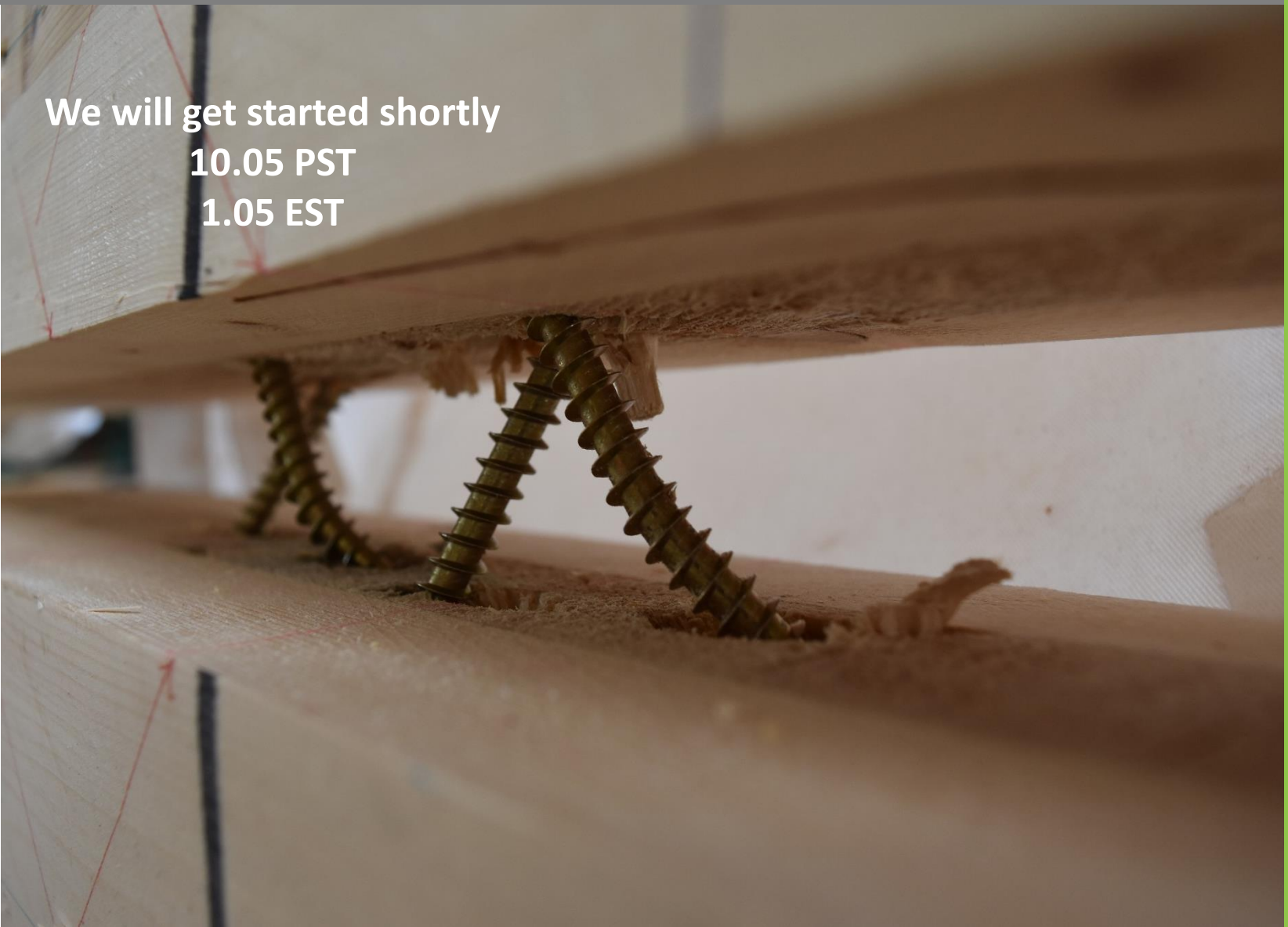
# WELCOME and THANK YOU for joining

MyTiCon Timber Connectors

## Performance of CLT Connections under Dynamic Loading



# Performance of CLT Connections under Dynamic Loading

**Presenter:** **Max Closen**

***Background:*** ***Timber Engineering***

# Performance of CLT Connections under Dynamic Loading

The webinar outlook:

- Refresher: Performance of CLT connections under *Static* loading
- Performance of CLT connections under *Cyclic* loading
- Summary of proposed design procedures and design values

# Outline

- Test Campaign #1 – Static Loading
  - Panel to Panel Connections
  - Surface Spline, Half Lapped & Butt Joint Connections
- Test Campaign #2 – Cyclic Loading
  - Panel to Panel Connections
  - Surface Spline, Half Lapped & Butt Joint Connections
- Test Data and Results
  - Statistics
  - Failure Modes
  - Proposed Design Methods/Values

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- Test Campaign #1 – Static Loading
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  - Statistics
  - Failure Modes
  - Proposed Design Methods/Values

## Disclaimer

Material presented are for informational purpose only

but

Verify existing or future code provisions for CLT connections through this small sample test series

# Test Campaign #1

## Static Loading

Surface Spline Joints

Half Lapped Joints

Butt Joints

# Test Campaign #1 : Static Loading

## Specimen List:

| Label | Type | STS Ø [mm] | STS Length [mm] | Angle [°] | Replicates | # STS per Shear Plane | STS action |
|---|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 8 | 80 | 90 | 6 | 16 | Shear |
| Series 1 – SS_90_3ply_NF | | | | | 3 | | |
| Series 2 – SS_90_5ply | | | 100 | | 6 | | |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 8 | 90 | 90 | 6 | 8 | Shear |
| Series 3 – LJ_90_3ply_NF | | | | | 3 | | |
| Series 4 – LJ_90_5ply | | | 160 | | 6 | | |
| Series 5 – LJ_45_3ply | | | 140 | 45 | 6 | 12 | Withdrawal |
| Series 5 – LJ_45_3ply_NF | | | | | 3 | | |
| Series 6 – LJ_45_5ply | | | 220 | | 6 | 10 | |
| Series 7 – LJ_45/90_3ply_WSSW | | | 90 + 140 | 45 + 90 | 6 | 8 | Shear + Withdrawal |
| Series 7 – LJ_45/90_3ply_WSSW_NF | | | | | 3 | | |
| Series 8 – LJ_45/90_5ply_WSSW | | | 160 + 220 | | 6 | 10 | |
| Series 9 – LJ_45/90_3ply_SWSWS | | | 90 + 140 | | | | |
| Series 10 – LJ_45/90_5ply_SWSWS | | | 160 + 220 | | | | |
| Series 11 – BJ_33/45_3ply | Butt Joint | 8 | 180 | 33 + 45 | 6 | 8 | Shear + Withdrawal |
| Series 11 – BJ_33/45_3ply_NF | | | | | 3 | | |
| Series 12 – BJ_45_3ply | | | 140 | 45 | 6 | | Shear |

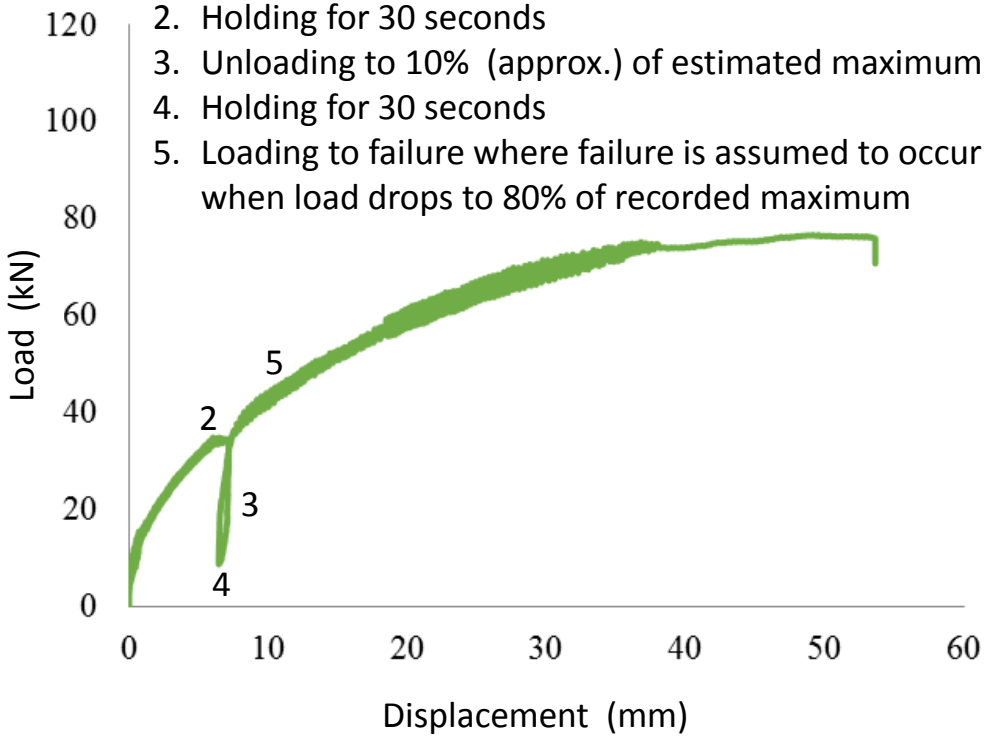
***Notes***:
SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint
WSSW = Screw arrangement within rows. Withdr. + Shear + Shear + Withdr.
SWSWS = Screw arrangement within rows. Shear + Withdr. + Shear + Withdr. + Shear

CrossLam® CLT Panels
V2M1 Grade

# Test Campaign #1 : Static Loading

- Test setup as per DIN 26891
  - Actuator loading from top
  - Load control
  - Load rate: 20kN/min
  - *Brandner et al. (2013)*

1. Loading up to 40% (approx.) of estimated maximum
2. Holding for 30 seconds
3. Unloading to 10% (approx.) of estimated maximum
4. Holding for 30 seconds
5. Loading to failure where failure is assumed to occur when load drops to 80% of recorded maximum

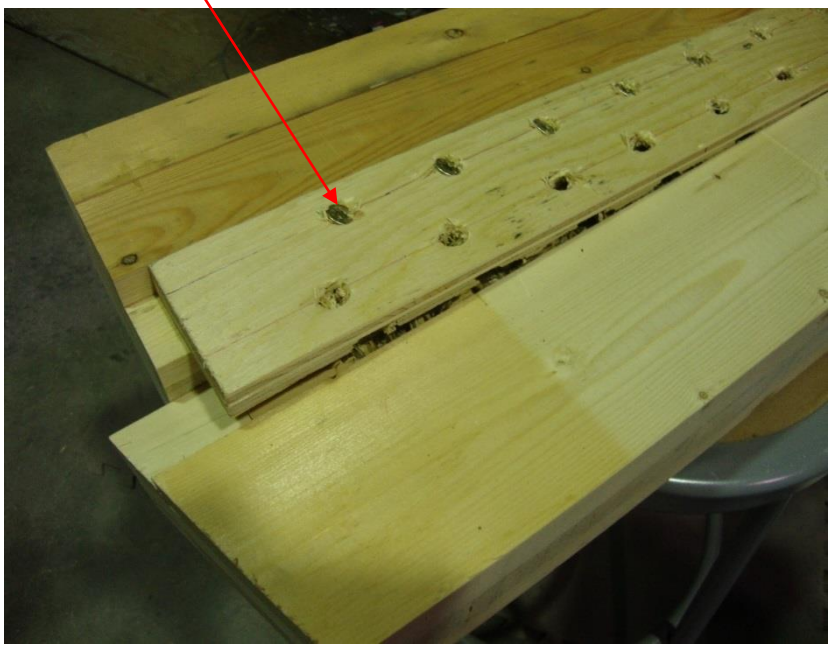


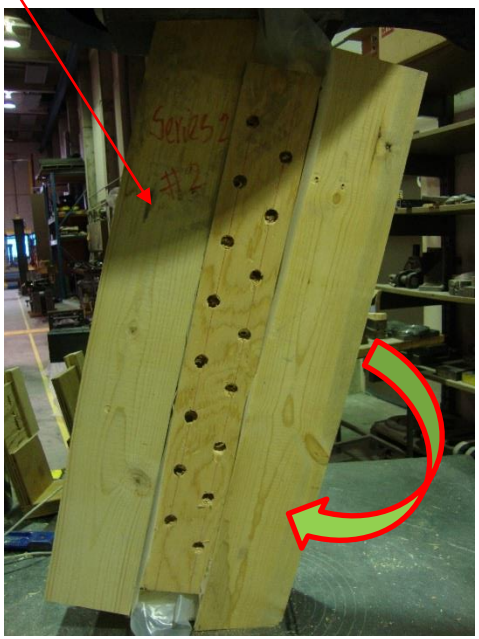

# Test Campaign #1 : Static Loading

- Most commonly observed failure modes

**- Surface Spline Joints:**

Head pull-in of screws leads to out-of-plane rotation of specimens



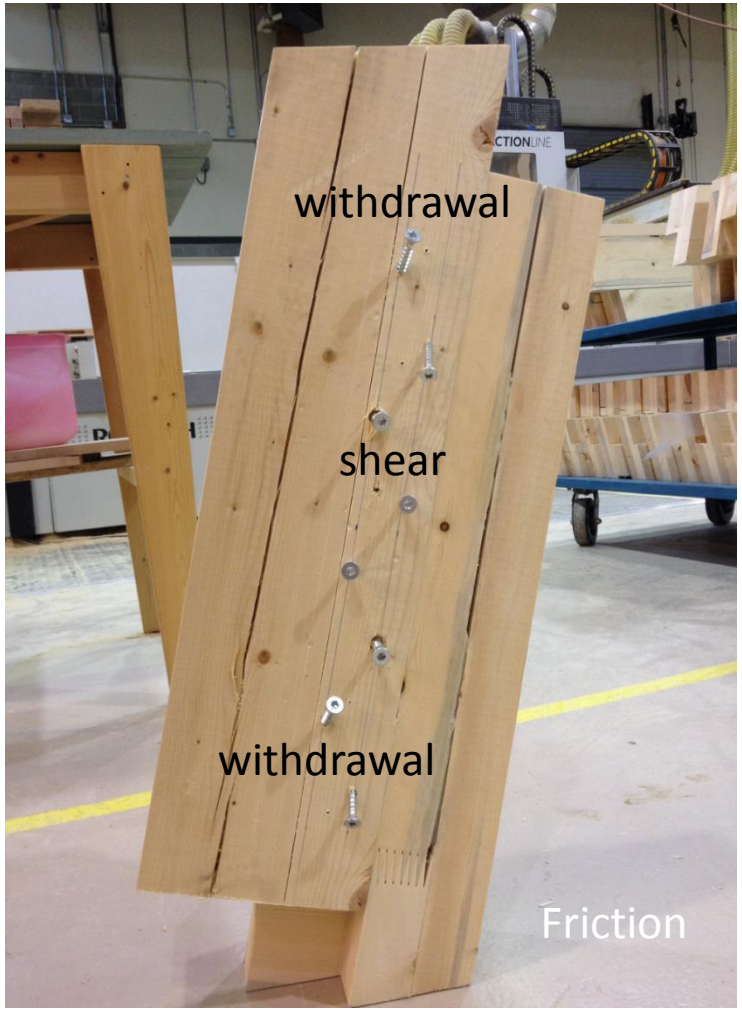


# Test Campaign #1 : Static Loading

- Most commonly observed failure modes

**- Half Lapped Joints with STS in Shear and Withdrawal:**

Head pull-in of screws + out of plane rotation



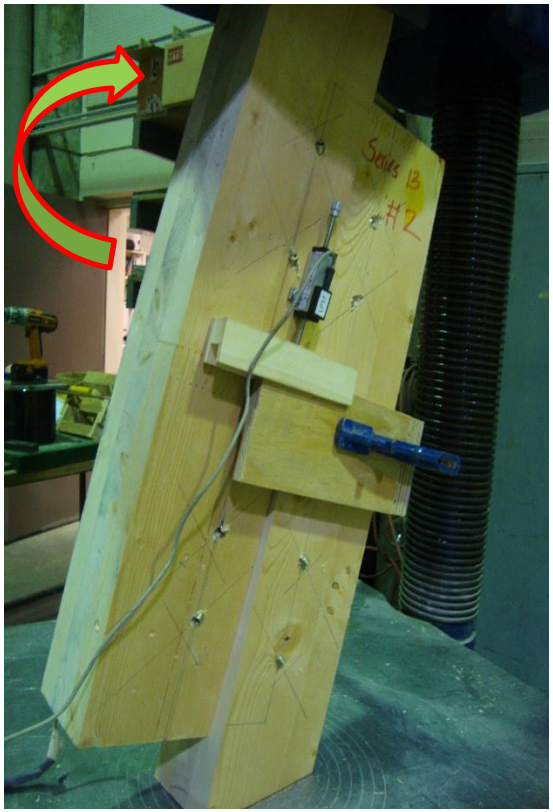

# Test Campaign #1 : Static Loading

- Most commonly observed failure modes

**- Half Lapped and Butt Joints with STS in Withdrawal:**

-Half Lapped Joints:
withdrawal (head push-out and pull-in)

