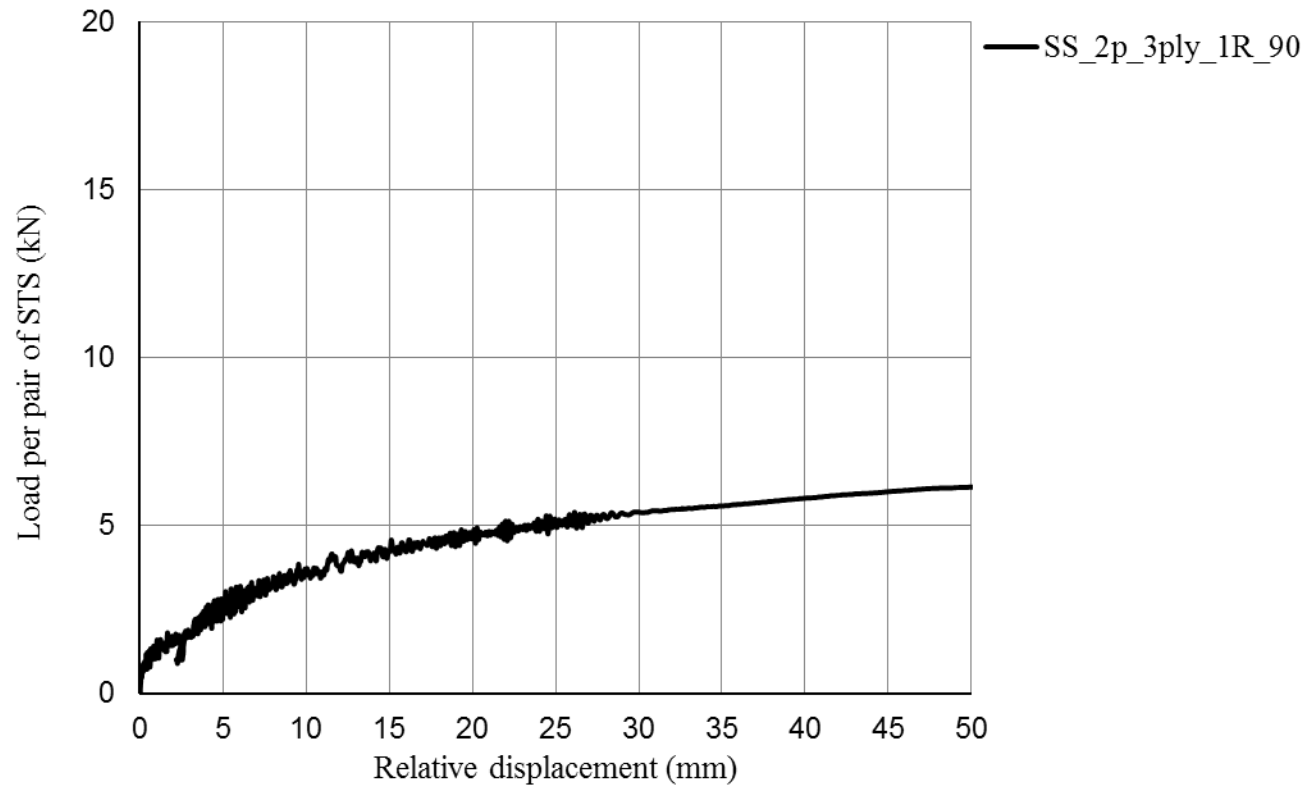
\*All values per pair of screws

- Results for 3-ply

Series	F <sub>max</sub> * [kN]	F* at 5mm disp. [kN]	Yield load F <sub>Y</sub> * (kN)
LJ_2p_3ply_1R_45-90	13.1	11.3	11.0
LJ_2p_3ply_1R_45-90_NF	13.0	11.2	10.5

## Panel to Panel Connections (2 Panels)

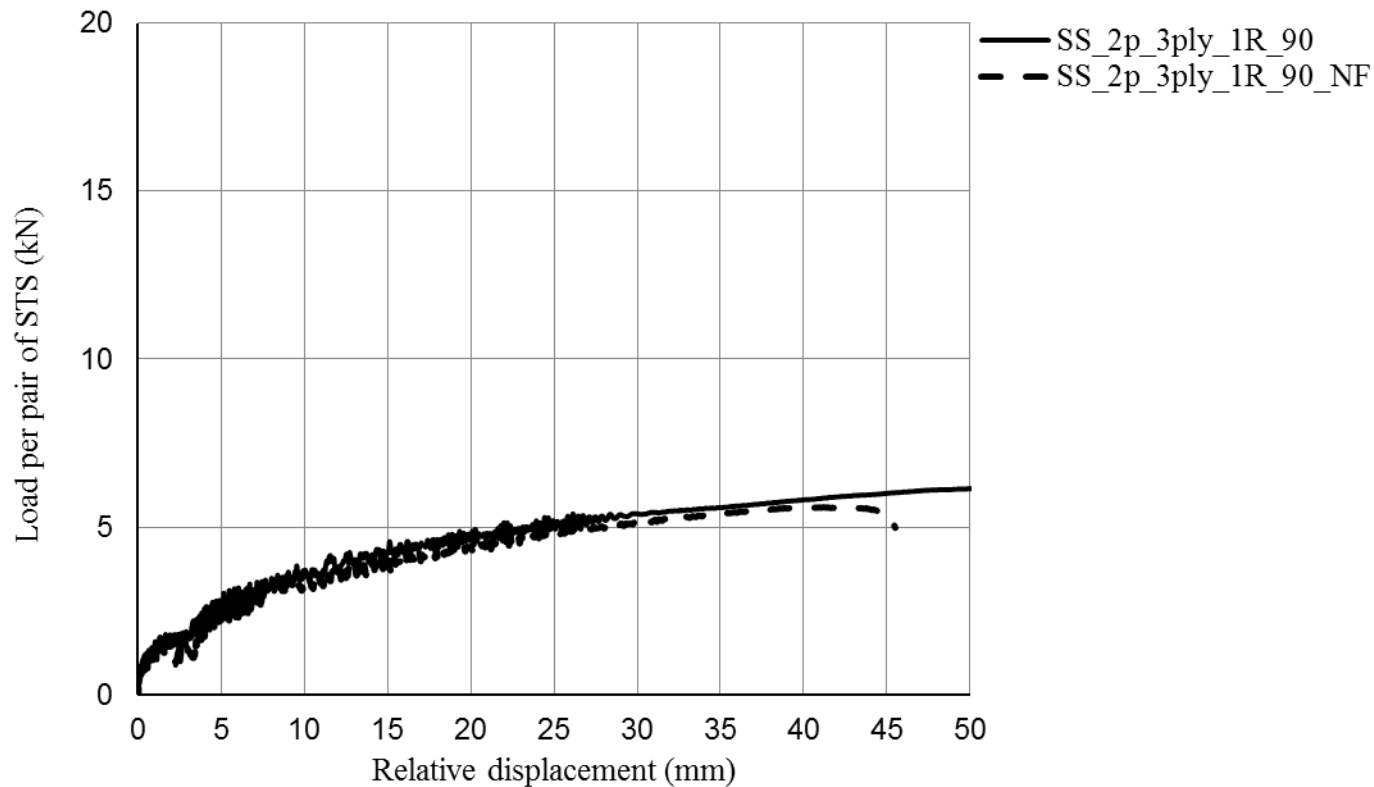
- Load-Displacement Curves





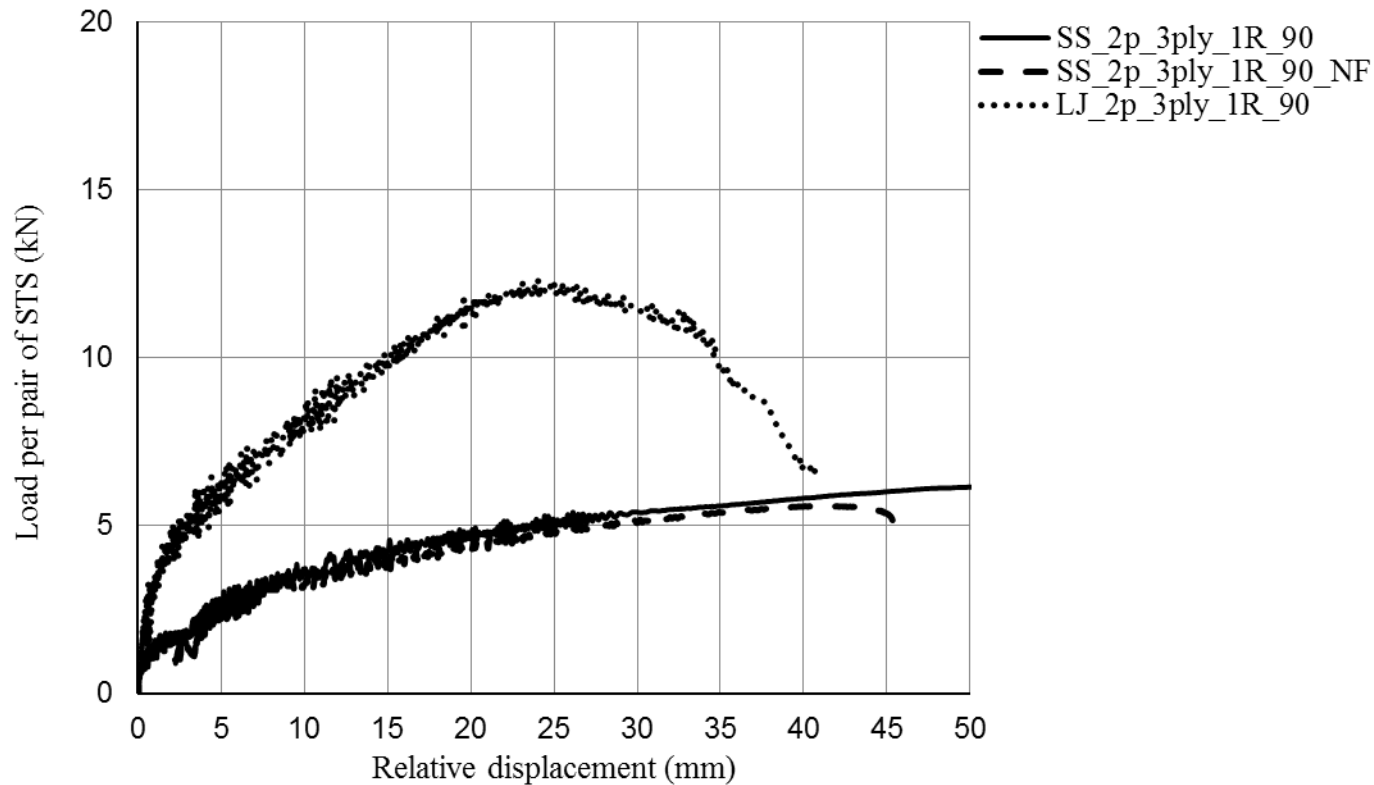
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