- Butt Joints:
Out of plane rotation



# Test Campaign #1 : Static Test Results

## Results for 3-ply Specimens:

| Label | Type | Total $F_{MAX}$ [kN] | $F_{MAX}$ [kN] | $F_Y$ [kN] | $\Delta_{MAX}$ [mm] | $\Delta_Y$ [mm] | $K_{0.4}$ [kN/mm] | Ductility |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 52.0 | 6.9 | 5.9 | 52.8 | 9.1 | 1.3 | 5.9 |
| Series 1 – SS_90_3ply_NF | | 51.2 | 6.4 | 5.1 | 52.0 | 6.2 | 1.3 | 8.5 |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 53.6 | 6.7 | 5.1 | 25.7 | 3.6 | 2.2 | 9.3 |
| Series 3 – LJ_90_3ply_NF | | 54.4 | 7.6 | 5.6 | 30.0 | 4.2 | 2.6 | 7.6 |
| Series 5 – LJ_45_3ply | | 86.4 | 7.2 | 6.4 | 4.1 | 1.2 | 14.4 | 3.6 |
| Series 5 – LJ_45_3ply_NF | | 83.7 | 6.6 | 5.9 | 5.8 | 1.5 | 10.9 | 3.8 |
| Series 7 – LJ_45/90_3ply_WSSW | | 53.6 | 6.7 | 5.9 | 19.5 | 1.0 | 11.4 | 21.1 |
| Series 7 – LJ_45/90_3ply_WSSW_NF | | 53.6 | 6.7 | 5.4 | 17.0 | 1.0 | 22.4 | 17.8 |
| Series 9 – LJ_45/90_3ply_SWSWS | | 47.2 | 4.9 | 4.2 | 24.7 | 1.4 | 8.3 | 17.6 |
| Series 11 – BJ_33/45_3ply | Butt Joint | 62.4 | 7.8 | 6.8 | 6.5 | 1.0 | 10.4 | 6.5 |
| Series 11 – BJ_33/45_3ply_NF | | 58.4 | 7.3 | 6.3 | 7.5 | 1.0 | 9.1 | 7.5 |
| Series 12 – BJ_45_3ply | | 54.4 | 6.8 | 6.2 | 39.2 | 10.2 | 1 | 3.8 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 6 specimens and 3 specimens for NF series
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #1 : Static Test Results

## Impact of Friction on 3ply Specimens:

| Label | Type | Total $F_{MAX}$ [kN] | $F_{MAX}$ [kN] | $F_Y$ [kN] | $\Delta_{MAX}$ [mm] | $\Delta_Y$ [mm] | $K_{0.4}$ [kN/mm] | Ductility |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 52.0 | 6.9 | 5.9 | 52.8 | 9.1 | 1.3 | 5.9 |
| Series 1 – SS_90_3ply_NF | | 51.2 | 6.4 | 5.1 | 52.0 | 6.2 | 1.3 | 8.5 |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 53.6 | 6.7 | 5.1 | 25.7 | 3.6 | 2.2 | 9.3 |
| Series 3 – LJ_90_3ply_NF | | 54.4 | 7.6 | 5.6 | 30.0 | 4.2 | 2.6 | 7.6 |
| Series 5 – LJ_45_3ply | | 86.4 | 7.2 | 6.4 | 4.1 | 1.2 | 14.4 | 3.6 |
| Series 5 – LJ_45_3ply_NF | | 83.7 | 6.6 | 5.9 | 5.8 | 1.5 | 10.9 | 3.8 |
| Series 7 – LJ_45/90_3ply_WSSW | | 53.6 | 6.7 | 5.9 | 19.5 | 1.0 | 11.4 | 21.1 |
| Series 7 – LJ_45/90_3ply_WSSW_NF | | 53.6 | 6.7 | 5.4 | 17.0 | 1.0 | 22.4 | 17.8 |
| Series 9 – LJ_45/90_3ply_SWSWS | | 47.2 | 4.9 | 4.2 | 24.7 | 1.4 | 8.3 | 17.6 |
| Series 11 – BJ_33/45_3ply | Butt Joint | 62.4 | 7.8 | 6.8 | 6.5 | 1.0 | 10.4 | 6.5 |
| Series 11 – BJ_33/45_3ply_NF | | 58.4 | 7.3 | 6.3 | 7.5 | 1.0 | 9.1 | 7.5 |
| Series 12 – BJ_45_3ply | | 54.4 | 6.8 | 6.2 | 39.2 | 10.2 | 1 | 3.8 |

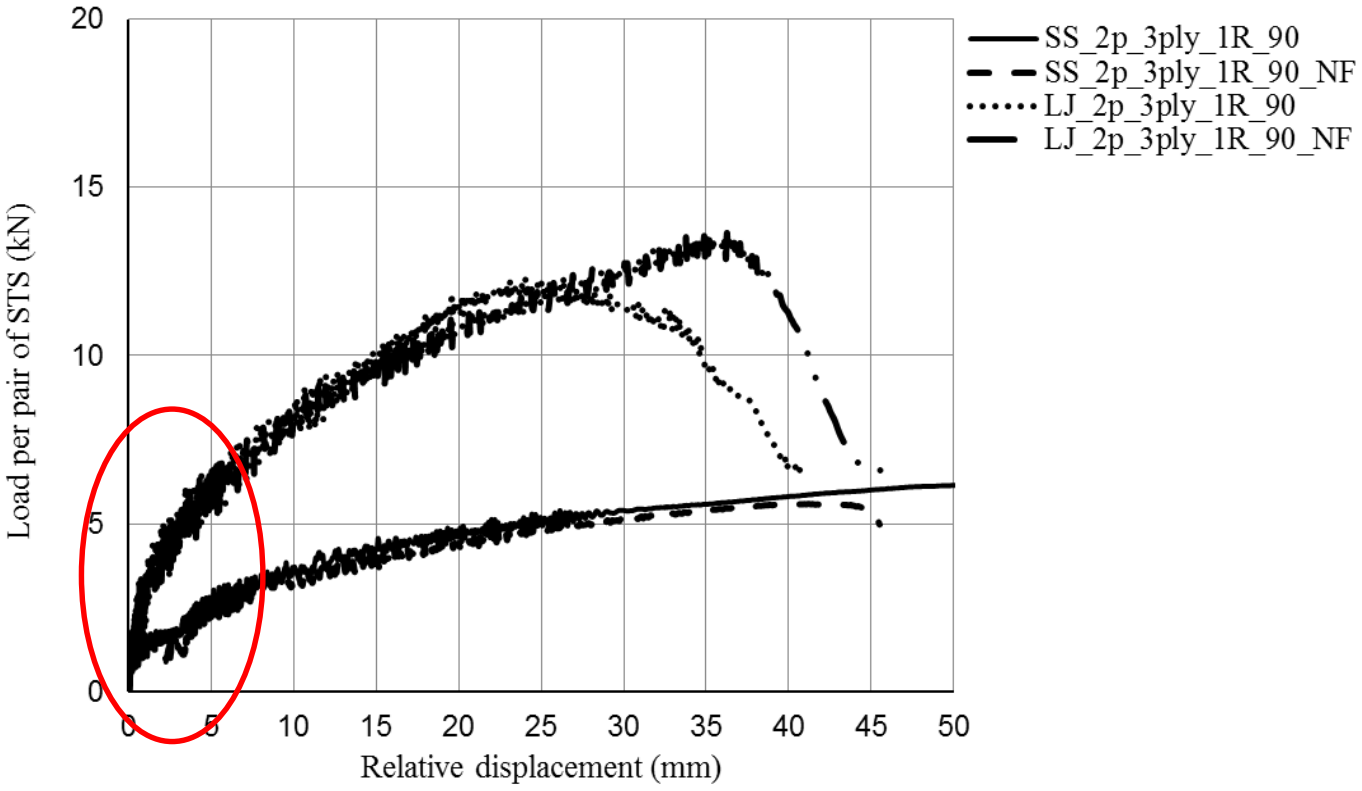
- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 6 specimens and 3 specimens for NF series
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; μ= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

Impact of friction seems to be low!

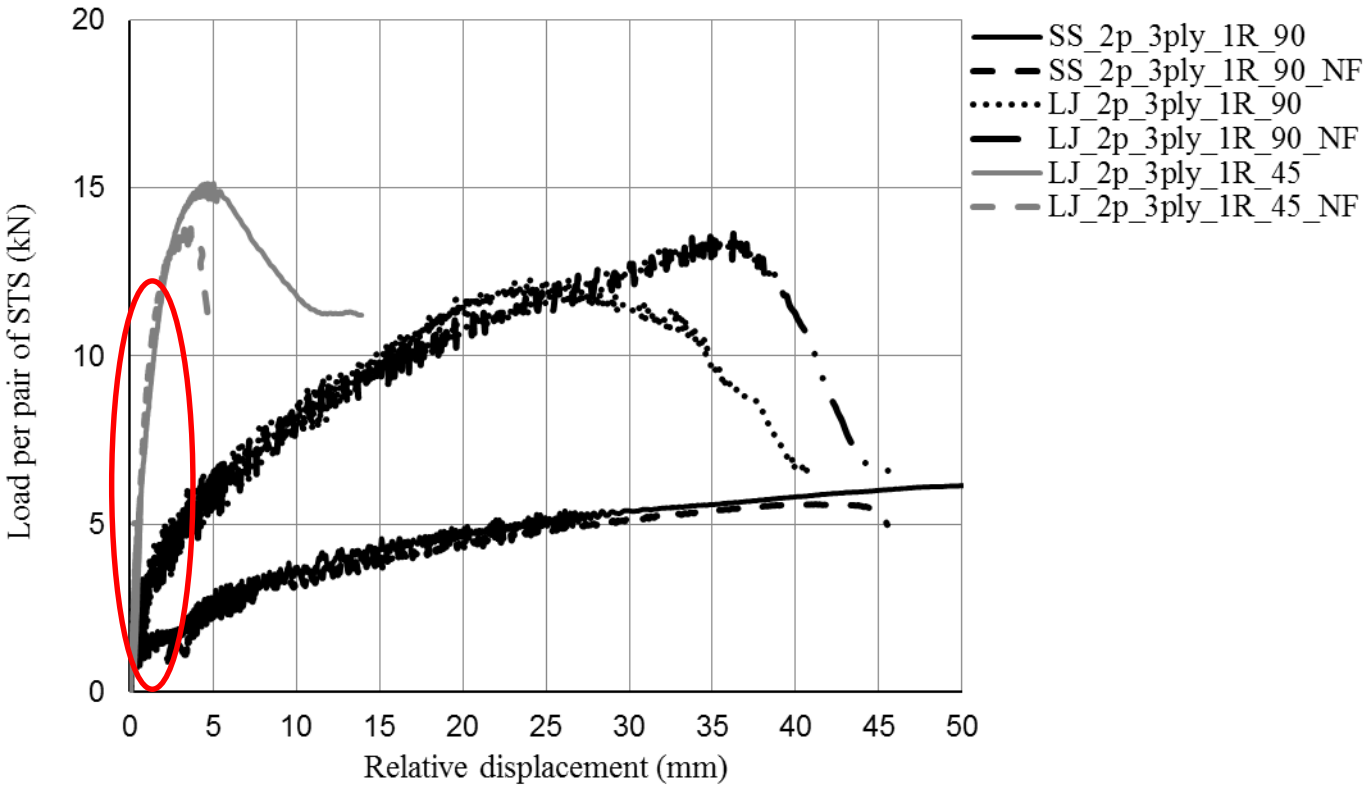
# Test Campaign #1 : Static Test Results

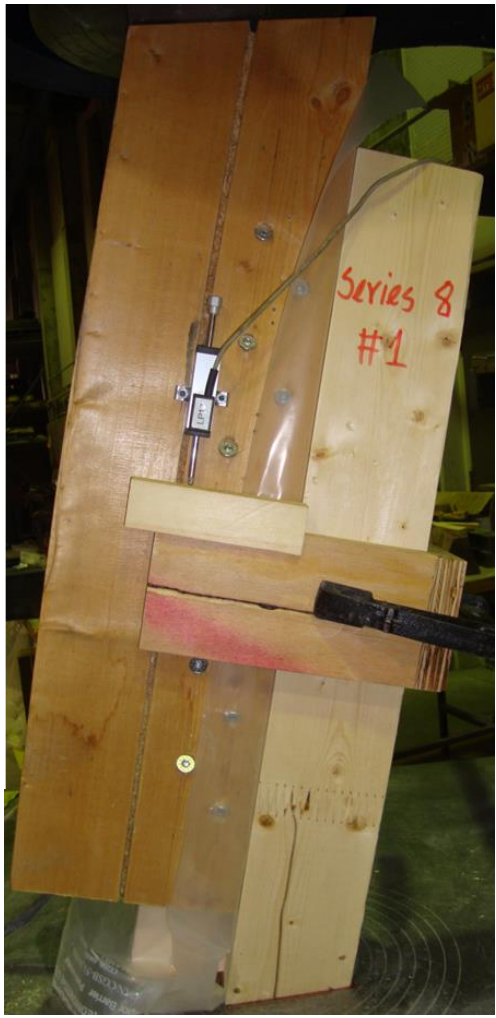
- Load-Displacement Curves




# Test Campaign #1 : Static Test Results

- Load-Displacement Curves

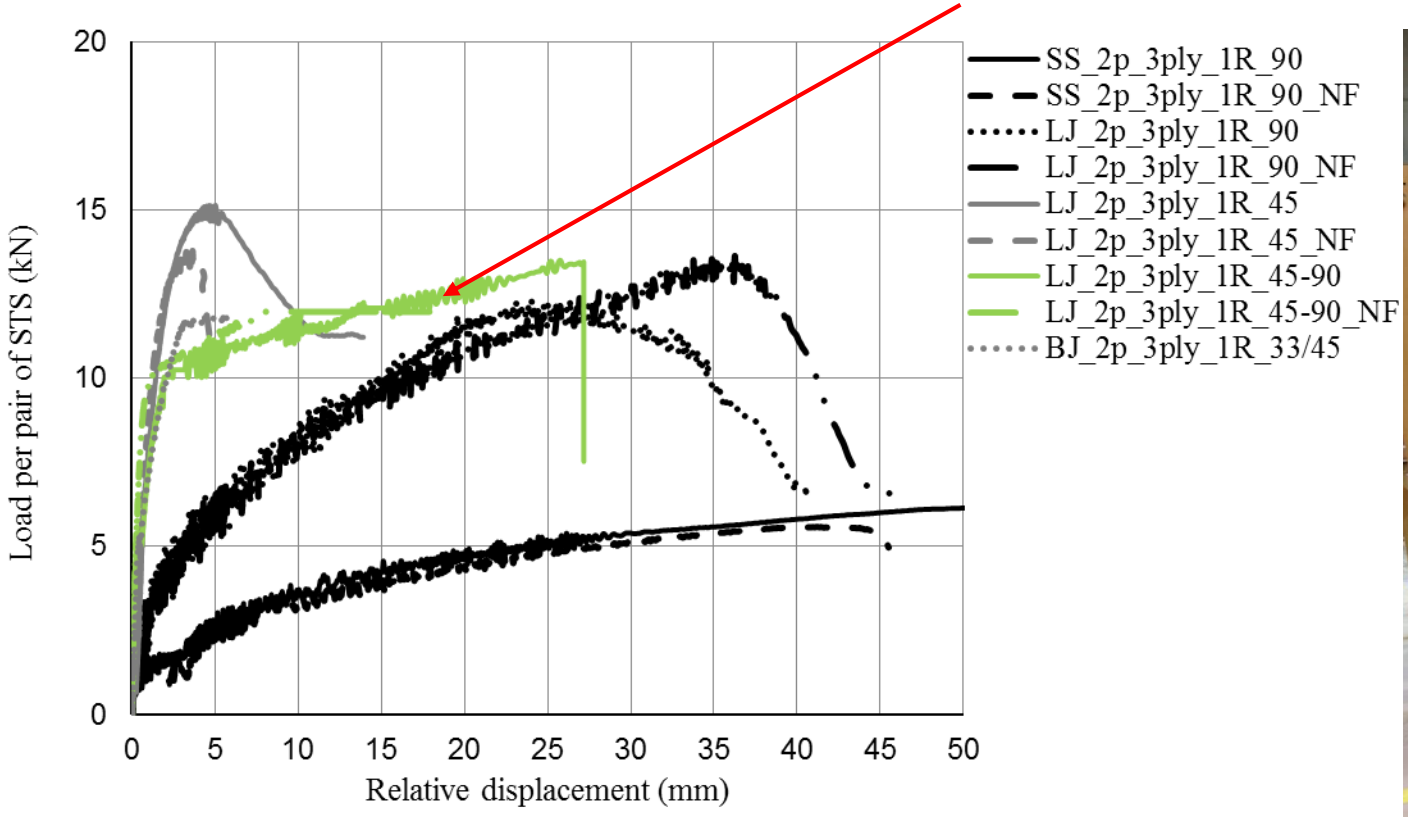


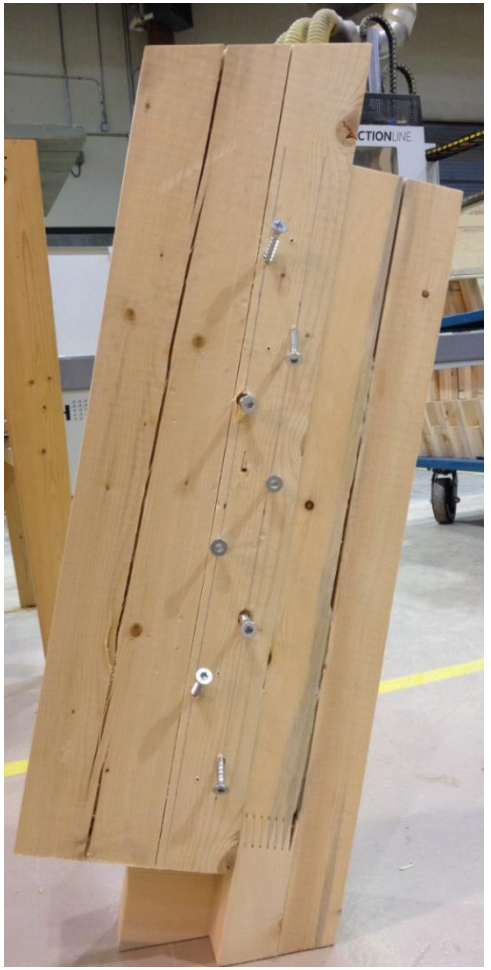



# Test Campaign #1 : Static Test Results

- Load-Displacement Curves

Combination of shear and tension screws
higher initial stiffness with ductility



# Test Campaign #1 : Static Test Results

## Results for 3-ply Specimens:

| Label | Type | Total $F_{MAX}$ [kN] | $F_{MAX}$ [kN] | $F_Y$ [kN] | $\Delta_{MAX}$ [mm] | $\Delta_Y$ [mm] | $K_{0.4}$ [kN/mm] | Ductility |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 52.0 | 6.9 | 5.5 | 46.8 | 9.1 | 1.3 | 5.9 |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 53.6 | 6.7 | 5.1 | 25.7 | 3.6 | 2.2 | 9.3 |
| Series 5 – LJ_45_3ply | | 86.4 | 7.2 | 6.4 | 4.1 | 1.2 | 14.4 | 3.6 |
| Series 7 – LJ_45/90_3ply_WSSW | | 52.0 | 6.5 | 5.9 | 19.5 | 1.0 | 11.4 | 21.1 |
| Series 9 – LJ_45/90_3ply_SWSWS | | 47.2 | 4.7 | 4.2 | 24.7 | 1.4 | 8.3 | 17.6 |
| Series 11 – BJ_33/45_3ply | Butt Joint | 62.4 | 7.8 | 6.8 | 6.5 | 1.0 | 10.4 | 6.5 |
| Series 12 – BJ_45_3ply | | 54.4 | 6.8 | 6.2 | 39.2 | 10.2 | 1.0 | 3.8 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 6 specimens and 3 specimens for NF series
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

WHICH STIFFNESS VALUE SHOULD BE USED FOR DESIGN?