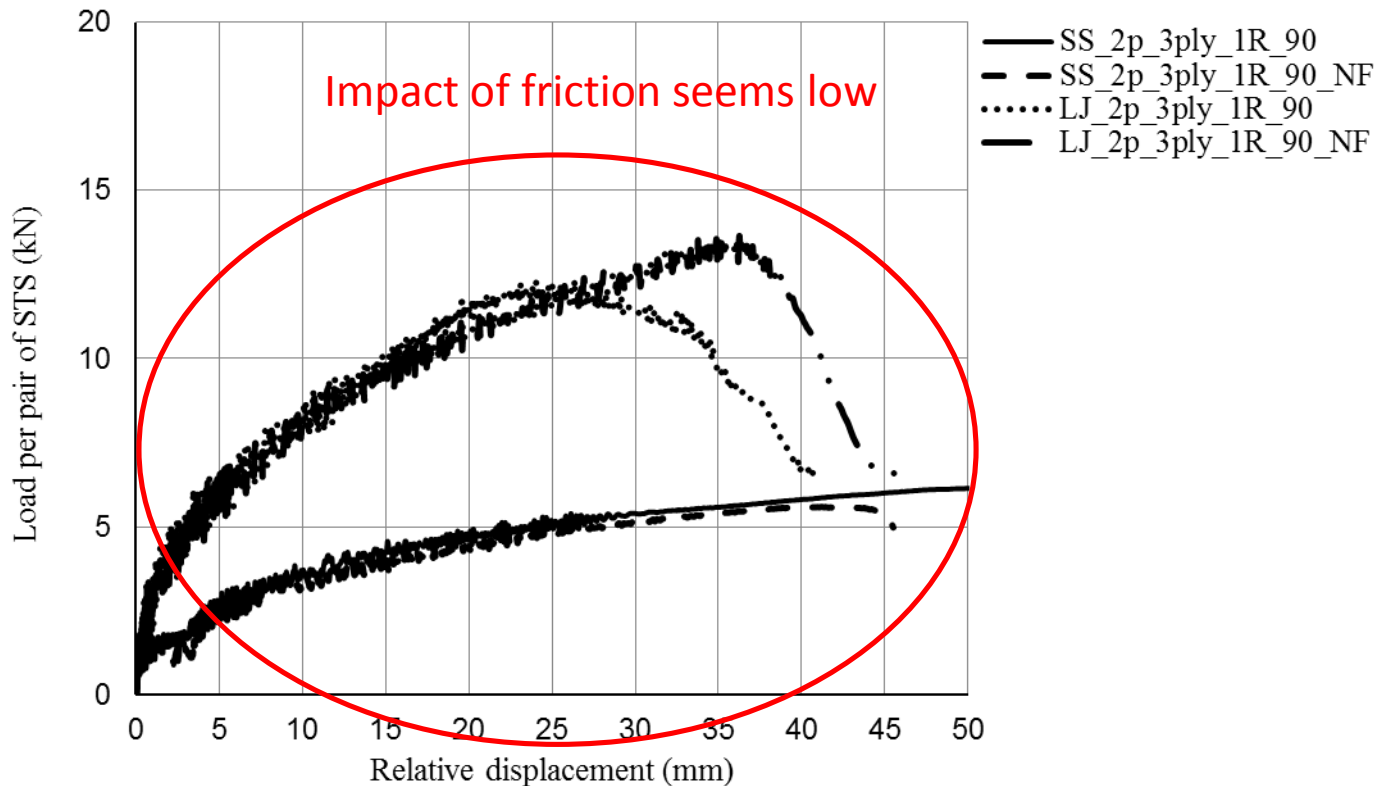
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



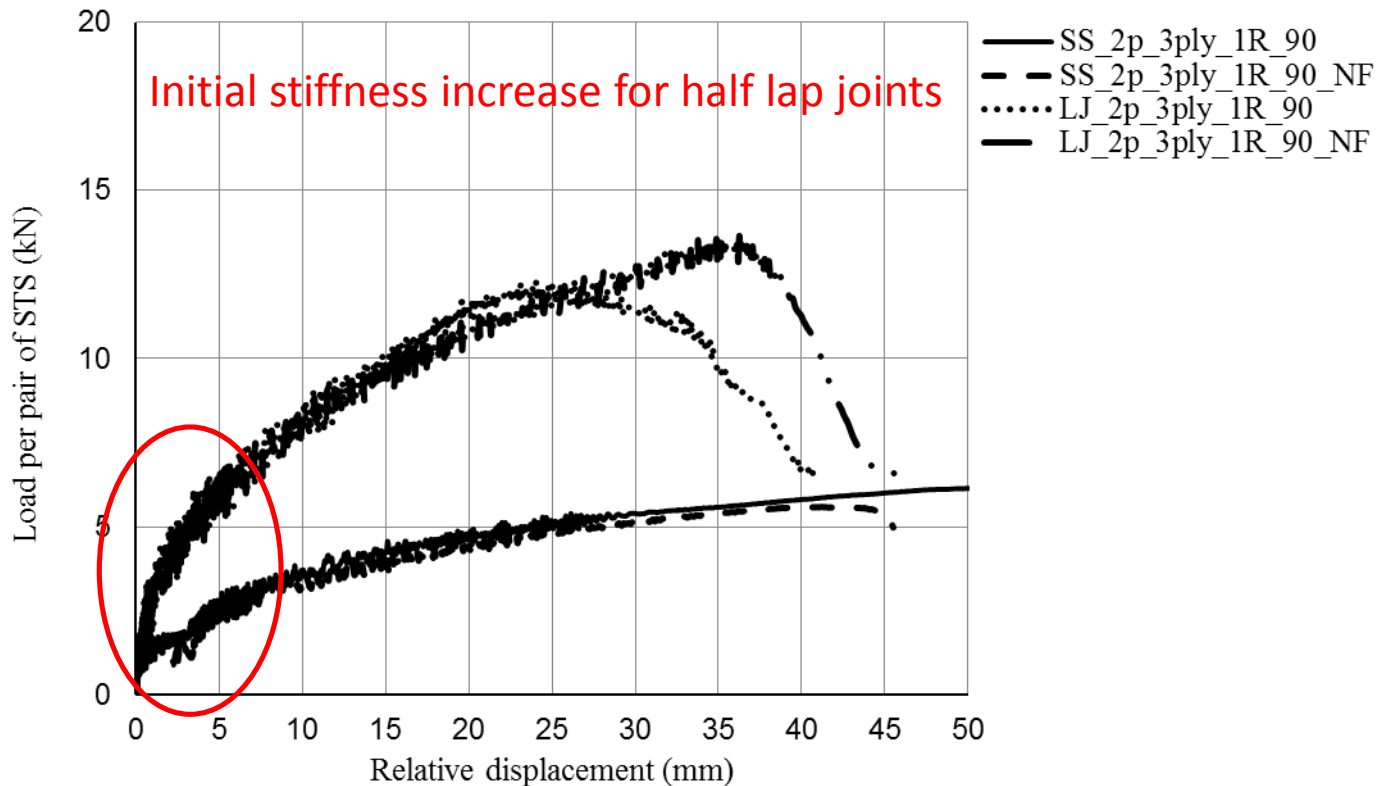
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



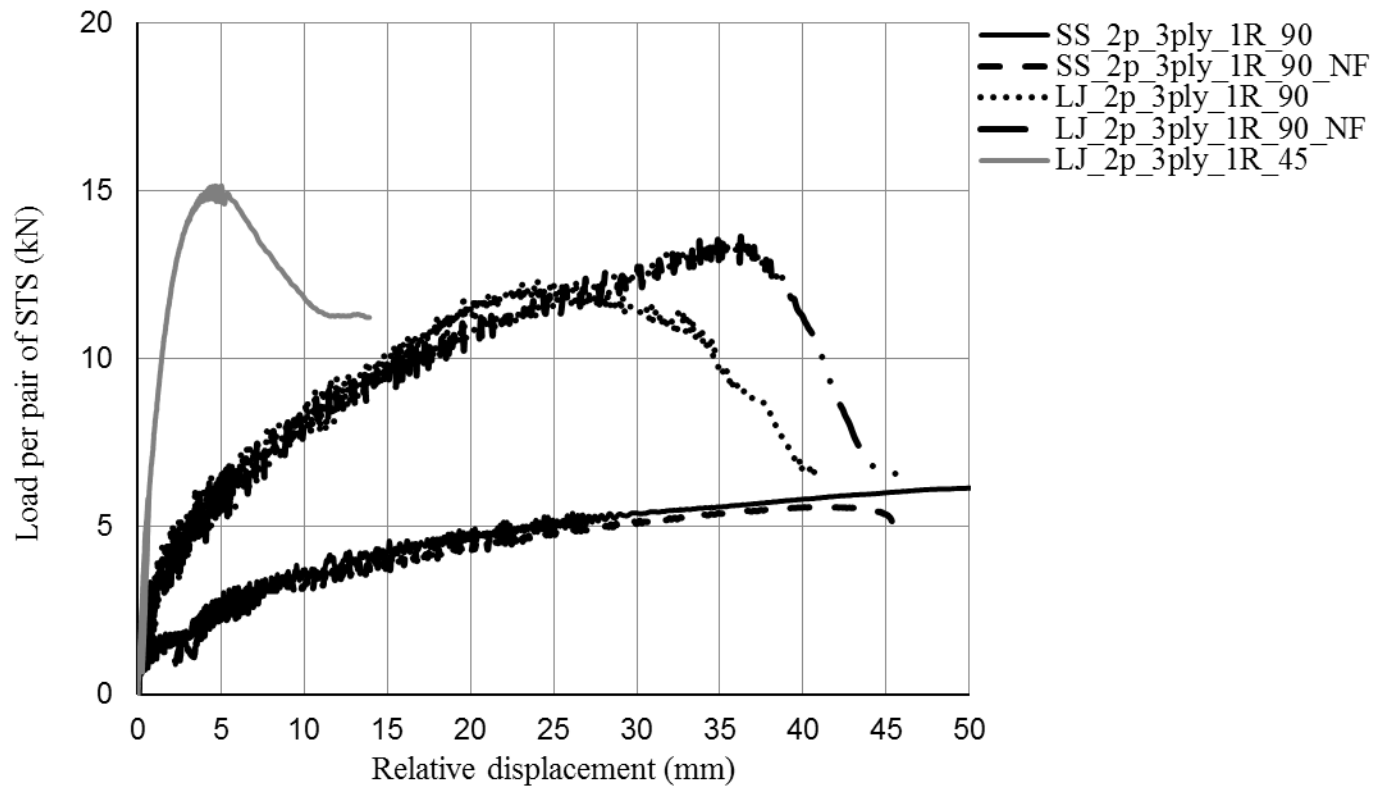
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



## Panel to Panel Connections (2 Panels)

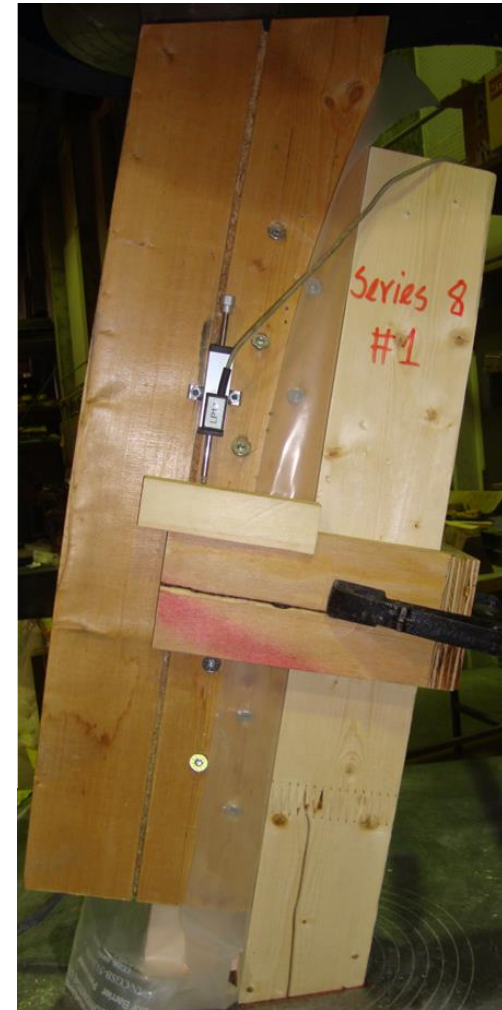
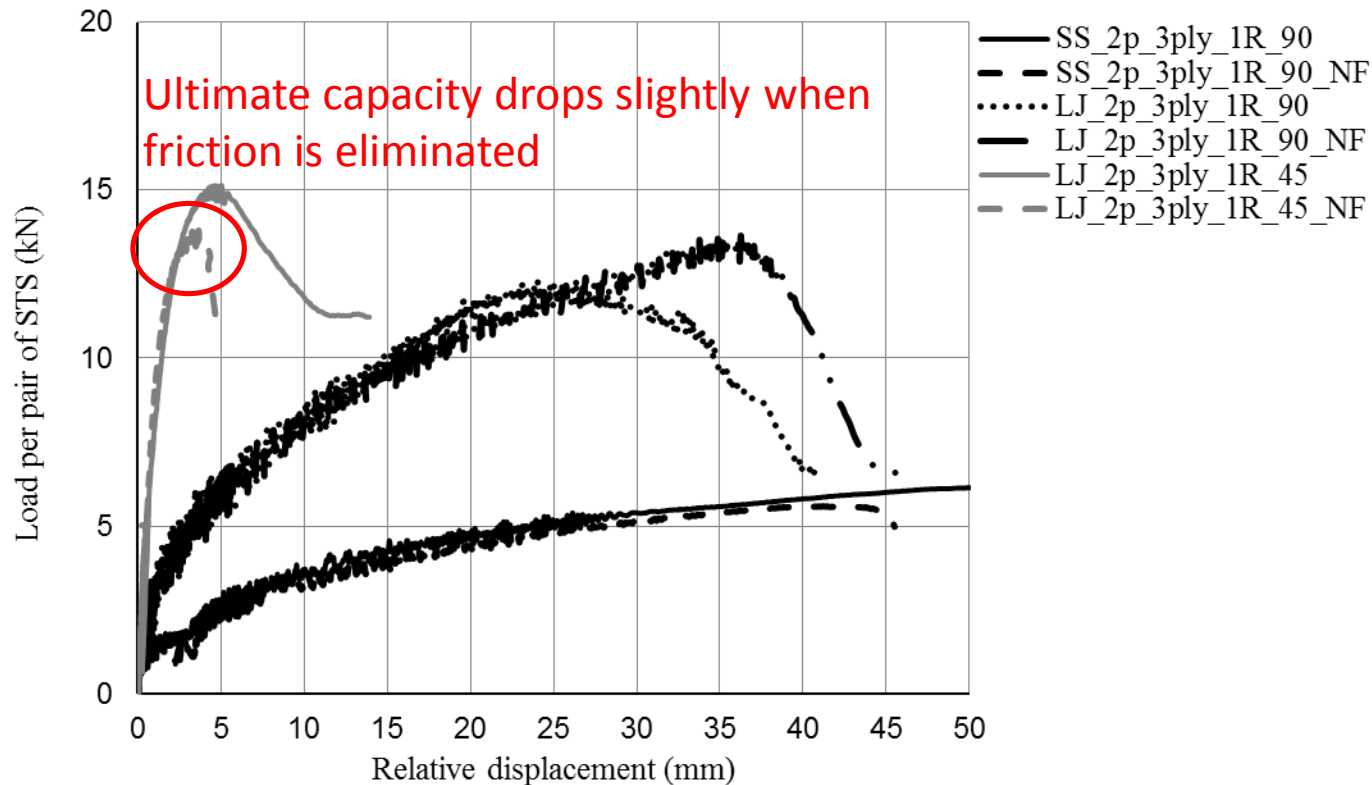
- Load-Displacement Curves