# Test Campaign #1 : Static Test Results

## Results for 3-ply Specimens:

| Label | Type | Total $F_{MAX}$ [kN] | $F_{MAX}$ [kN] | $F_Y$ [kN] | $\Delta_{MAX}$ [mm] | $\Delta_Y$ [mm] | $K_{0.4}$ [kN/mm] | Ductility |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 52.0 | 6.5 | 5.5 | 46.8 | 8.6 | 1.3 | 5.9 |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 53.6 | 6.7 | 5.1 | 25.7 | 3.6 | 2.2 | 9.3 |
| Series 5 – LJ_45_3ply | | 86.4 | 7.2 | 6.4 | 4.1 | 1.2 | 14.4 | 3.6 |
| Series 7 – LJ_45/90_3ply_WSSW | | 52.0 | 6.5 | 5.9 | 19.5 | 1.0 | 11.4 | 21.1 |
| Series 9 – LJ_45/90_3ply_SWSWS | | 47.2 | 4.7 | 4.2 | 24.7 | 1.4 | 8.3 | 17.6 |
| Series 11 – BJ_33/45_3ply | Butt Joint | 62.4 | 7.8 | 6.8 | 6.5 | 1.00 | 10.4 | 6.5 |
| Series 12 – BJ_45_3ply | | 54.4 | 6.8 | 6.2 | 39.2 | 10.2 | 1.0 | 3.8 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 6 specimens and 3 specimens for NF series
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; μ= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

COMBINATION OF STS IN SHEAR AND WITHDRAWAL, BEST OF BOTH WORLDS?

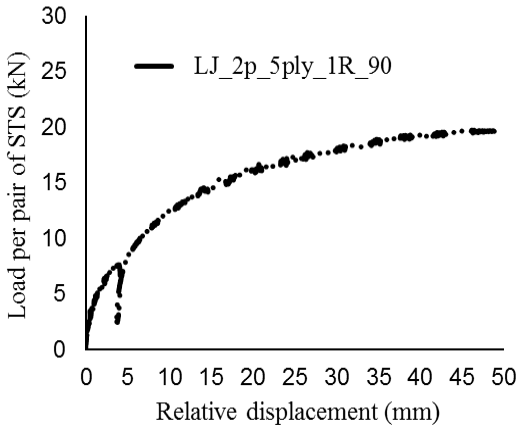
# Test Campaign #1 : Static Test Results

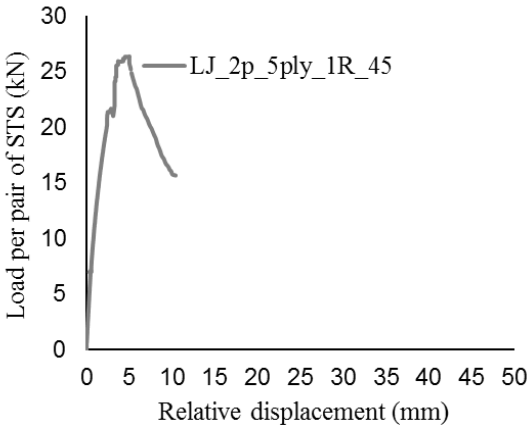
## Results for 5-ply Specimens:

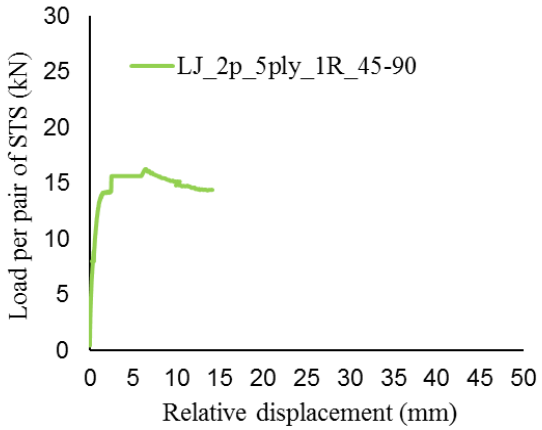
| Label | Type | Total $F_{MAX}$ [kN] | $F_{MAX}$ [kN] | $F_Y$ [kN] | $\Delta_{MAX}$ [mm] | $\Delta_Y$ [mm] | $K_{0.4}$ [kN/mm] | Ductility |
|---|---|---|---|---|---|---|---|---|
| Series 2 – SS_90_5ply | Surface Spline Joint | 56.8 | 7.1 | 5.6 | 45.8 | 7.3 | 1.5 | 7.7 |
| Series 4 – LJ_90_5ply | Half Lapped Joint | 95.2 | 11.9 | 9.5 | 64.3 | 9.0 | 1.5 | 7.4 |
| Series 6 – LJ_45_5ply | | 130 | 13 | 11.5 | 4.7 | 1.8 | 10.6 | 2.7 |
| Series 8 – LJ_45/90_5ply_WSSW | | 78.4 | 9.8 | 8.1 | 3.4 | 0.3 | 10.2 | 11.7 |
| Series 10 – LJ_45/90_5ply_SWSWS | | 61.6 | 7.7 | 6.6 | 4.3 | 0.3 | 9.7 | 14.3 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 6 specimens and 3 specimens for NF series
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; μ= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

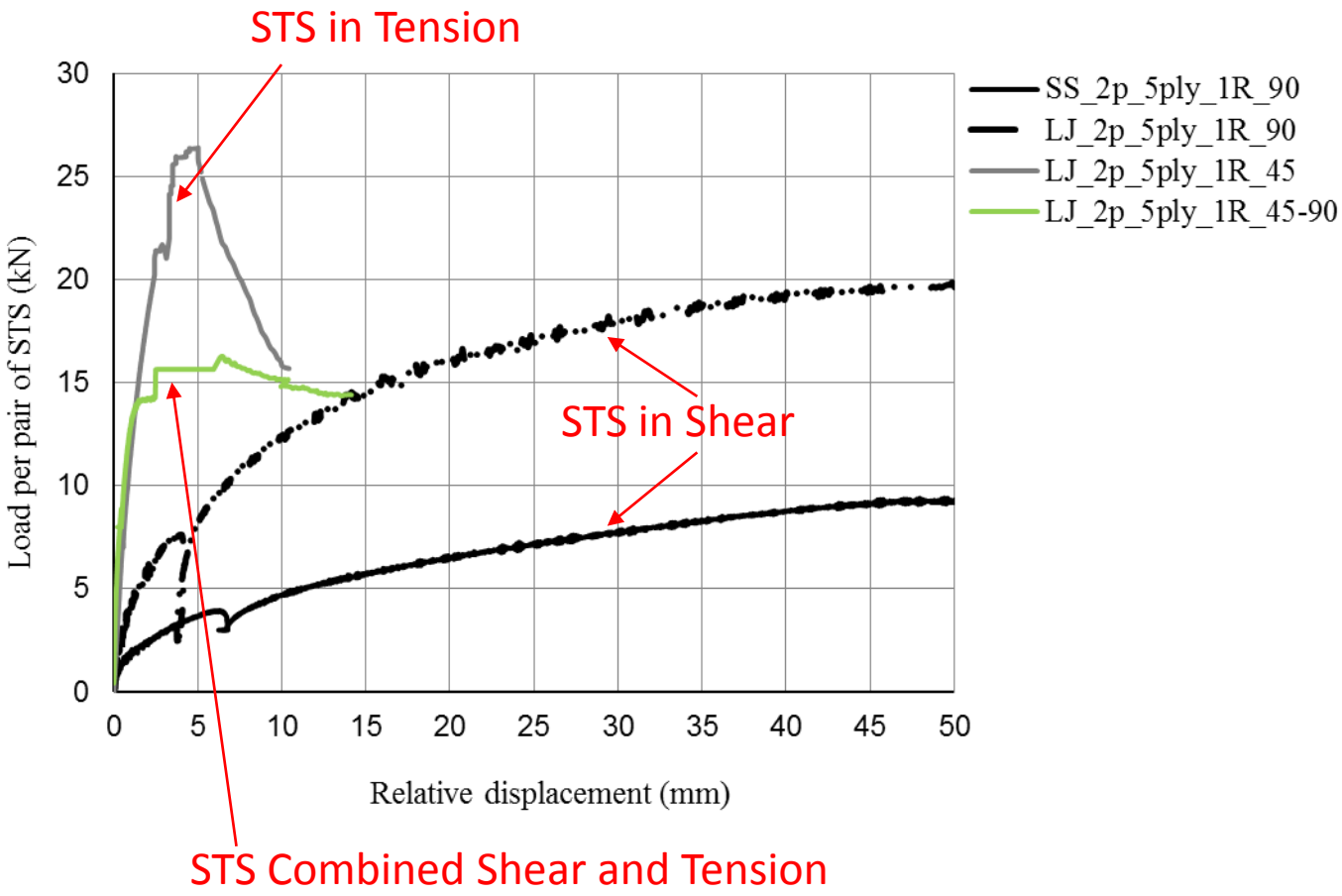


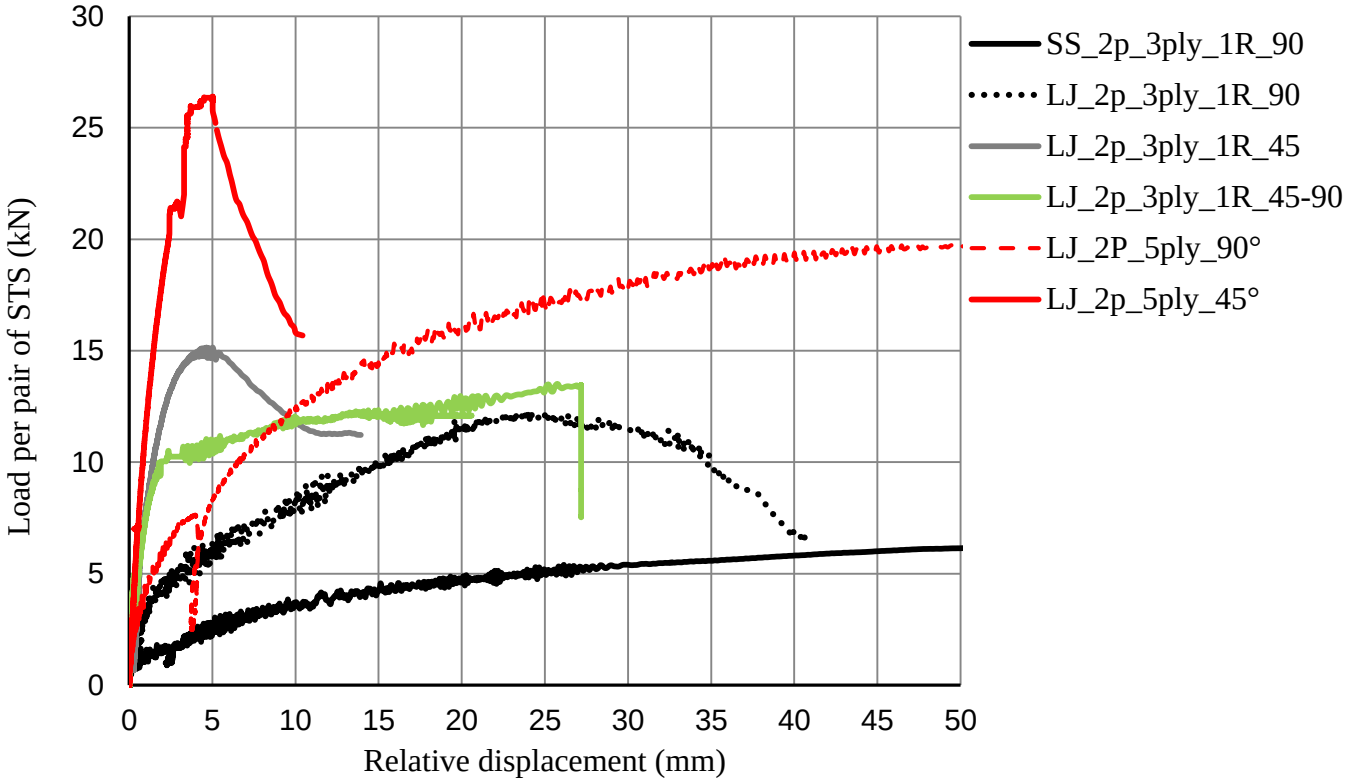
# Test Campaign #1 : Static Test Results

## Load-Displacement Curves:




# Test Campaign #1 : Static Test Results

## Load-Displacement Curves:



# Test Campaign #1 : Static Test Results

## Comparison Between 3-ply & 5-ply:

| Label | Type | $F_{MAX}$ [kN] | $\Delta_{MAX}$ [mm] | $K_{0.4}$ [kN/mm] | **Variation** from 3-ply to 5-ply | |
|---|---|---|---|---|---|---|
| | | | | | $F_{MAX}$ | $K_{0.4}$ |
| Series 1 – SS_90_3ply | Surface Spline Joint | 6.9 | 46.8 | 1.3 | 52% | 15% |
| Series 2 – SS_90_5ply | | 10.5 | 57.5 | 1.5 | | |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 6.7 | 25.7 | 2.2 | 78% | -32% |
| Series 4 – LJ_90_5ply | | 11.9 | 64.3 | 1.5 | | |
| Series 5 – LJ_45_3ply | | 7.2 | 4.1 | 14.4 | 75% | -26% |
| Series 6 – LJ_45_5ply | | 12.6 | 4.7 | 10.6 | | |
| Series 7 – LJ_45/90_3ply_WSSW | | 6.5 | 19.5 | 11.4 | 20% | -11% |
| Series 8 – LJ_45/90_5ply_WSSW | | 7.8 | 3.5 | 10.2 | | |
| Series 9 – LJ_45/90_3ply_SWSWS | | 4.7 | 24.7 | 8.3 | 32% | 17% |
| Series 10 – LJ_45/90_5ply_SWSWS | | 6.2 | 4.3 | 9.7 | | |