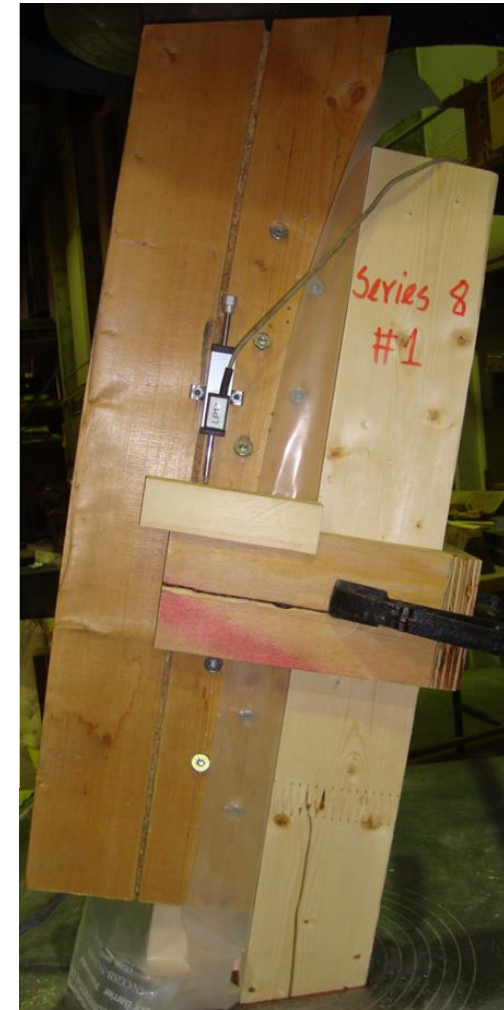
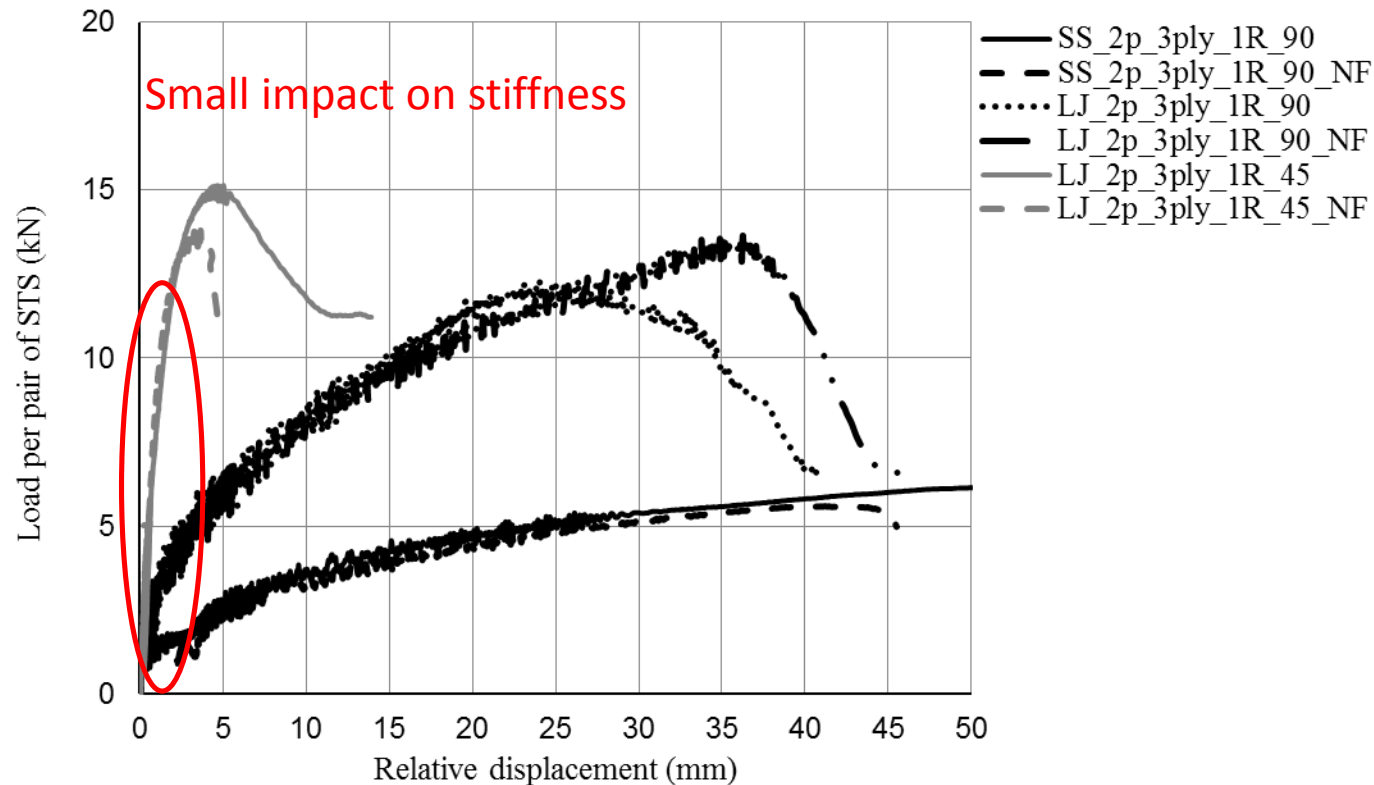
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



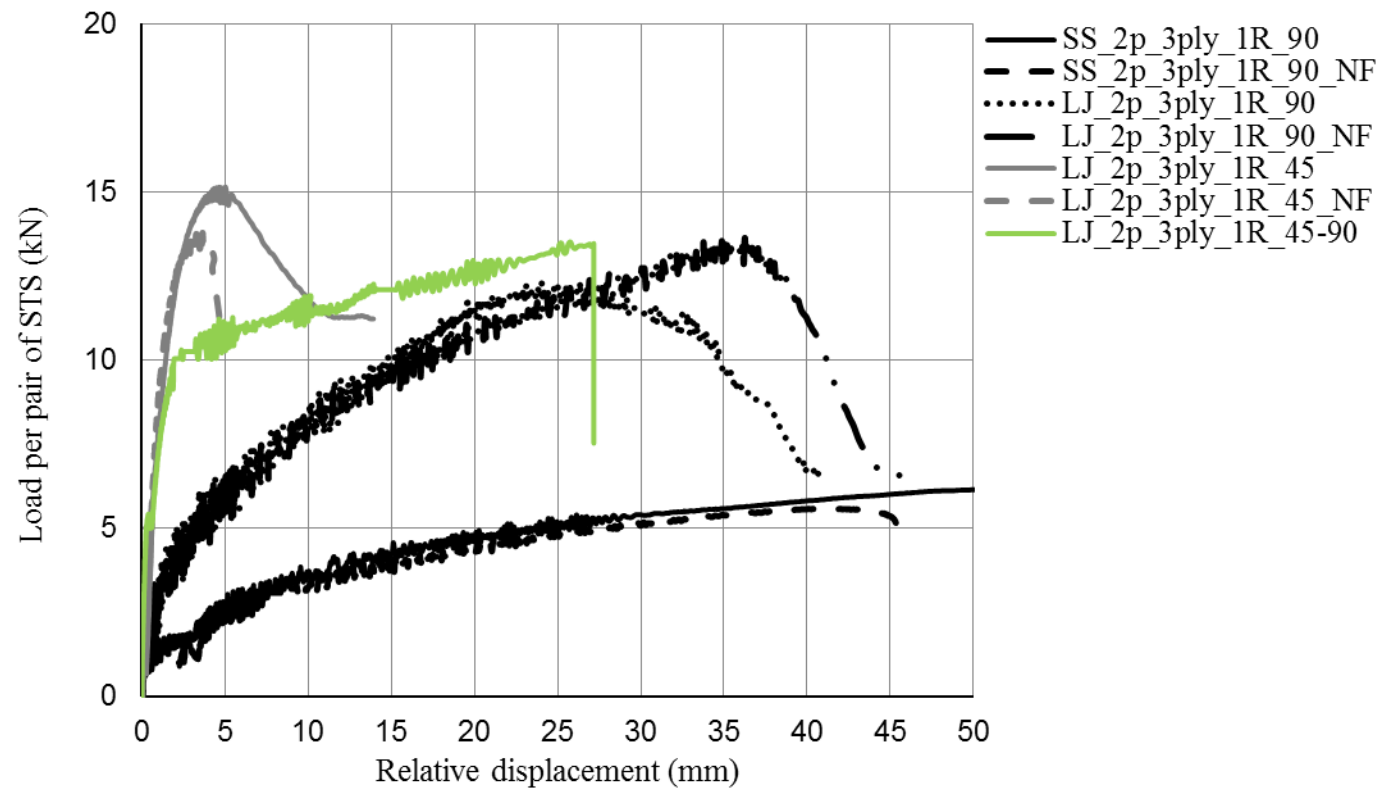
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