Going to 5-ply = increase in connection capacity

# Test Campaign #1 : Static Test Results

## Comparison Between 3-ply & 5-ply:

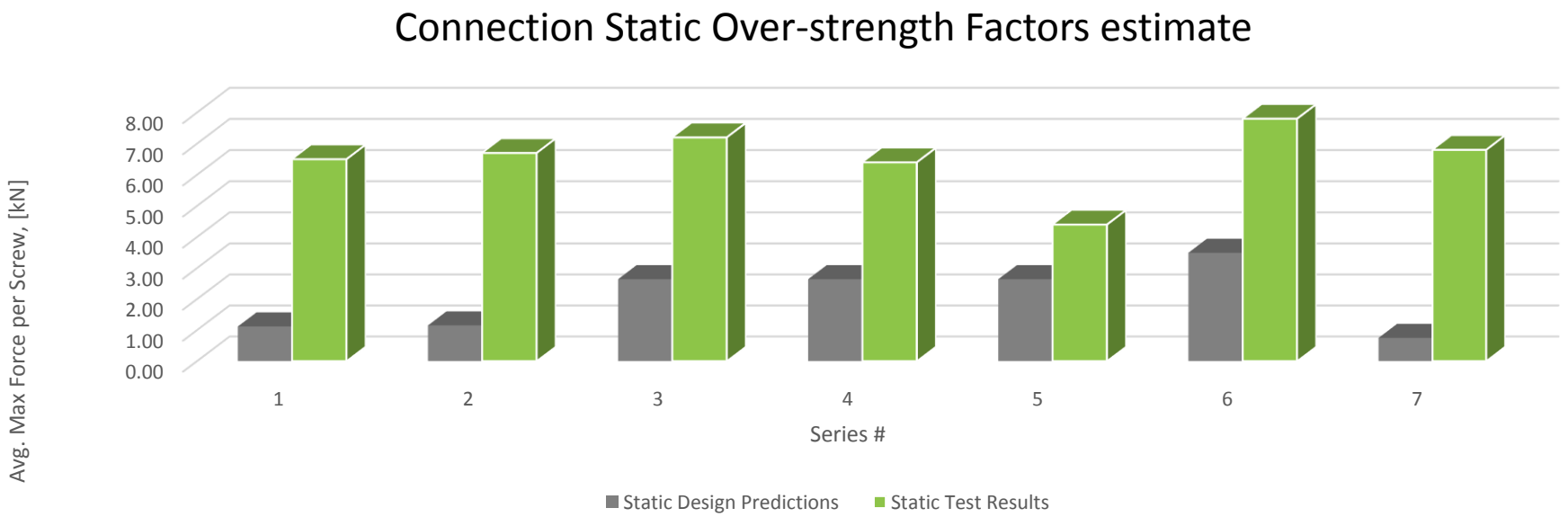
| Label | Type | $F_{MAX}$ [kN] | $\Delta_{MAX}$ [mm] | $K_{0.4}$ [kN/mm] | **Variation** from 3-ply to 5-ply | |
|---|---|---|---|---|---|---|
| | | | | | $F_{MAX}$ | $K_{0.4}$ |
| Series 1 – SS_90_3ply | Surface Spline Joint | 6.9 | 46.8 | 1.3 | 52% | 15% |
| Series 2 – SS_90_5ply | | 10.5 | 57.5 | 1.5 | | |
| Series 3 – LJ_90_3ply | Half Lapped Joint | 6.7 | 25.7 | 2.2 | 78% | -32% |
| Series 4 – LJ_90_5ply | | 11.9 | 64.3 | 1.5 | | |
| Series 5 – LJ_45_3ply | | 7.2 | 4.1 | 14.4 | 75% | -26% |
| Series 6 – LJ_45_5ply | | 12.6 | 4.7 | 10.6 | | |
| Series 7 – LJ_45/90_3ply_WSSW | | 6.5 | 19.5 | 11.4 | 20% | -11% |
| Series 8 – LJ_45/90_5ply_WSSW | | 7.8 | 3.5 | 10.2 | | |
| Series 9 – LJ_45/90_3ply_SWSWS | | 4.7 | 24.7 | 8.3 | 32% | 17% |
| Series 10 – LJ_45/90_5ply_SWSWS | | 6.2 | 4.3 | 9.7 | | |

Going to 5-ply = increase in connection stiffness not for all series

# Test Campaign #1 : Static Test Results

## Comparison Between Design & Test Data:

| Label | Type | $F_{MAX}$ [kN] | Predicted* $F_{MAX}$ [kN] | $\Delta_{MAX}$ [mm] | $K_{0.4}$ [kN/mm] | Over-Strength Ratio |
|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 6.9 | 1.12 | 46.8 | 1.3 | 5.8 |
| Series 2 – LJ_90_3ply | Half Lapped Joint | 6.7 | 1.15 | 25.7 | 2.2 | 5.8 |
| Series 3 – LJ_45_3ply | | 7.2 | 2.64 | 4.1 | 14.4 | 2.7 |
| Series 4 – LJ_45/90_3ply_WSSW | | 6.5 | | 19.5 | 11.4 | 2.5 |
| Series 5 – LJ_45/90_3ply_SWSWS | | 4.7 | | 24.7 | 8.3 | 1.8 |
| Series 6 – BJ_33/45_3ply | Butt Joint | 7.8 | 3.49 | 6.5 | 10.4 | 2.2 |
| Series 7 – BJ_45_3ply | | 6.8 | 0.75 | 39.2 | 1.0 | 9.1 |



# Test Campaign #2

## Cyclic Loading

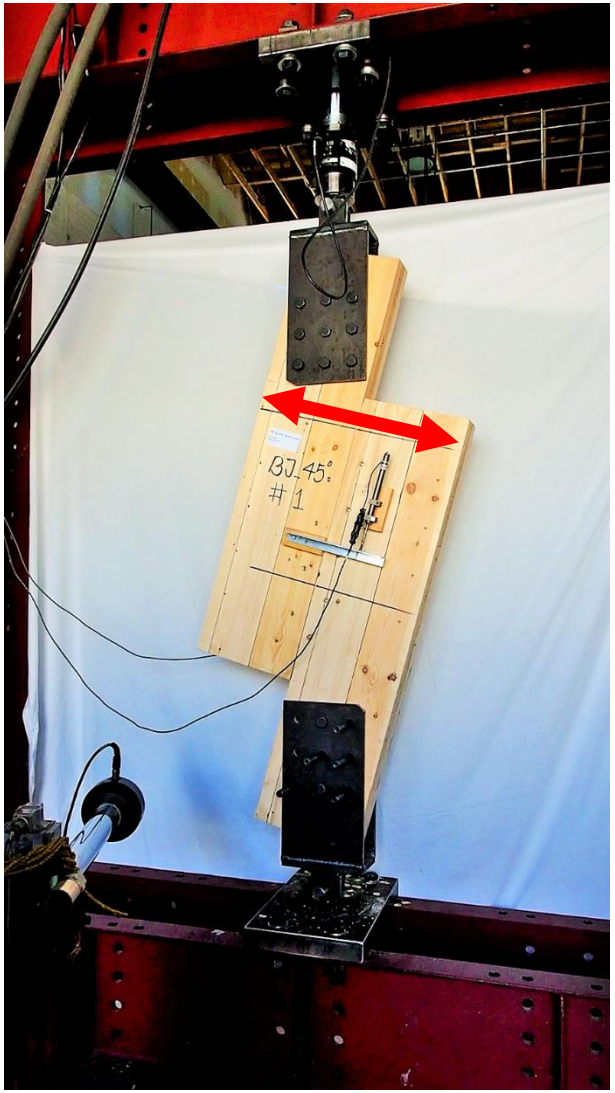
Surface Spline Joints

Half Lapped Joints

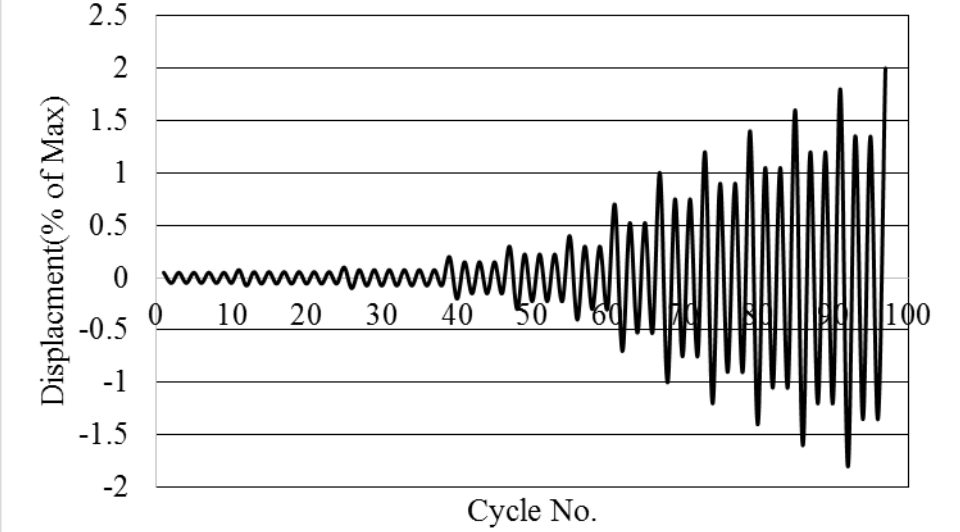
Butt Joints

# Test Campaign #2 : Cyclic Loading

## General Test Setup




## CUREE Loading Protocol (ASTM 2126-09)




- Displacement Controlled
- Displacement Rate: 2.5mm/sec
- Ductility Calculations: EEEP – ASTM 2126-09
- Stiffness Calculations: as per EN-26891 (10-40%)

# Test Campaign #2 : Test Series

## Series from Static Testing Chosen for Cyclic Testing

| Label | Type | STS Ø [mm] | STS Length [mm] | Angle [°] | Replicates | # STS per Shear Plane | STS action |
|---|---|---|---|---|---|---|---|
| Series 1 – SS @ 90 - 3ply | Surface Spline Joint | 8 | 80 | 90 | 6 | 8 | Shear |
| Series 2 – LJ @ 90 - 3ply | Half Lapped Joint | 8 | 90 | 90 | 6 | 8 | Shear |
| Series 3 – LJ @ 45 - 3ply | | 8 | 140 | 45 | 6 | 12 | Withdrawal |
| Series 4 – LJ @ 45&90 (1) - 3ply WSSW | | 8 | 90 + 140 | 45 + 90 | 6 | 8 | Shear + Withdrawal |
| Series 5 – LJ @ 45&90 (2) - 3ply SWSWS | | 8 | 90 + 140 | | 6 | 10 | |
| Series 6 – BJ @ 33&45 - 3ply | Butt Joint | 8 | 180 | 33 + 45 | 6 | 8 | Withdrawal |
| Series 7 – BJ @ 45 - 3ply | | | | 45 | 6 | | Shear |

***Notes***:
SS=Surface Spline, LJ=Lap Joint, BJ=Butt Joint
WSSW = Screw arrangement within rows. Withdr. + Shear + Shear + Withdr.
SWSWS = Screw arrangement within rows. Shear + Withdr. + Shear + Withdr. + Shear

Surface Spline Joints

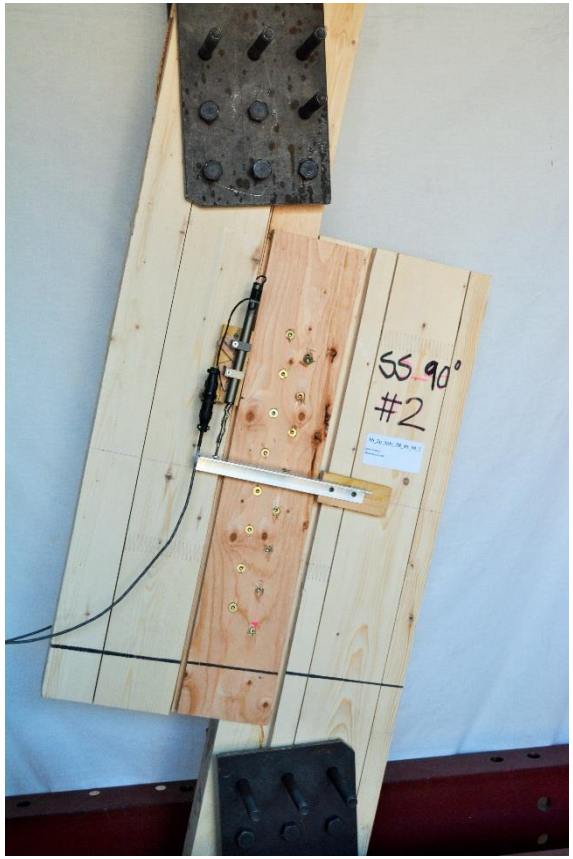
Half Lapped Joints

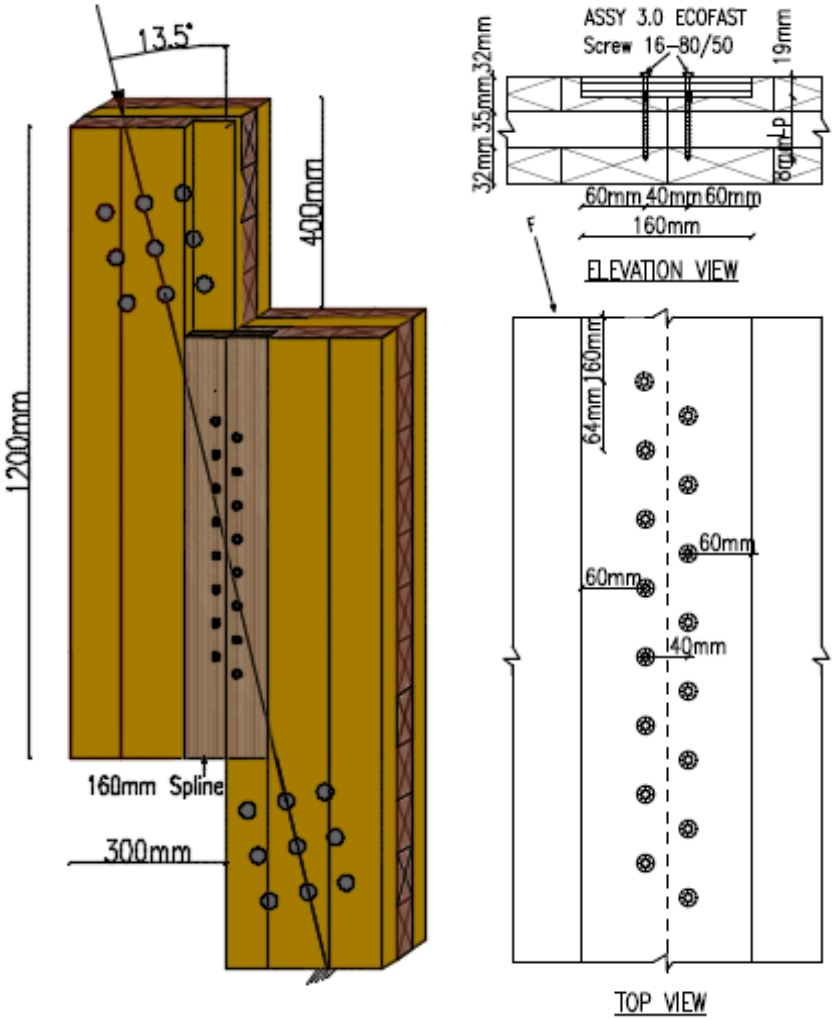
Butt Joints

CrossLam® CLT Panels
V2M1 Grade

# Test Series #1 : Configuration

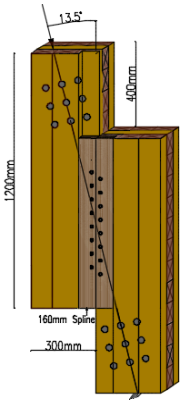
## Surface Spline Joint with STS in Shear




Courtesy of: Afrin Hossain©

# Test Series #1 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #1 = Surface Spline Joints with STS in Shear Action (α=90°)

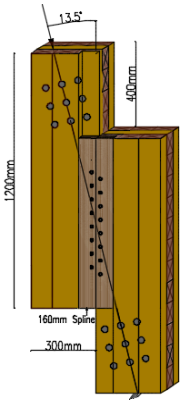
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - SS @ 90°

Static Test Results - SS @ 90°

# Test Series #1 : Backbone Curve




**Static v Dynamic Testing**

Series #1 = Surface Spline Joints with STS in Shear Action (α=90°)

Force per screw [kN]

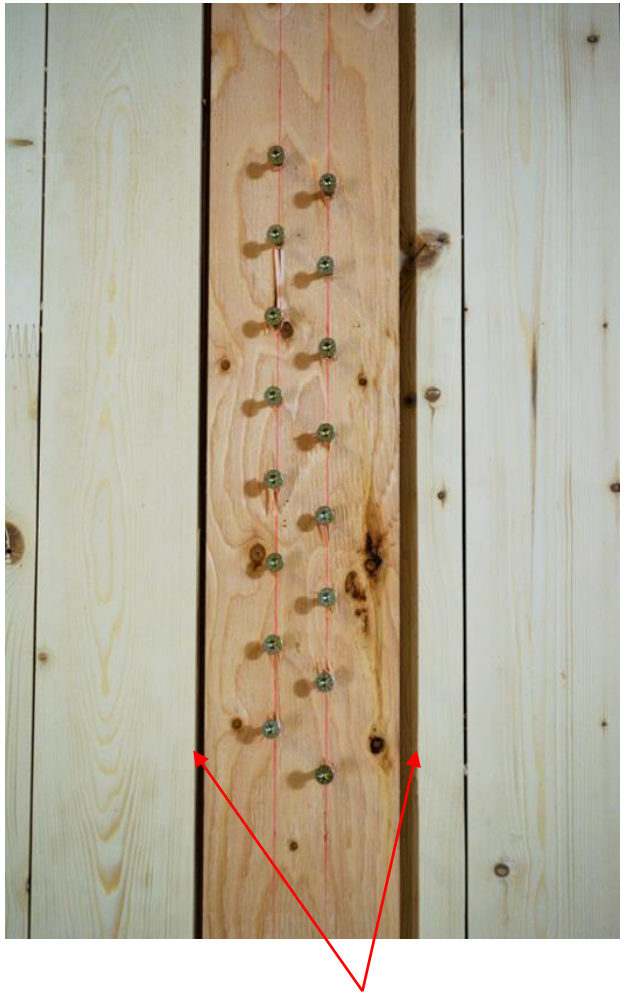
Displacement [mm]

Static Test Results - SS @ 90°

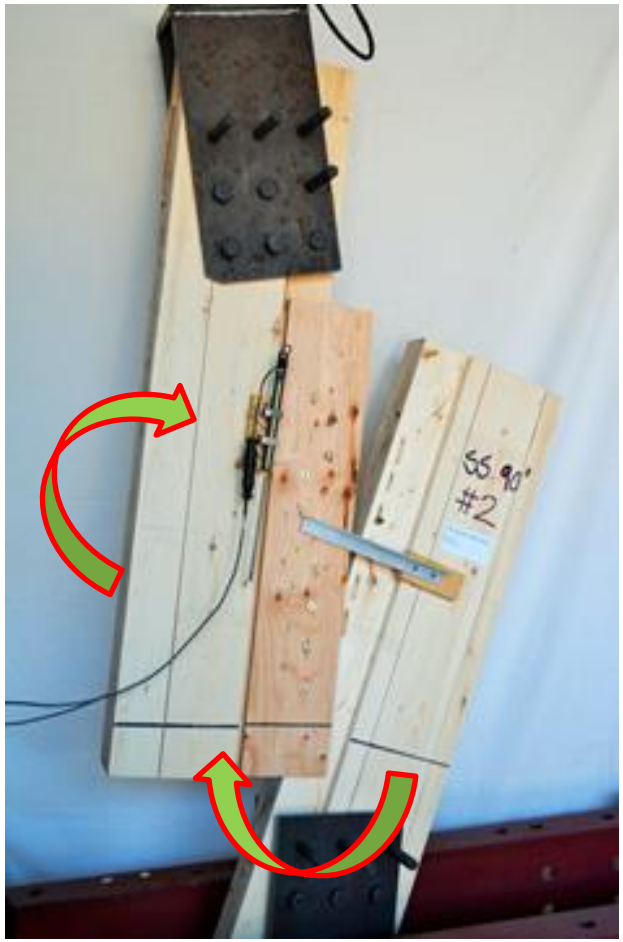
Backbone Curve

# Test Series #1 : Connection Performance

## Overall Connection Behaviour at Failure



Separation of members in ultimate state



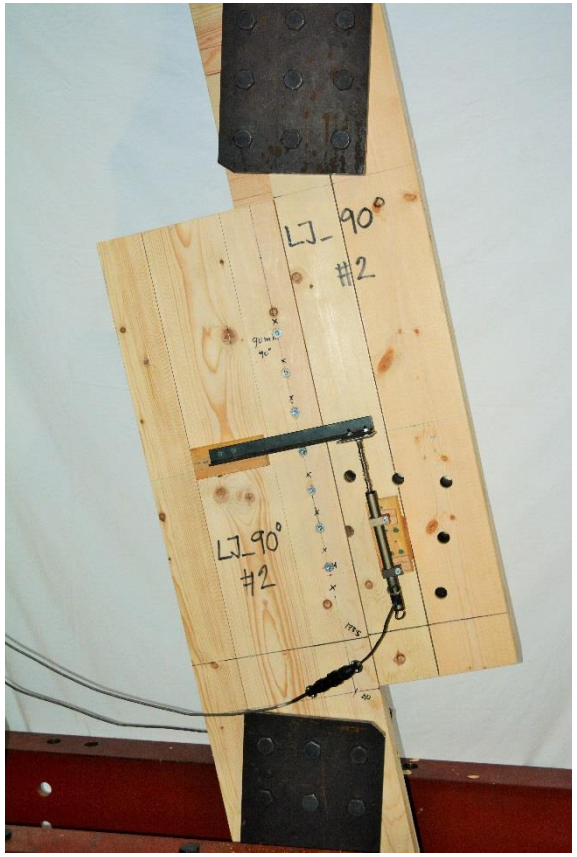

In and out-of-plane rotation

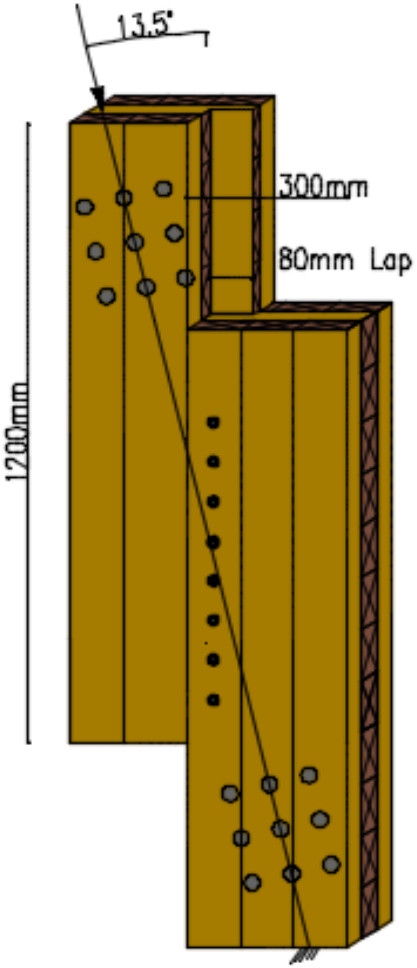
# Test Series #1 : Connection Performance

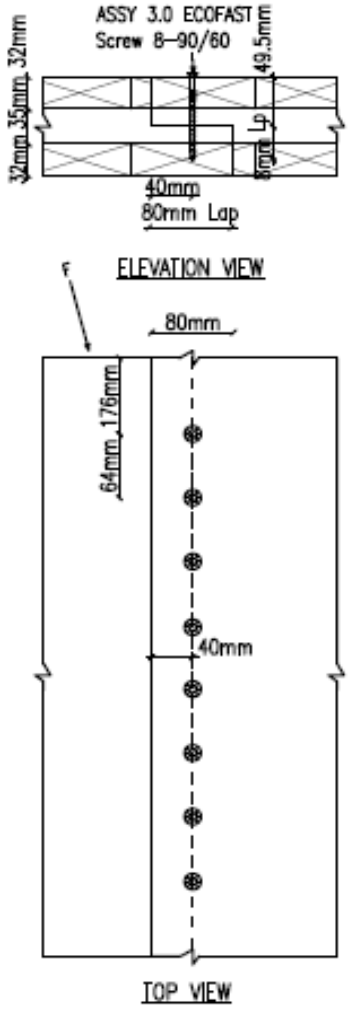
## STS Behaviour at Failure

# Test Series #2 : Configuration

## Half Lapped Joint with STS in Shear

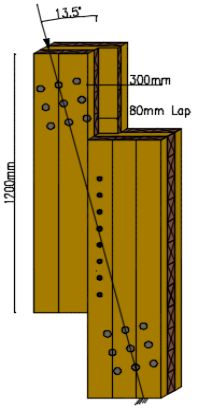



Courtesy of: Afrin Hossain©

# Test Series #2 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #2 = Half Lap Joint with STS in Shear Action (α=90°)

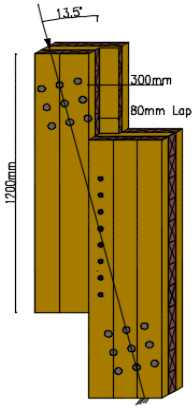
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - LJ @ 90°

Static Test Results - LJ @ 90°

# Test Series #2 : Backbone Curve




**Static v Dynamic Testing**

Series #2 = Half Lap Joint with STS in Shear Action (α=90°)

Force per screw [kN]

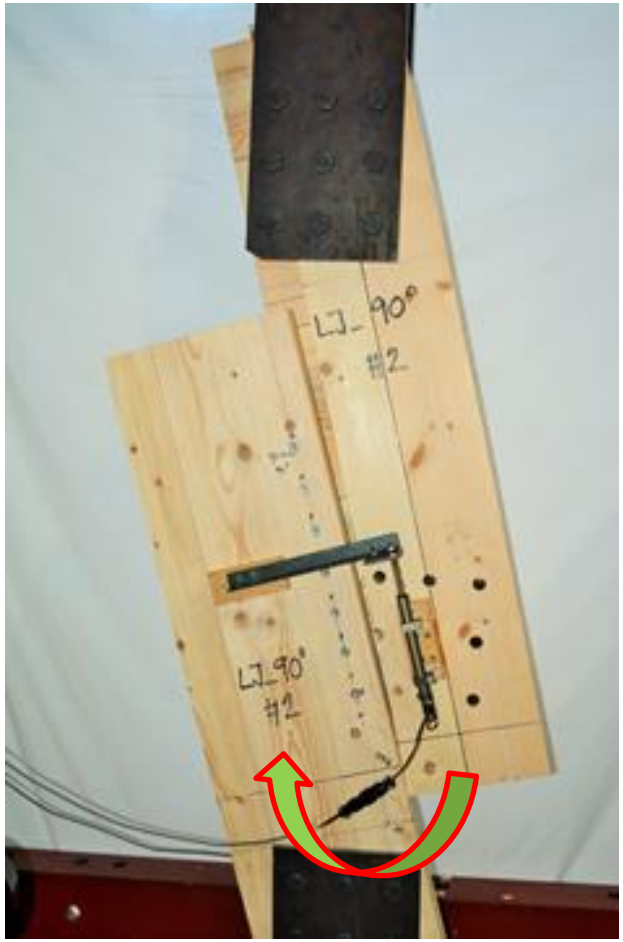
Displacement [mm]

Static Test Results - LJ @ 90°

Backbone Curve

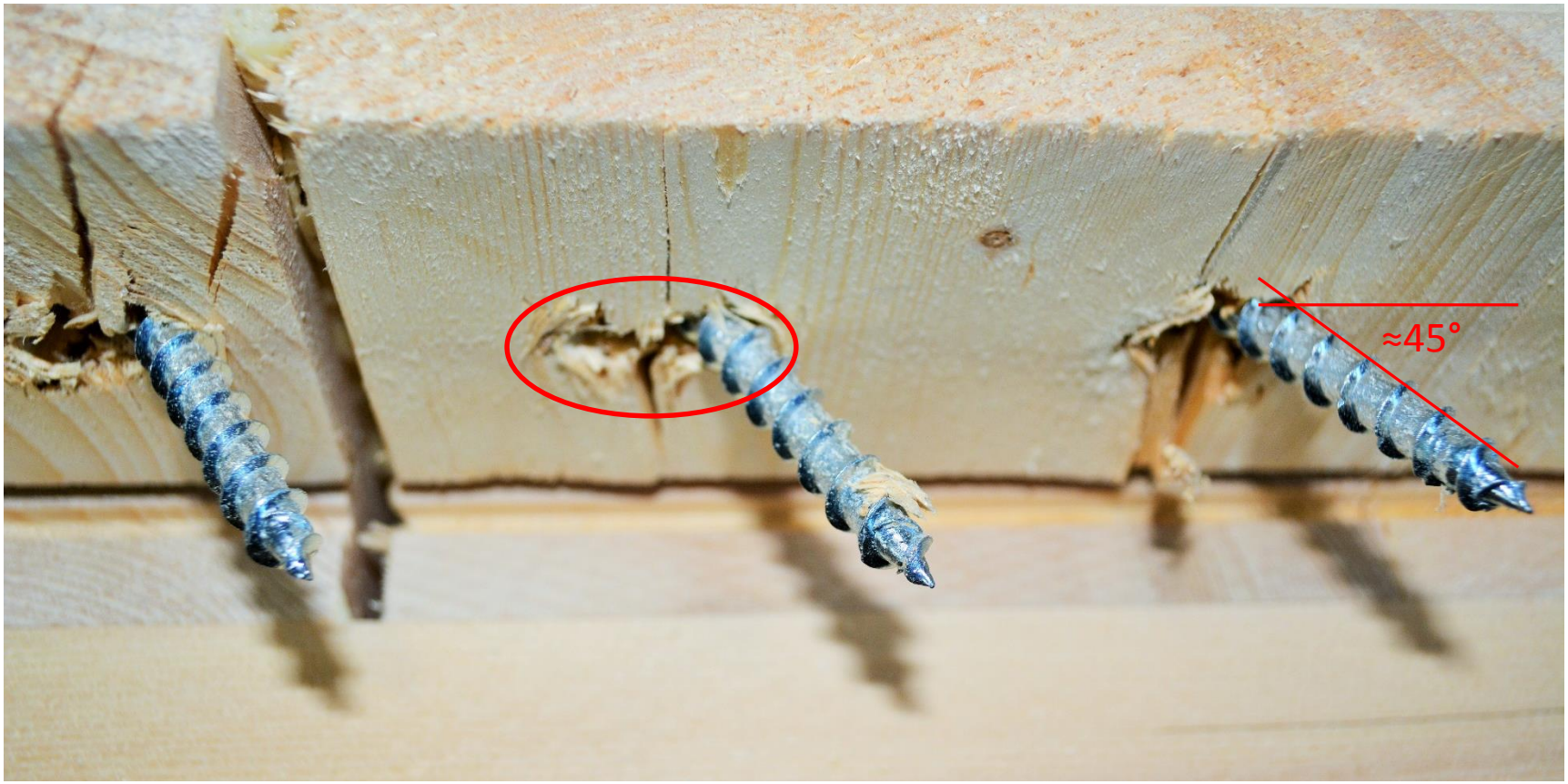
# Test Series #2 : Connection Performance

## Overall Connection Behaviour at Failure

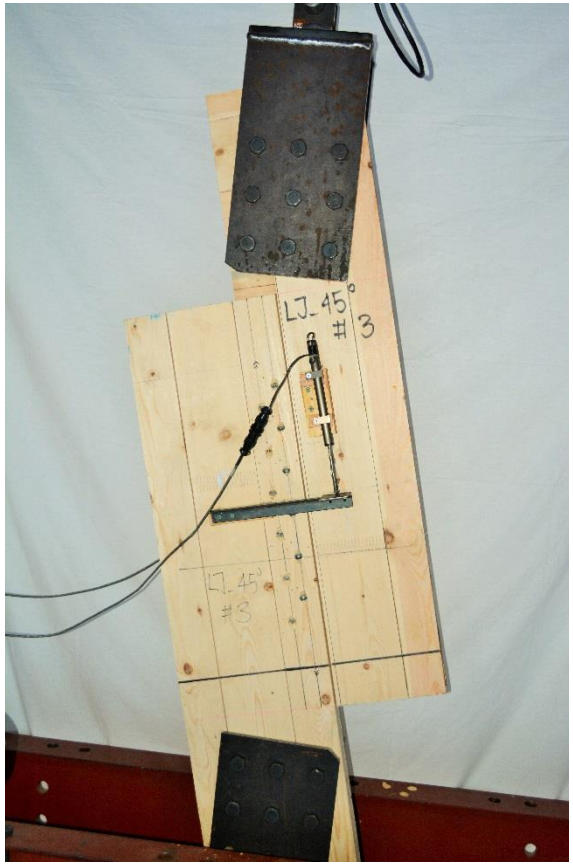
# Test Series #2 : Connection Performance

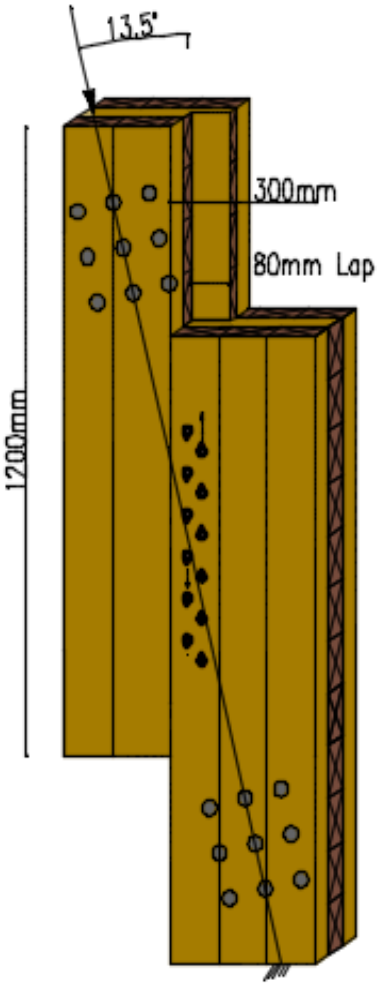
## STS Behaviour at Failure

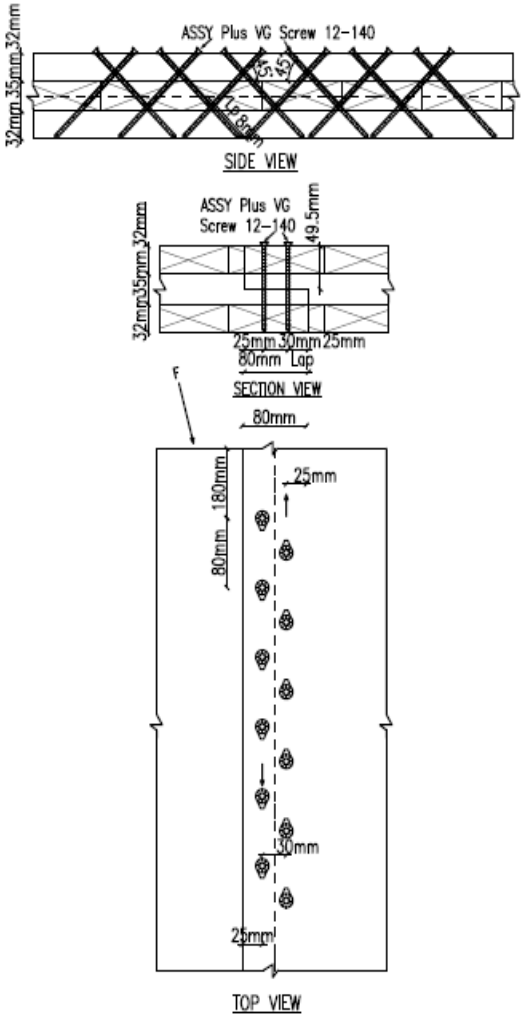


# Test Series #3 : Configuration

## Half Lapped Joint with STS in Tension

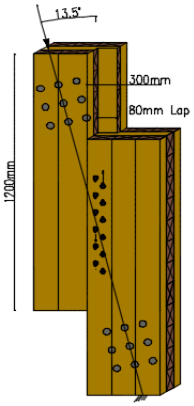



Courtesy of: Afrin Hossain©

# Test Series #3 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #3 = Half Lap Joint with STS in Withdrawal Action (α=45°)