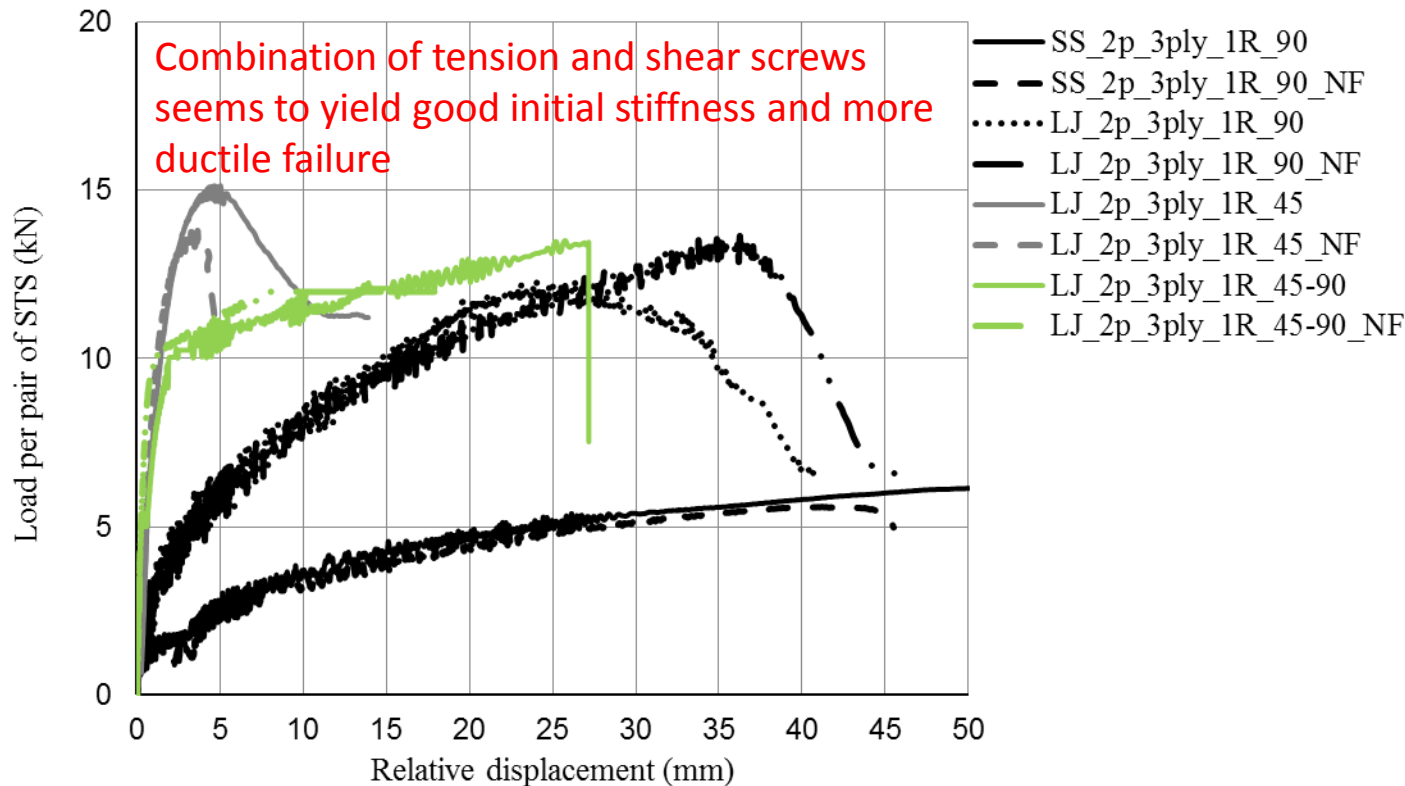
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



## Panel to Panel Connections (2 Panels)

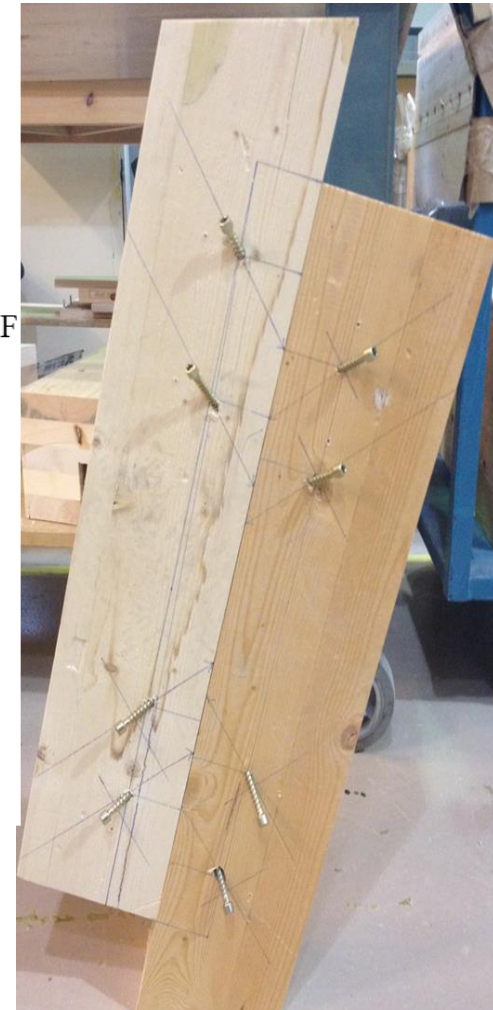
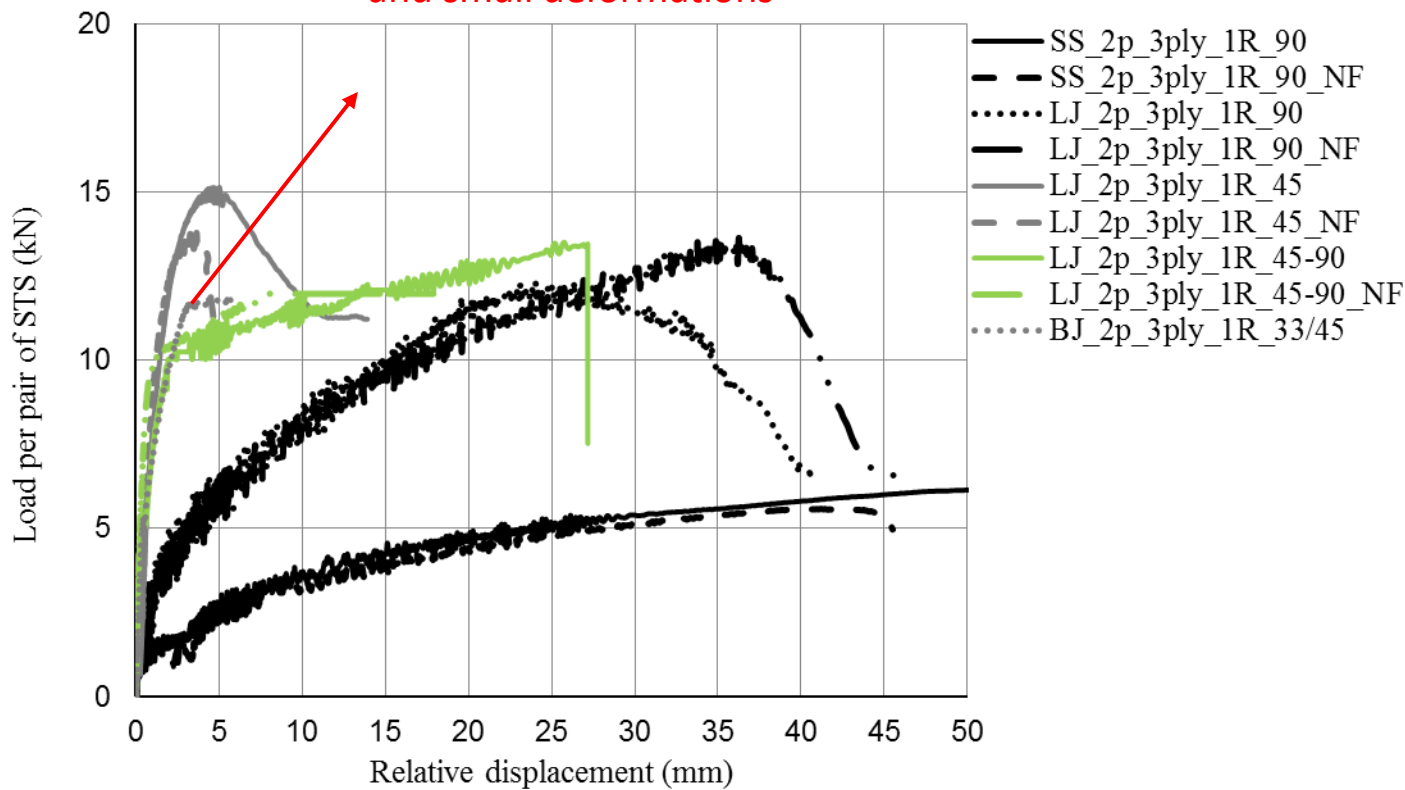
- Load-Displacement Curves



## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves

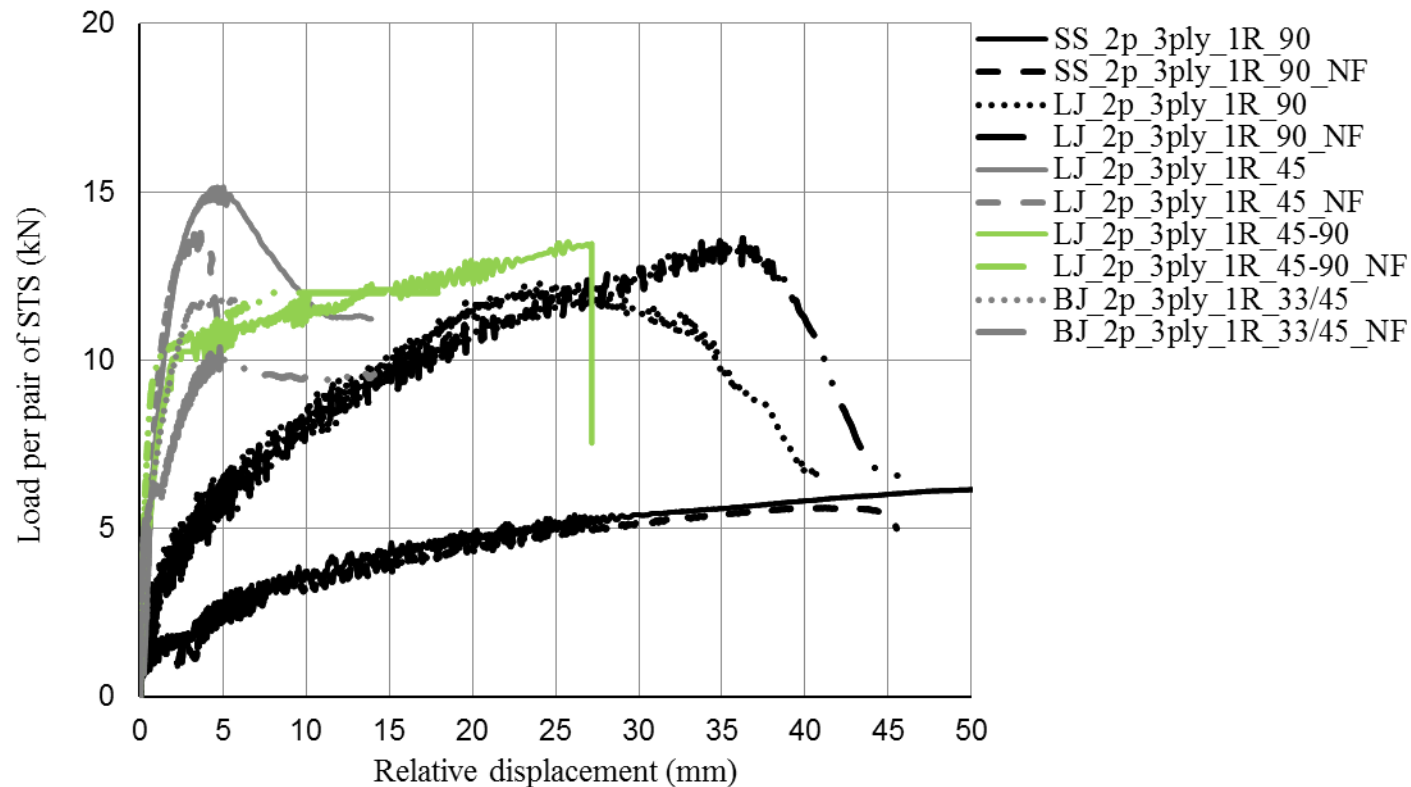
Double inclined screw  
connection with good stiffness  
and small deformations





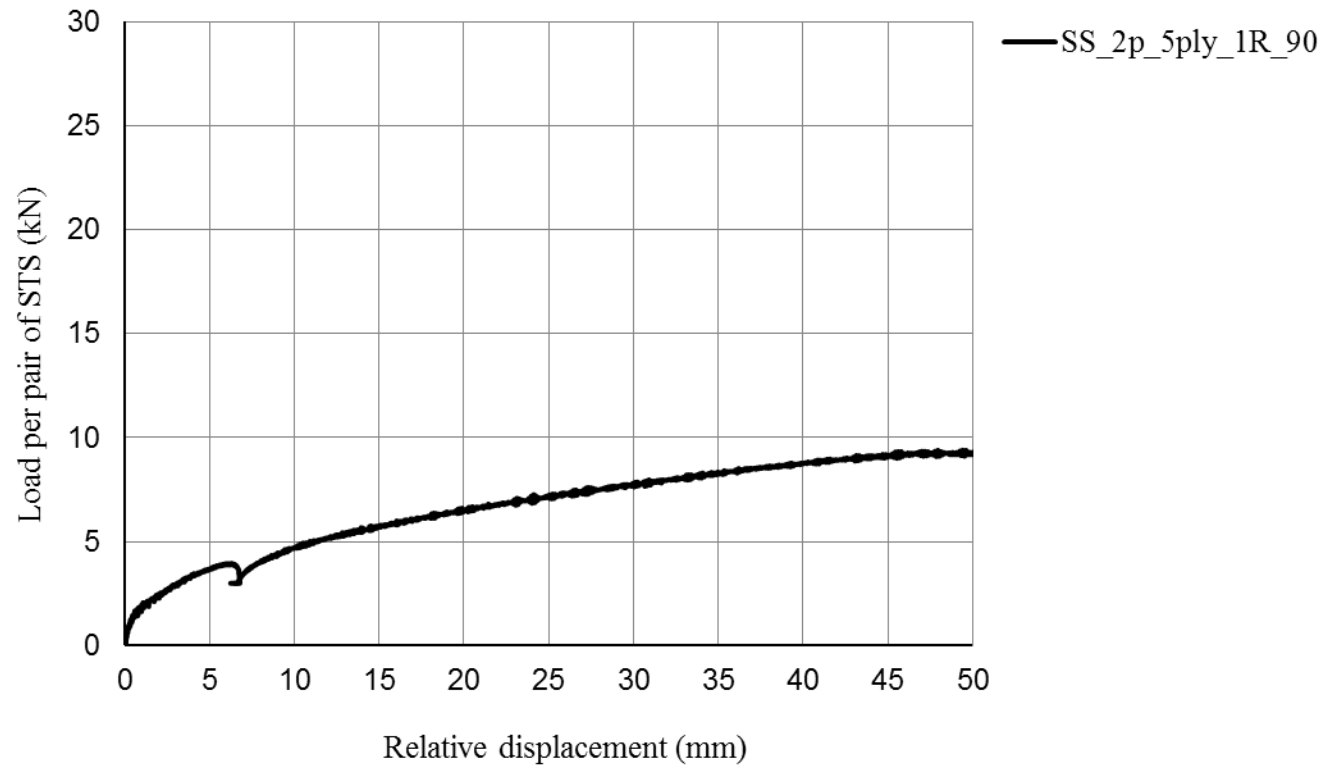
- Load-Displacement Curves

## Machine time reduced with butt joint



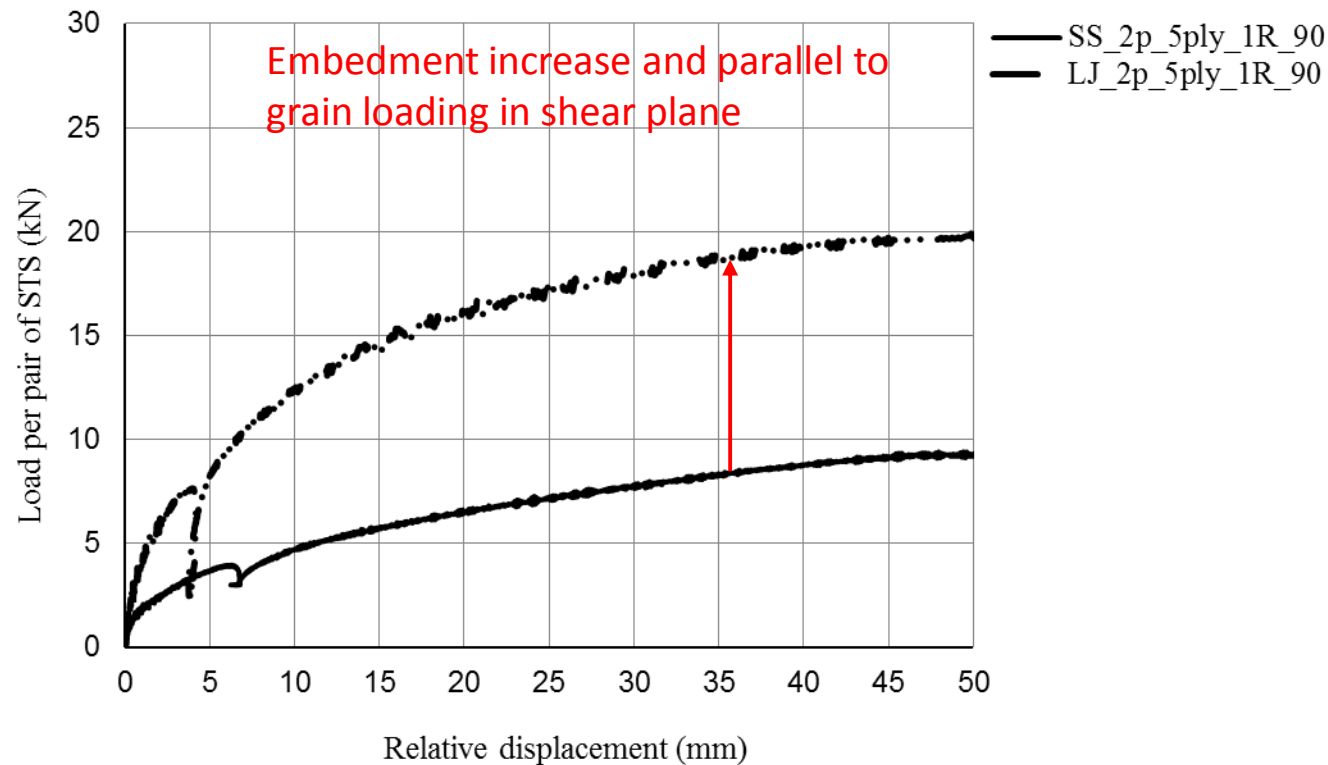
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