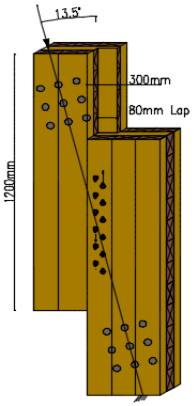
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - LJ @ 45°

Static Test Results - LJ @ 45°

# Test Series #3 : Backbone Curve




**Static v Dynamic Testing**

Series #3 = Half Lap Joint with STS in Withdrawal Action (α=45°)

Force per screw [kN]

Displacement [mm]

Static Test Results - LJ @ 45°

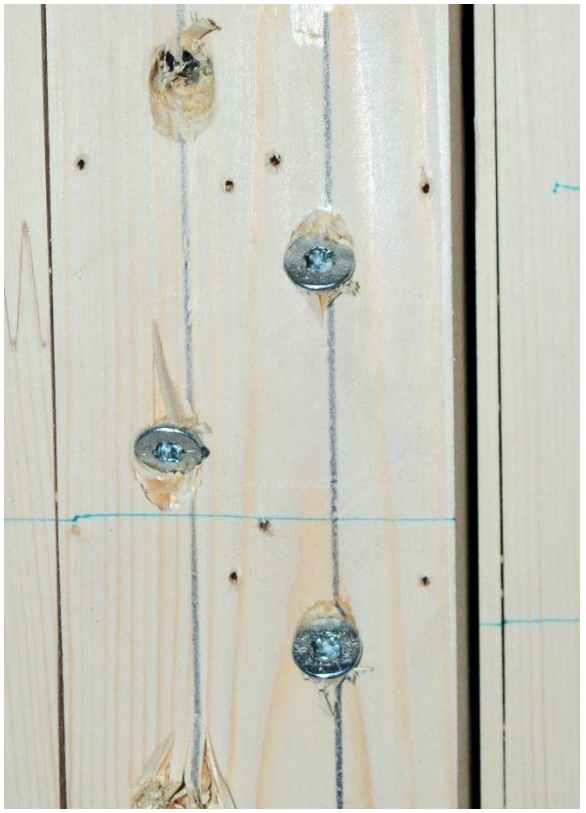
Backbone Curve

# Test Series #3 : Connection Performance

## Overall Connection Behaviour at Failure

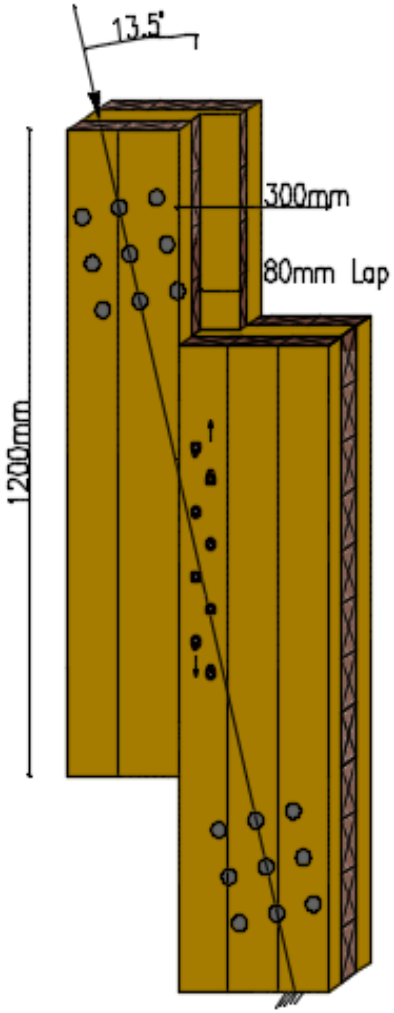

# Test Series #3 : Connection Performance

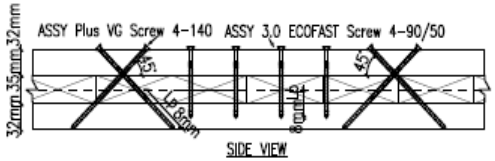
## STS Behaviour at Failure

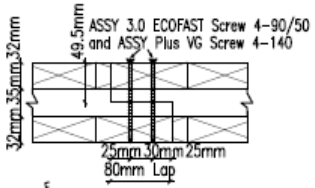


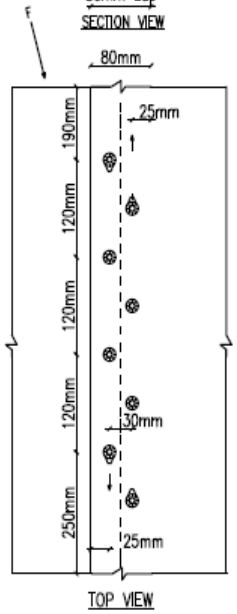
# Test Series #4 : Configuration

## Half Lapped Joint with STS in Shear and Tension

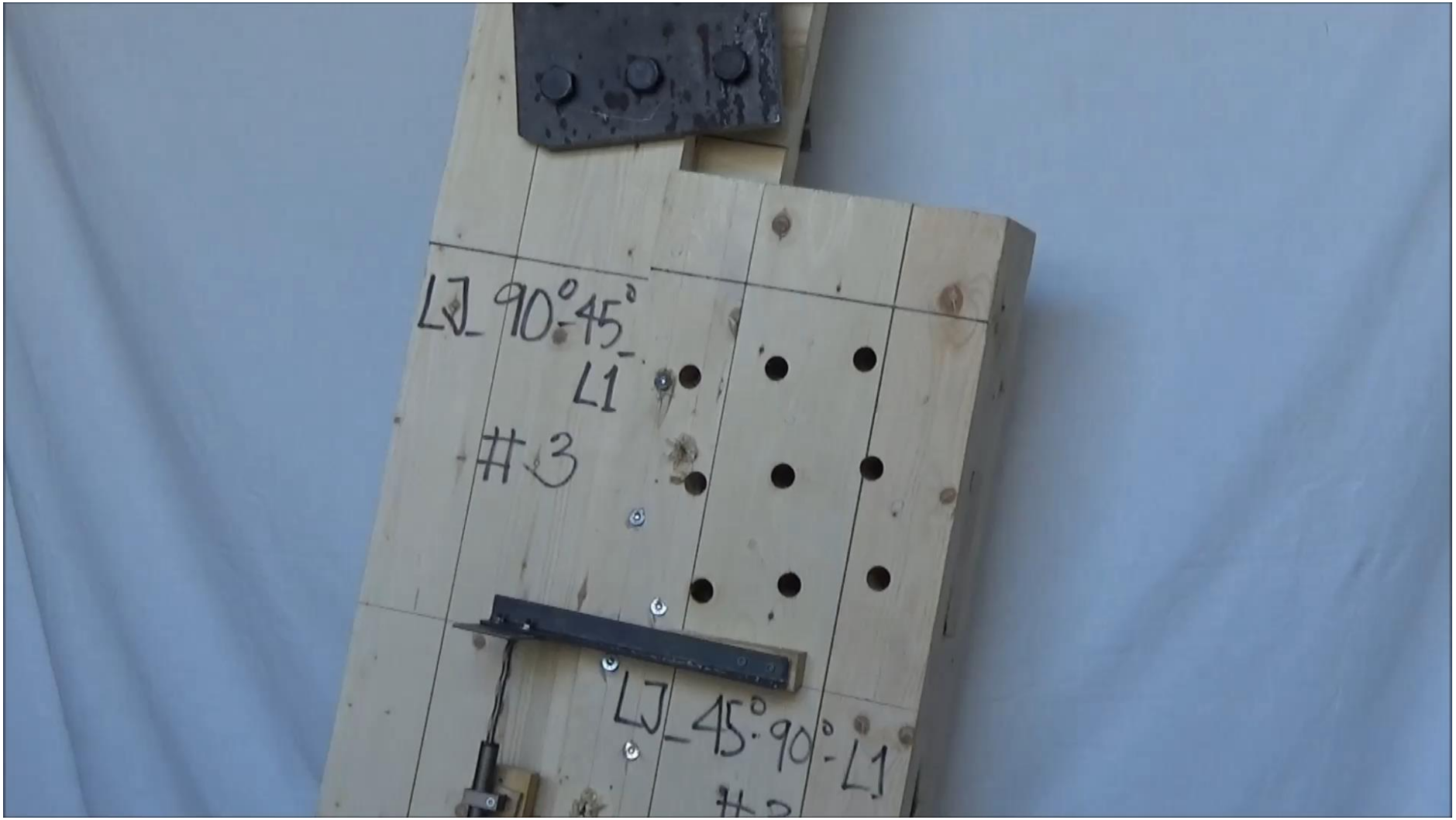



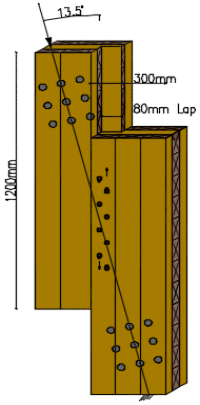

Courtesy of: Afrin Hossain©

# Test Series #4 : Testing Video

## Half Lapped Joint with STS in Shear and Tension



# Test Series #4 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #4 = Half Lap Joint with STS in Withdrawal and Shear Action (1) (α=45° & 90°)

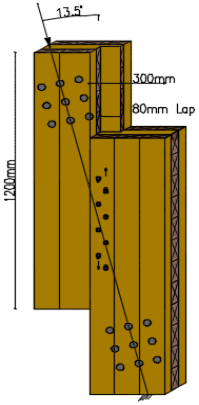
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - LJ @ 45°&90°

Static Test Results - LJ @ 45°&90°

# Test Series #4 : Backbone Curve




**Static v Dynamic Testing**

Series #4 = Half Lap Joint with STS in Withdrawal and Shear Action (1) (α=45° & 90°)

Force per screw [kN]

Displacement [mm]

Static Test Results - LJ @ 45°&90°

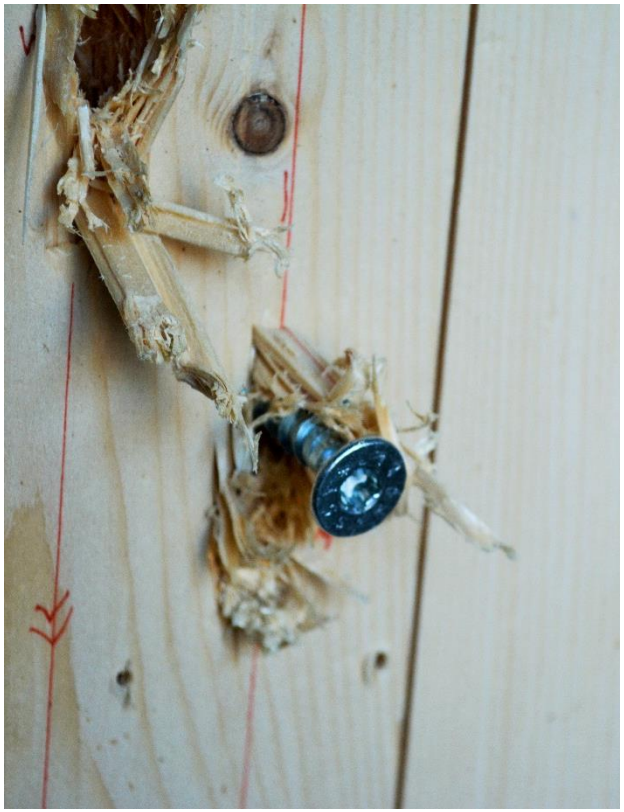
Backbone Curve

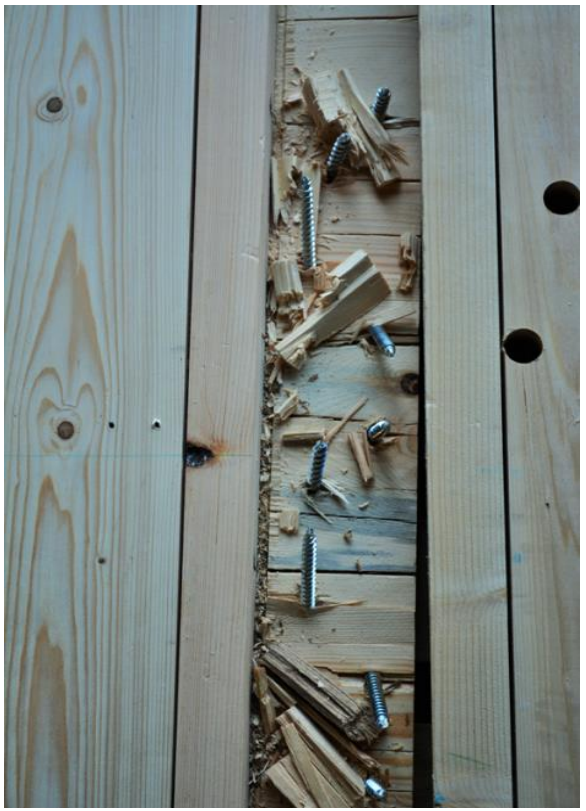
# Test Series #4 : Connection Performance

## Overall Connection Behaviour at Failure

# Test Series #4 : Connection Performance

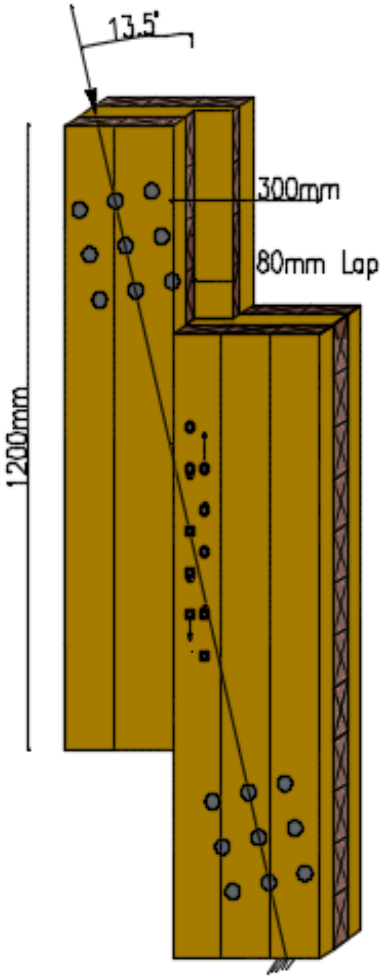
## STS Behaviour at Failure

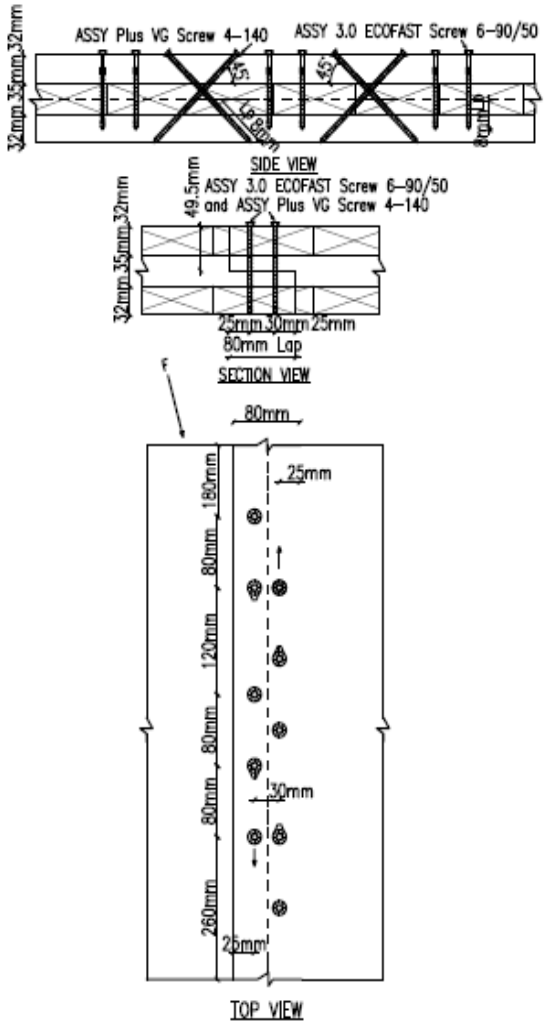




# Test Series #5 : Configuration

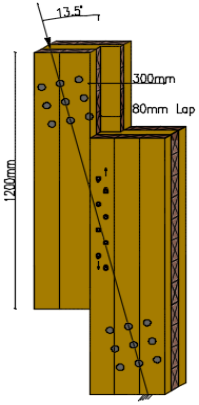
## Half Lapped Joint with STS in Shear and Tension

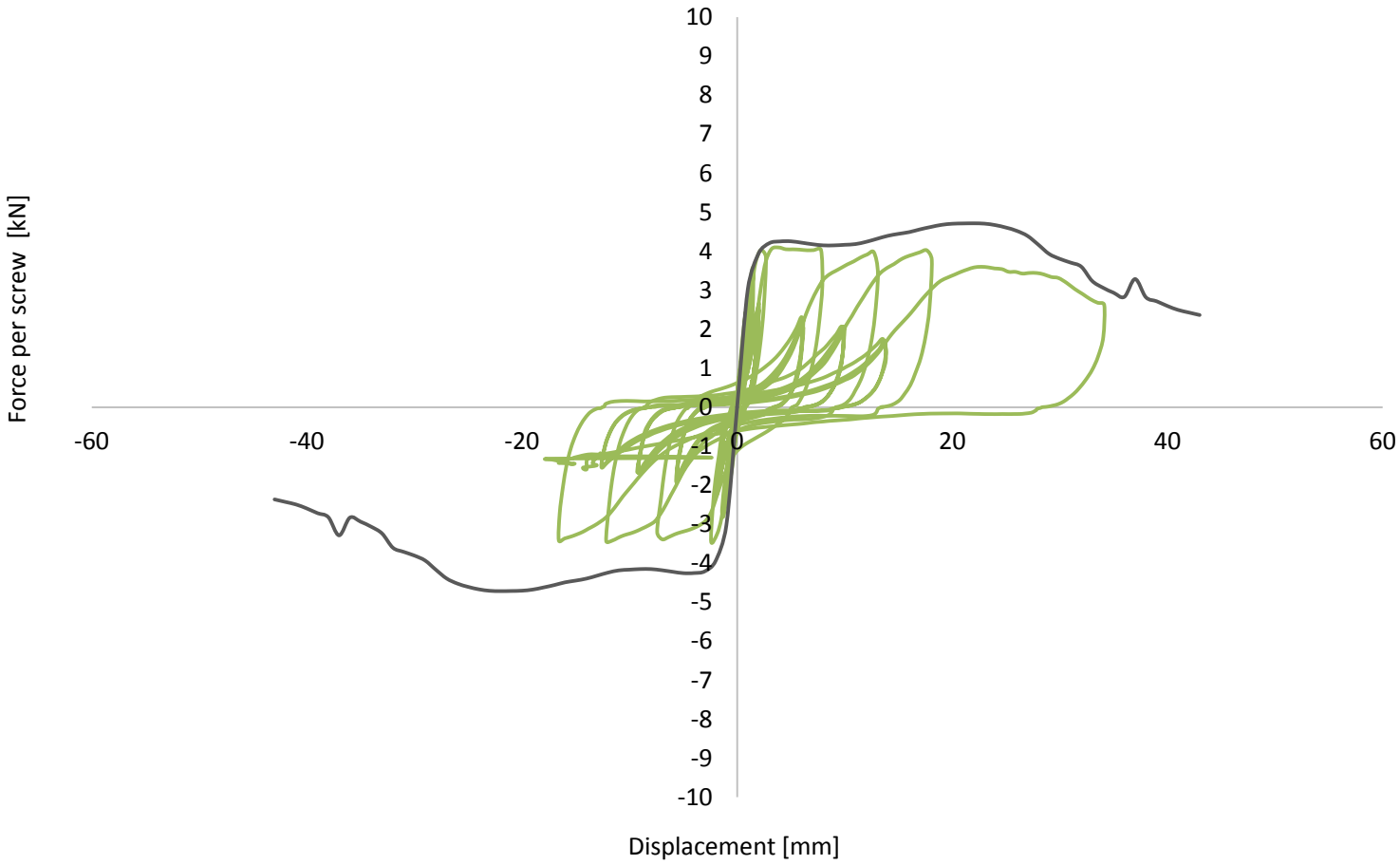

Courtesy of: Afrin Hossain©

# Test Series #5 : Load-Displacement Curve




**Static v Dynamic Testing**

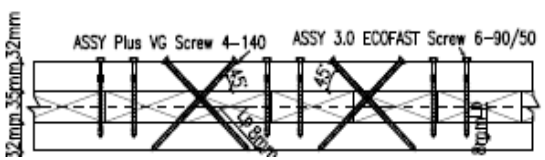
Series #5 = Half Lap Joint with STS in Withdrawal and Shear Action (2) (α=45° & 90°)

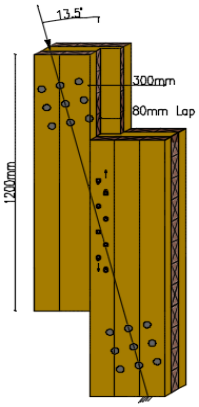



Cyclic Test Results - LJ @ 45°&90°

Static Test Results - LJ @ 45°&90°

# Test Series #5 : Backbone Curve

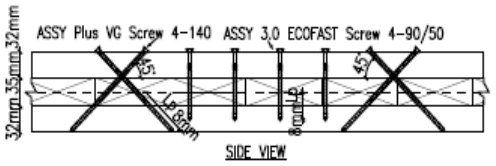



**Static v Dynamic Testing**

Series #5 = Half Lap Joint with STS in Withdrawal and Shear Action (2) (α=45° & 90°)



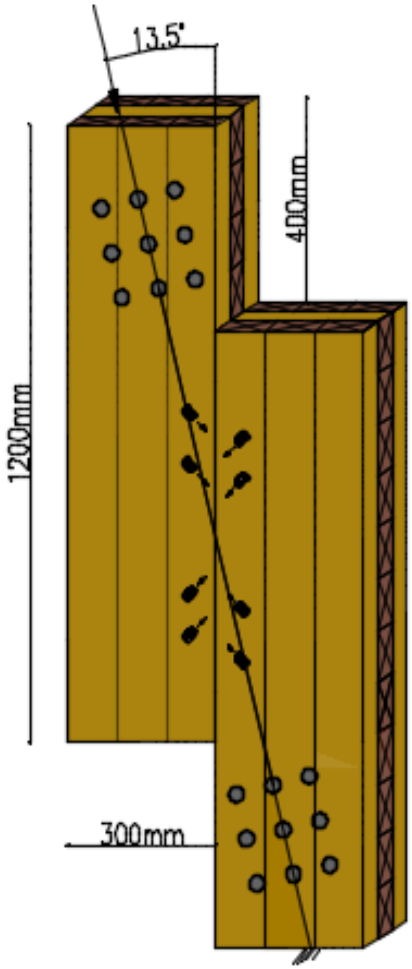



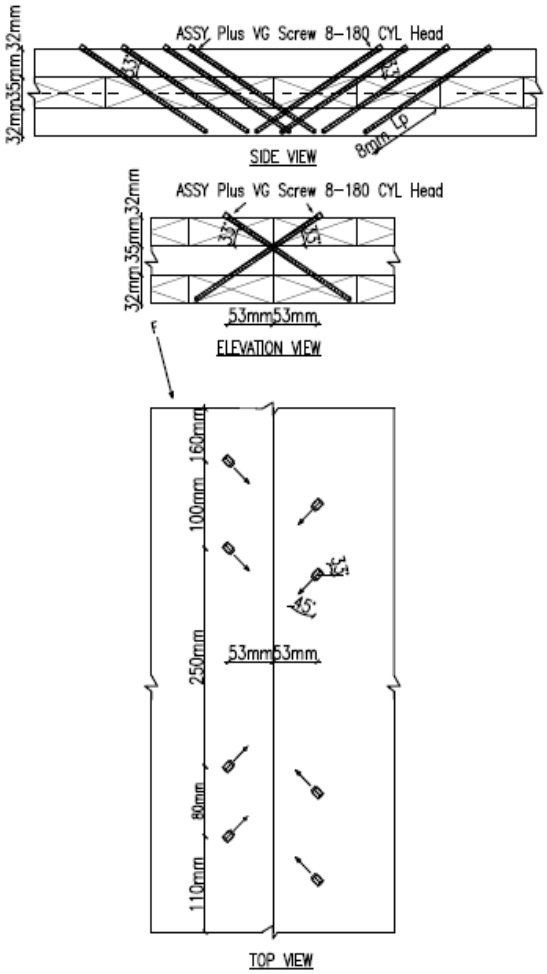
# Test Series #5 : Connection Performance

## Overall Connection Behaviour at Failure

# Test Series #6 : Configuration

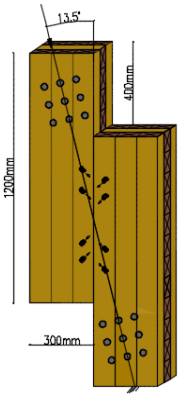
## Butt Joint with STS in Shear and Tension


Courtesy of: Afrin Hossain©

# Test Series #6 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #6 = Butt Joint with STS in Withdrawal Action (α=45° & 33°)

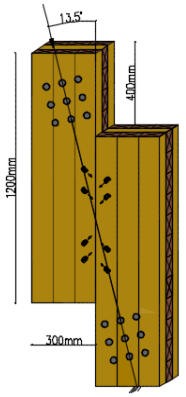
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - BJ @ 33°&45°

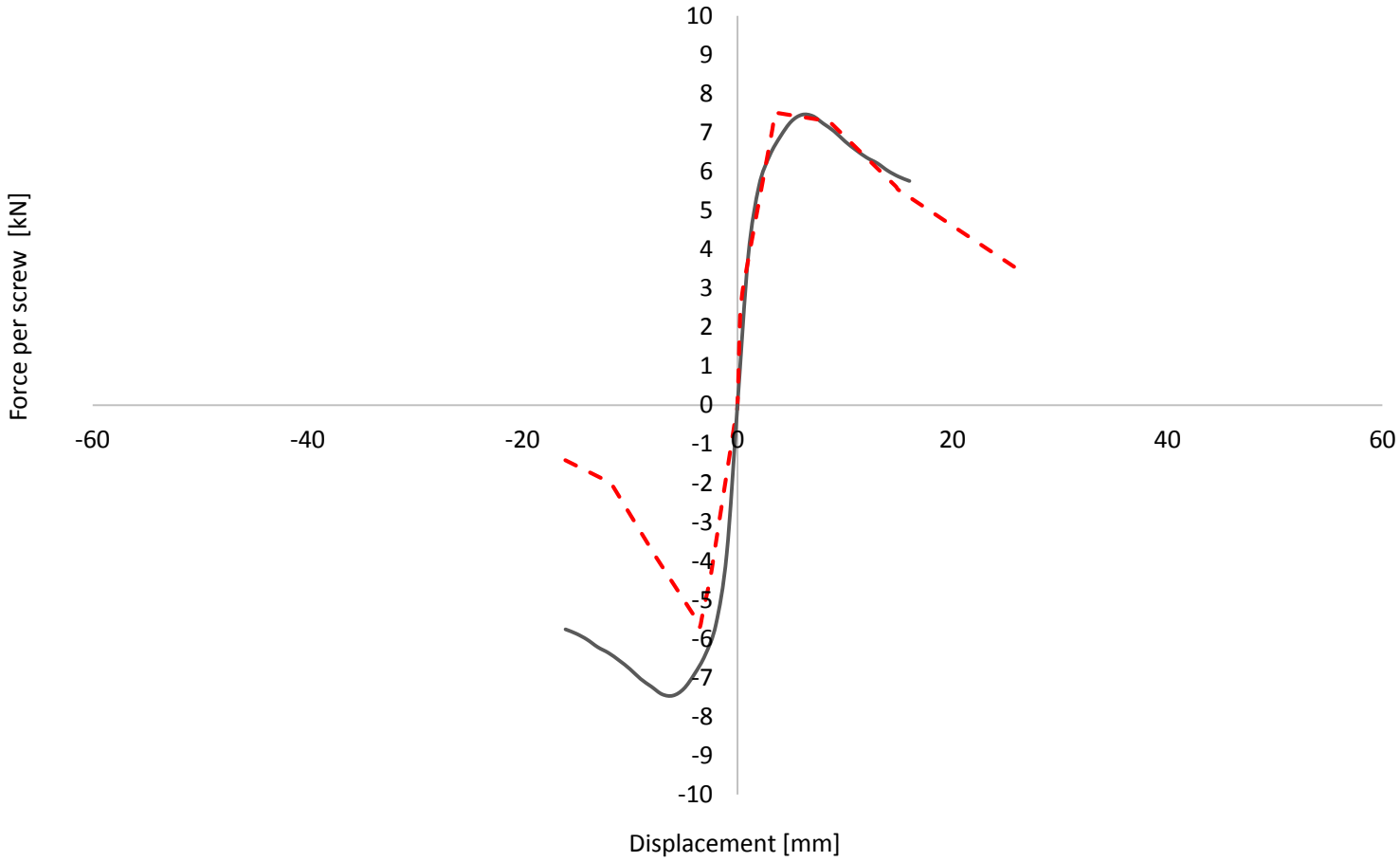
Static Test Results - BJ @ 33°&45°

# Test Series #6 : Backbone Curve



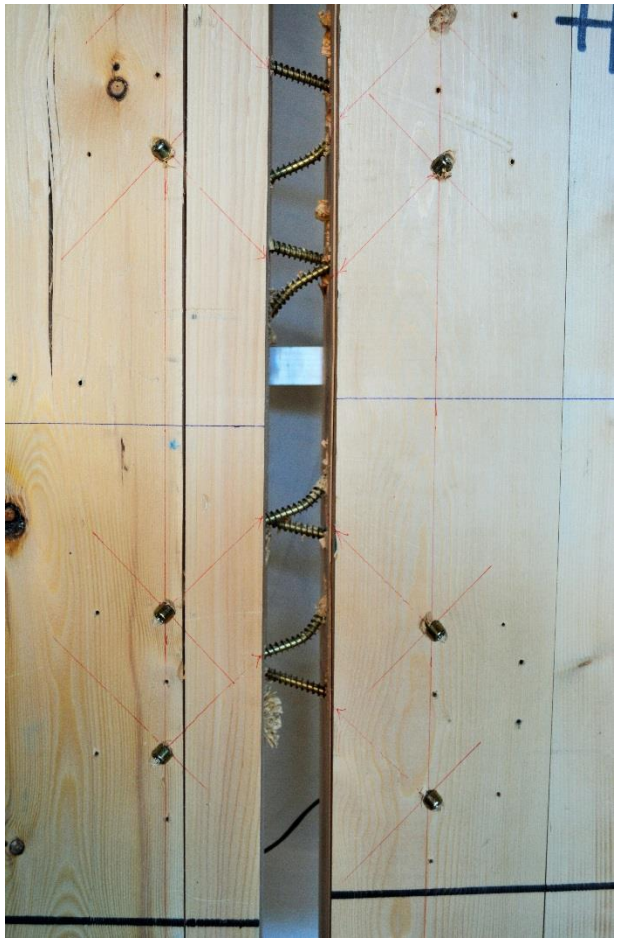

**Static v Dynamic Testing**

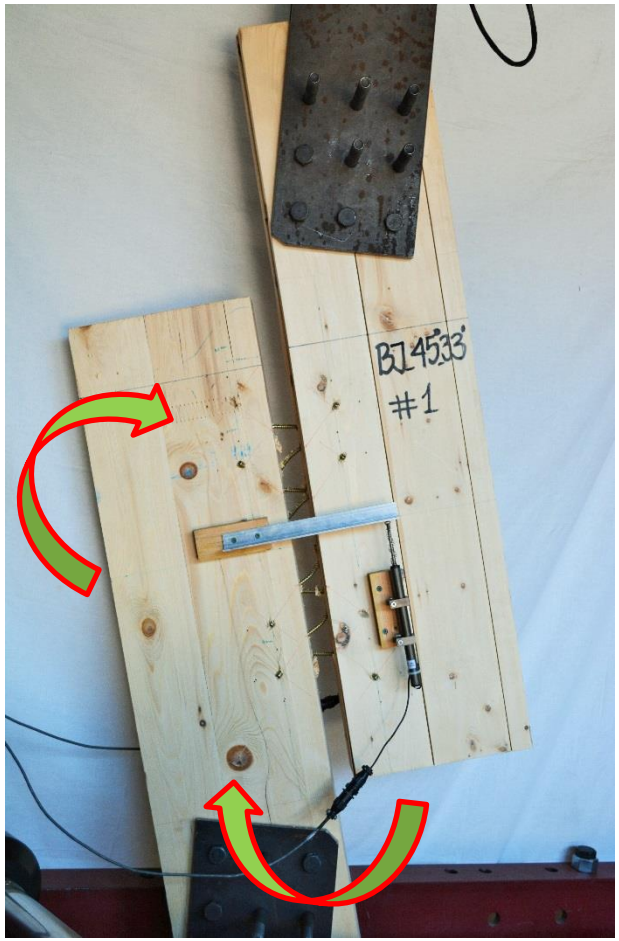
Series #6 = Half Lap Joint with STS in Withdrawal Action (α=45° & 33°)