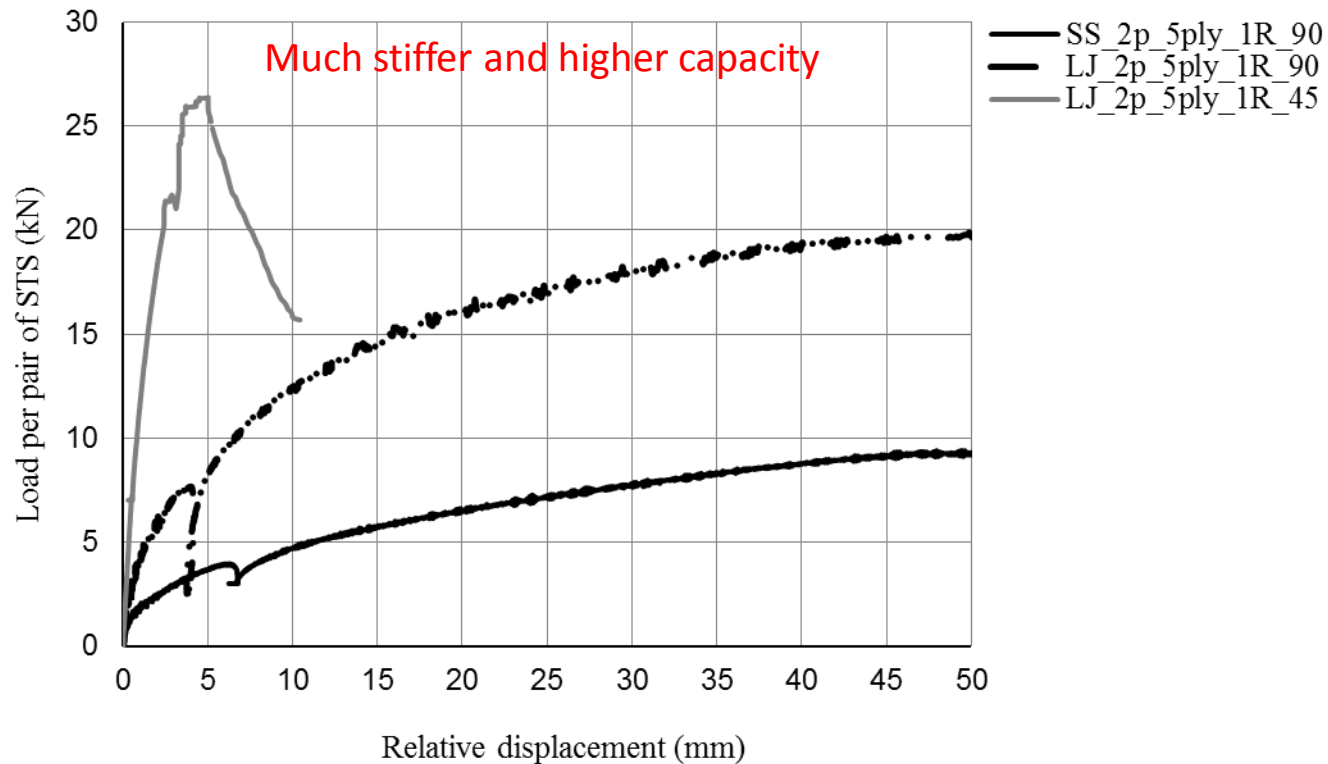
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



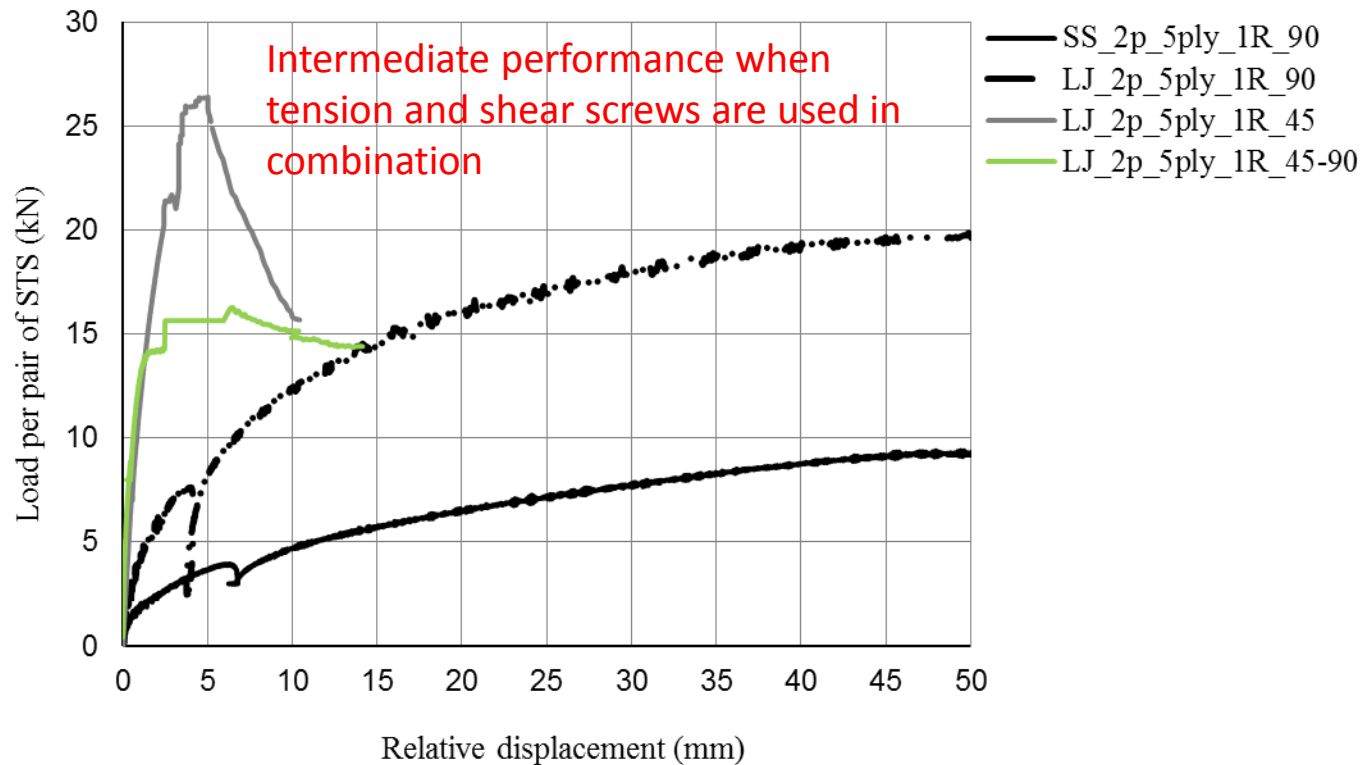
## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves



## Panel to Panel Connections (2 Panels)

- Load-Displacement Curves





# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
SS_2p_3ply_1R_90	16	50.46	47.60	20.18	5.00	35.32	11.50	1.06	4.04	3.07
SS_2p_5ply_1R_90	16	84.50	56.30	33.80	6.33	59.15	24.50	1.50	5.34	2.41
LJ_2p_3ply_1R_90	8	54.12	26.50	21.65	4.17	37.88	12.25	2.04	5.19	3.09
LJ_2p_5ply_1R_90	8	85.59	54.70	34.23	4.67	59.91	13.83	1.56	7.33	4.33
LJ_2p_3ply_1R_45	12	84.71	5.40	33.88	0.40	59.30	1.07	15.69	84.71	55.42
LJ_2p_5ply_1R_45	10	126.56	4.40	50.62	0.80	88.59	1.87	28.76	63.28	47.38
LJ_2p_3ply_1R_45-90	8	52.21	19.50	20.89	0.52	36.55	1.63	2.68	40.17	22.42
LJ_2p_5ply_1R_45-90	8	71.84	3.00	28.73	0.38	50.29	0.82	23.95	75.62	61.32
BJ_2p_3ply_1R_33/45	8	62.77	5.80	25.11	0.62	43.94	1.67	10.82	40.50	26.31

Note: Results listed in this table are average measurements out of 6 tests.  
All values per shear plane

# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Fmax [kN]	Displ. F max [mm]	0.4 F max [kN]	Displ. 0.4 F max [mm]	0.7 F max [kN]	Displ. 0.7 F max [mm]	Stiffness ultimate [kN/mm]	Stiffness 0.4 F max [kN/mm]	Stiffness 0.7 F max [kN/mm]
SS_2p_3ply_1R_90	16	50.46	47.60	20.18	5.00	35.32	11.50	1.06	4.04	3.07
SS_2p_5ply_1R_90	16	84.50	56.30	33.80	6.33	59.15	24.50	1.50	5.34	2.41
LJ_2p_3ply_1R_90	8	54.12	26.50	21.65	4.17	37.88	12.25	2.04	5.19	3.09
LJ_2p_5ply_1R_90	8	85.59	54.70	34.23	4.67	59.91	13.83	1.56	7.33	4.33
LJ_2p_3ply_1R_45	12	84.71	5.40	33.88	0.40	59.30	1.07	15.69	84.71	55.42
LJ_2p_5ply_1R_45	10	126.56	4.40	50.62	0.80	88.59	1.87	28.76	63.28	47.38
LJ_2p_3ply_1R_45-90	8	52.21	19.50	20.89	0.52	36.55	1.63	2.68	40.17	22.42
LJ_2p_5ply_1R_45-90	8	71.84	3.00	28.73	0.38	50.29	0.82	23.95	75.62	61.32
BJ_2p_3ply_1R_33/45	8	62.77	5.80	25.11	0.62	43.94	1.67	10.82	40.50	26.31

Note: Results listed in this table are average measurements out of 6 tests.  
All values per shear plane

Which stiffness is reasonable for design?

# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
SS_2p_3ply_1R_90	16	12.39	1.73	7.17	50.46	47.60	1.06	4.07
SS_2p_5ply_1R_90	16	15.66	1.75	8.95	84.50	56.30	1.50	5.40
LJ_2p_3ply_1R_90	8	4.92	2.35	2.09	54.12	26.50	2.04	11.01
LJ_2p_5ply_1R_90	8	12.00	2.62	4.58	85.59	54.70	1.56	7.13
LJ_2p_3ply_1R_45	12	24.46	0.58	42.48	84.71	5.40	15.69	3.46
LJ_2p_5ply_1R_45	10	31.77	0.74	42.72	126.56	4.40	28.76	3.98
LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
LJ_2p_5ply_1R_45-90	8	13.93	0.74	18.73	71.84	3.00	23.95	5.16

Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
 For designing the lap joints with screws in tension and shear, only tension screws were considered for design

\* Load duration factor for short term loading was applied (KD= 1.15)

# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
SS_2p_3ply_1R_90	16	12.39	1.73	7.17	50.46	47.60	1.06	4.07
SS_2p_5ply_1R_90	16	15.66	1.75	8.95	84.50	56.30	1.50	5.40
LJ_2p_3ply_1R_90	8	4.92	2.35	2.09	54.12	26.50	2.04	11.01
LJ_2p_5ply_1R_90	8	12.00	2.62	4.58	85.59	54.70	1.56	7.13
LJ_2p_3ply_1R_45	12	24.46	0.58	42.48	84.71	5.40	15.69	3.46
LJ_2p_5ply_1R_45	10	31.77	0.74	42.72	126.56	4.40	28.76	3.98
LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
LJ_2p_5ply_1R_45-90	8	13.93	0.74	18.73	71.84	3.00	23.95	5.16

Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
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# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
SS_2p_3ply_1R_90	16	12.39	1.73	7.17	50.46	47.60	1.06	4.07
SS_2p_5ply_1R_90	16	15.66	1.75	8.95	84.50	56.30	1.50	5.40
LJ_2p_3ply_1R_90	8	4.92	2.35	2.09	54.12	26.50	2.04	11.01
LJ_2p_5ply_1R_90	8	12.00	2.62	4.58	85.59	54.70	1.56	7.13
LJ_2p_3ply_1R_45	12	24.46	0.58	42.48	84.71	5.40	15.69	3.46
LJ_2p_5ply_1R_45	10	31.77	0.74	42.72	126.56	4.40	28.76	3.98
LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
LJ_2p_5ply_1R_45-90	8	13.93	0.74	18.73	71.84	3.00	23.95	5.16

Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
 For designing the lap joints with screws in tension and shear, only tension screws were considered for design  
 \* Load duration factor for short term loading was applied (KD= 1.15)

Small design resistance value obtained from design method yields small displacements and seemingly high stiffness estimate



# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
SS_2p_3ply_1R_90	16	12.39	1.73	7.17	50.46	47.60	1.06	4.07
SS_2p_5ply_1R_90	16	15.66	1.75	8.95	84.50	56.30	1.50	5.40
LJ_2p_3ply_1R_90	8	4.92	2.35	2.09	54.12	26.50	2.04	11.01
LJ_2p_5ply_1R_90	8	12.00	2.62	4.58	85.59	54.70	1.56	7.13
LJ_2p_3ply_1R_45	12	24.46	0.58	42.48	84.71	5.40	15.69	3.46
LJ_2p_5ply_1R_45	10	31.77	0.74	42.72	126.56	4.40	28.76	3.98
LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
LJ_2p_5ply_1R_45-90	8	13.93	0.74	18.73	71.84	3.00	23.95	5.16

Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
 For designing the lap joints with screws in tension and shear, only tension screws were considered for design

\* Load duration factor for short term loading was applied ( $K_D = 1.15$ )

Fasteners in shear neglected for design resistance estimate

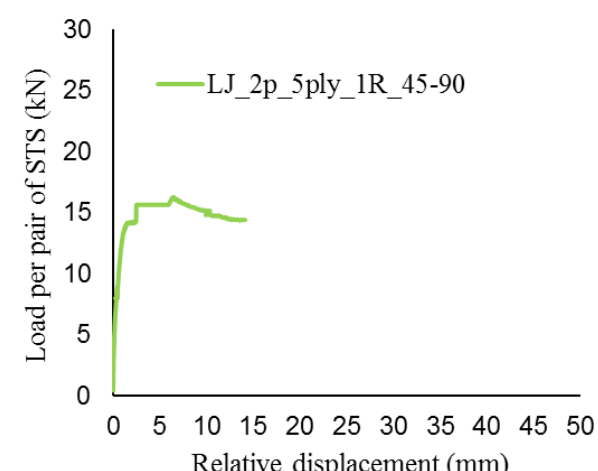
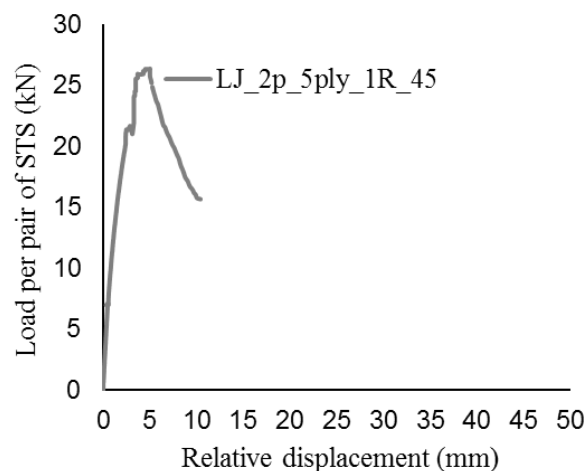
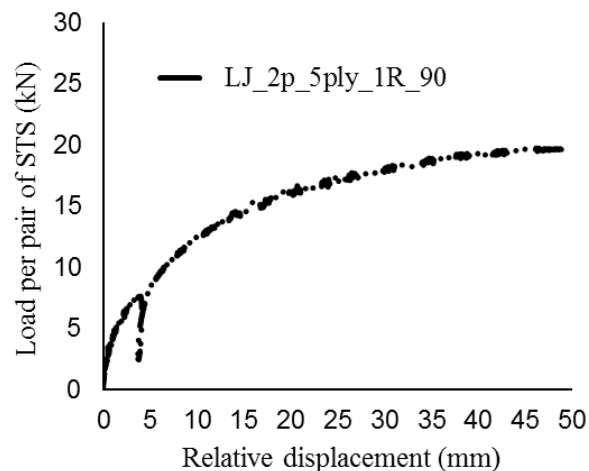


# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
SS_2p_3ply_1R_90	16	12.39	1.73	7.17	50.46	47.60	1.06	4.07
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LJ_2p_5ply_1R_45	10	31.77	0.74	42.72	126.56	4.40	28.76	3.98
LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
LJ_2p_5ply_1R_45-90	8	13.93	0.74	18.73	71.84	3.00	23.95	5.16

Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
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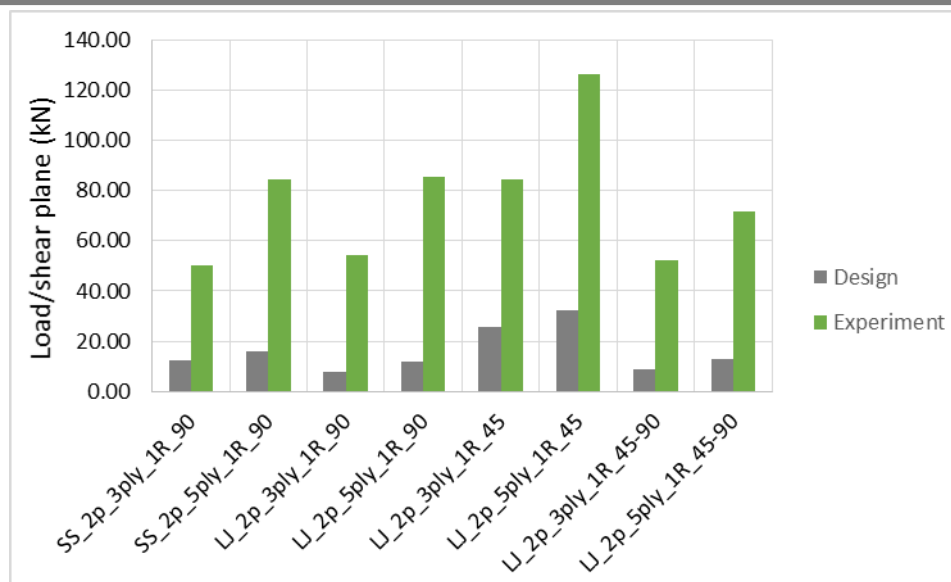
\* Load duration factor for short term loading was applied (KD= 1.15)



# Panel to Panel Connections (2 Panels)

Series	STS per shear plane [mm]	Design Resistance* [kN]	Design Displ. (based on design resistance) [mm]	Design Estimated stiffness [kN/mm]	Test Fmax [kN]	Test Displ. F max [mm]	Test Stiffness ultimate [kN/mm]	Overstrength
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LJ_2p_3ply_1R_45-90	8	9.10	0.58	15.80	52.21	19.50	2.68	5.74
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Note: Results listed in this table are average measurements out of 6 tests. All values are per shear plane  
 For designing the lap joints with screws in tension and shear, only tension screws were considered for design  
 \* Load duration factor for short term loading was applied (KD= 1.15)



## Panel to Panel Connections

### Series #1

- Results of testing in series #2 are not equivalent to the results of series #1
- Rotation of specimen and resulting friction and wood splitting may impact results



## Panel to Panel Connections

### Series #2

-Results from series #2  
yield better estimate for  
design approach and  
the actual performance  
of the fastener





- Prof. Dr. Thomas Tannert, UBC
- Afrin Hossain, PhD. student UBC

Thank you for attending!

# Structural Screw Technology in Tall Wood



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