# Test Series #6 : Connection Performance

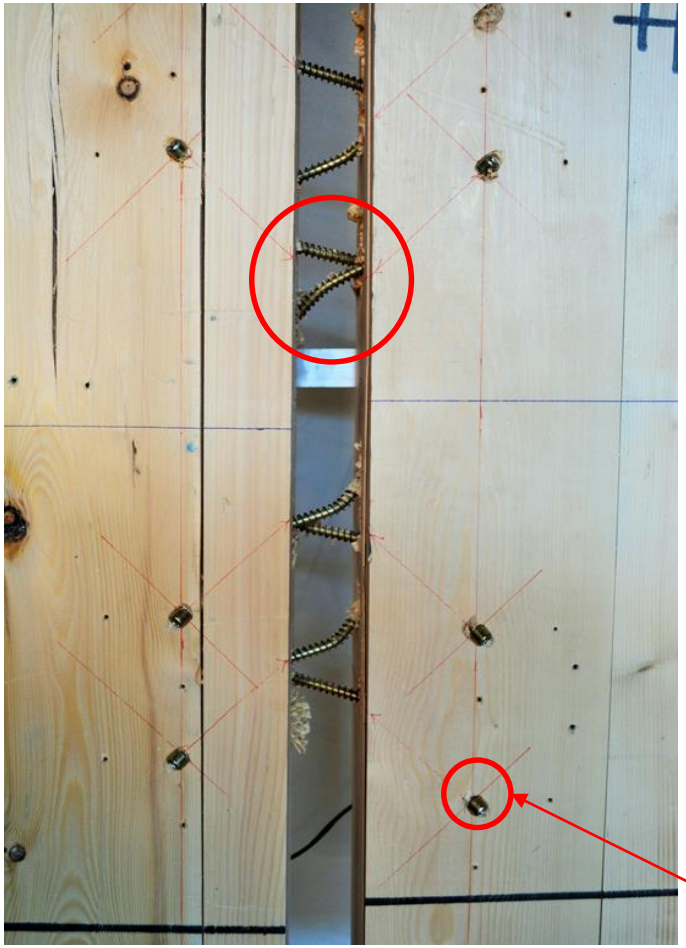
## Overall Connection Behaviour at Failure





# Test Series #6 : Connection Performance

## STS Behaviour at Failure

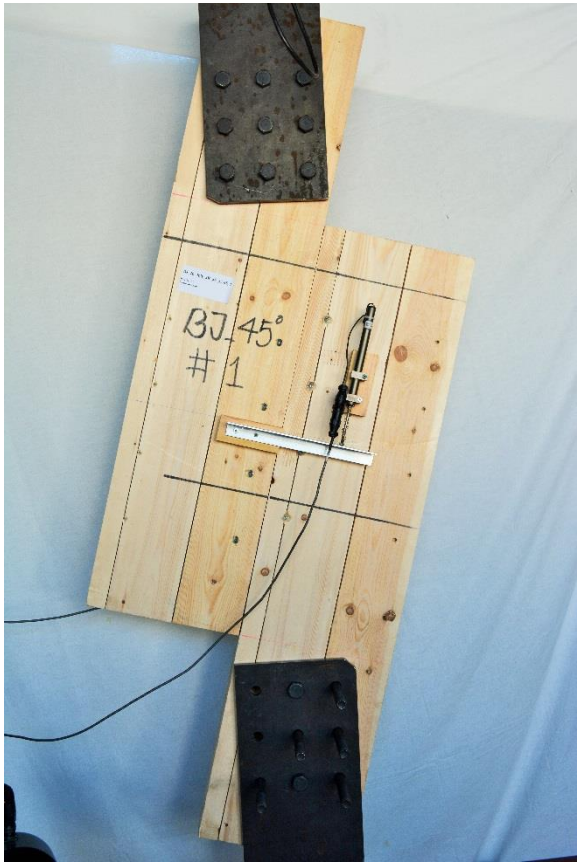


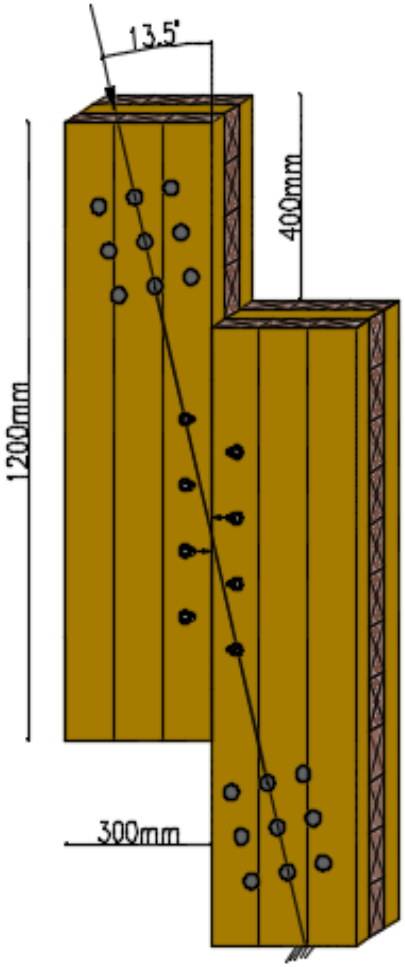
Overall good ductility is observed for tension screw connection

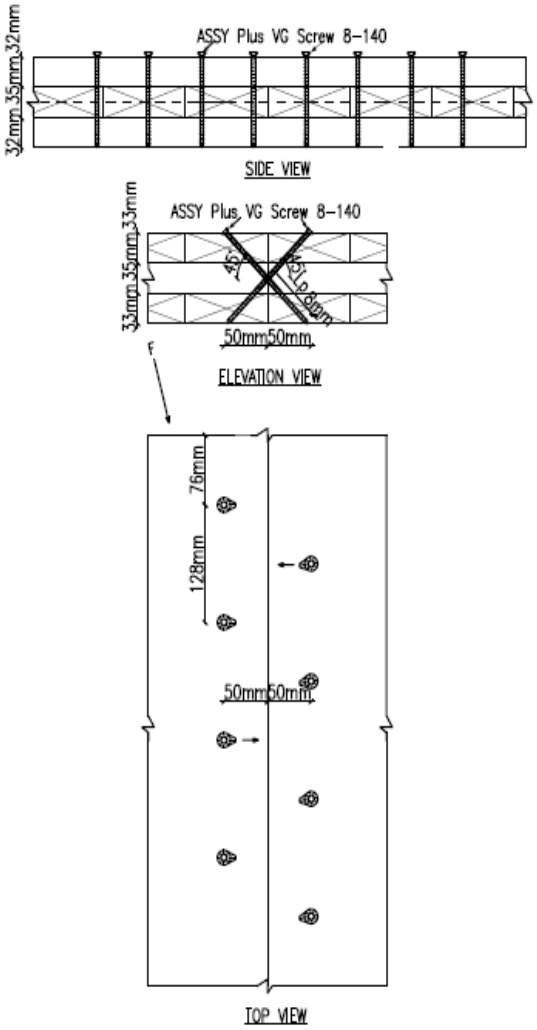
Withdrawal failure and yielding

# Test Series #7 : Configuration

## Butt Joint with STS in Shear

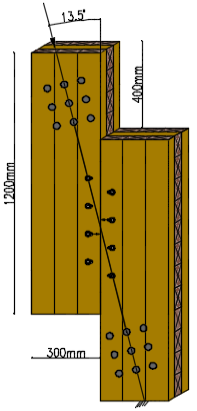



Courtesy of: Afrin Hossain©

# Test Series #7 : Load-Displacement Curve




**Static v Dynamic Testing**

Series #7 = Butt Joint with STS in Shear Action (α=45°)

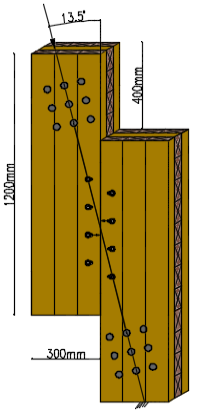
Force per screw [kN]

Displacement [mm]

Cyclic Test Results - BJ @ 45°

Static Test Results - BJ @ 45°

# Test Series #7 : Backbone Curve




**Static v Dynamic Testing**

Series #7 = Half Lap Joint with STS in Shear Action (α=45°)

Force per screw [kN]

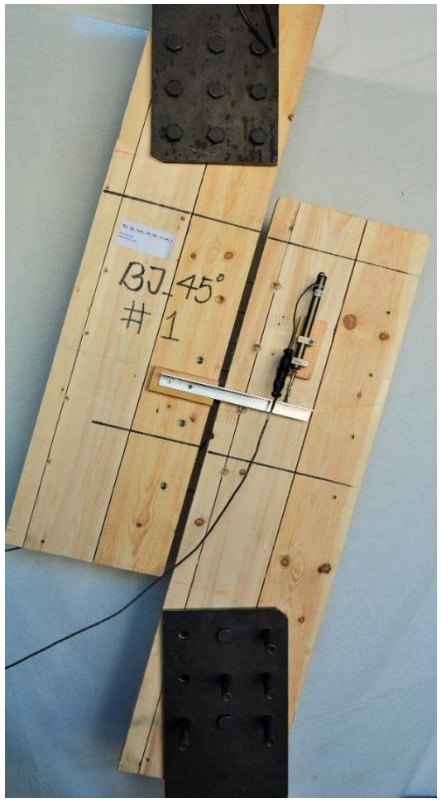
Displacement [mm]

Static Test Results - BJ @ 45°

Backbone Curve

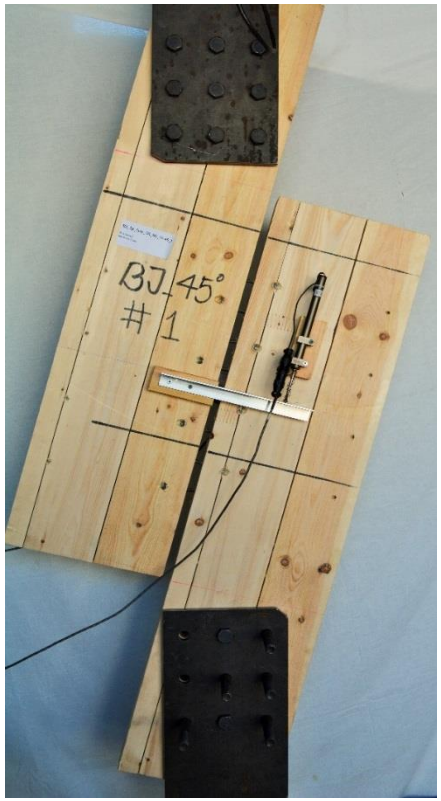
# Test Series #7 : Connection Performance

## Overall Connection Behaviour at Failure



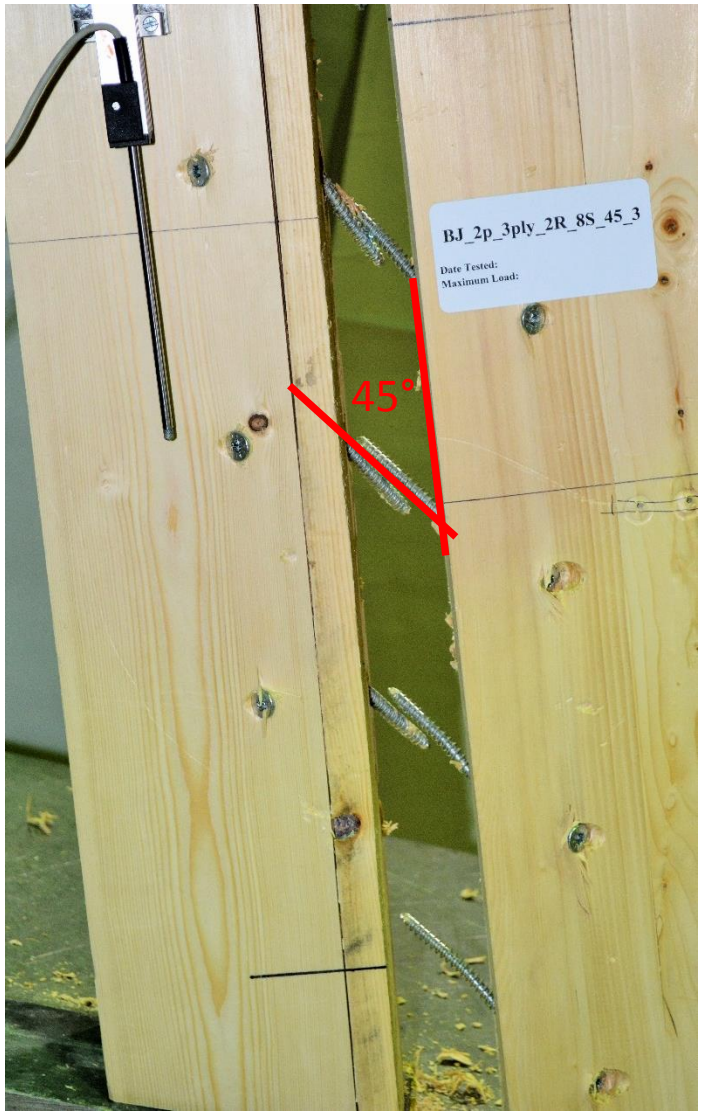

# Test Series #7 : Connection Performance

## Overall Connection Behaviour at Failure



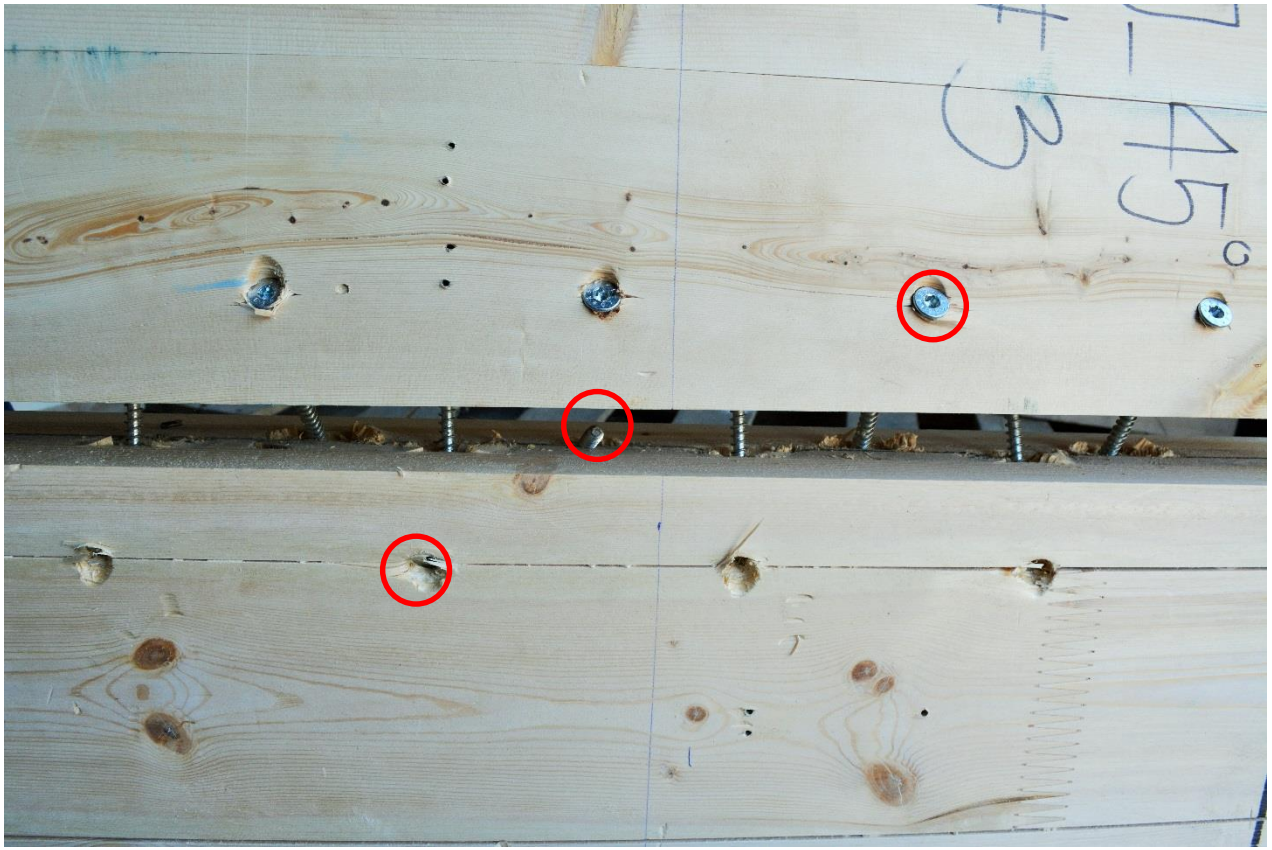


Large displacement

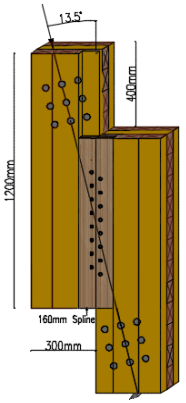


# Test Series #7 : Connection Performance

## STS Behaviour at Failure



# Cyclic Backbone Curve Comparison




**Dynamic Testing**

Comparison of Backbone Curves for Connections

Force per screw [kN]

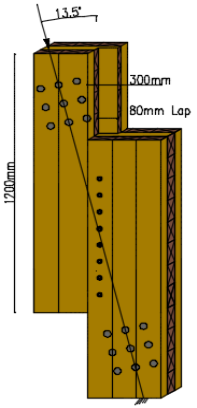
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10

-60 -40 -20 0 20 40 60

Displacement [mm]

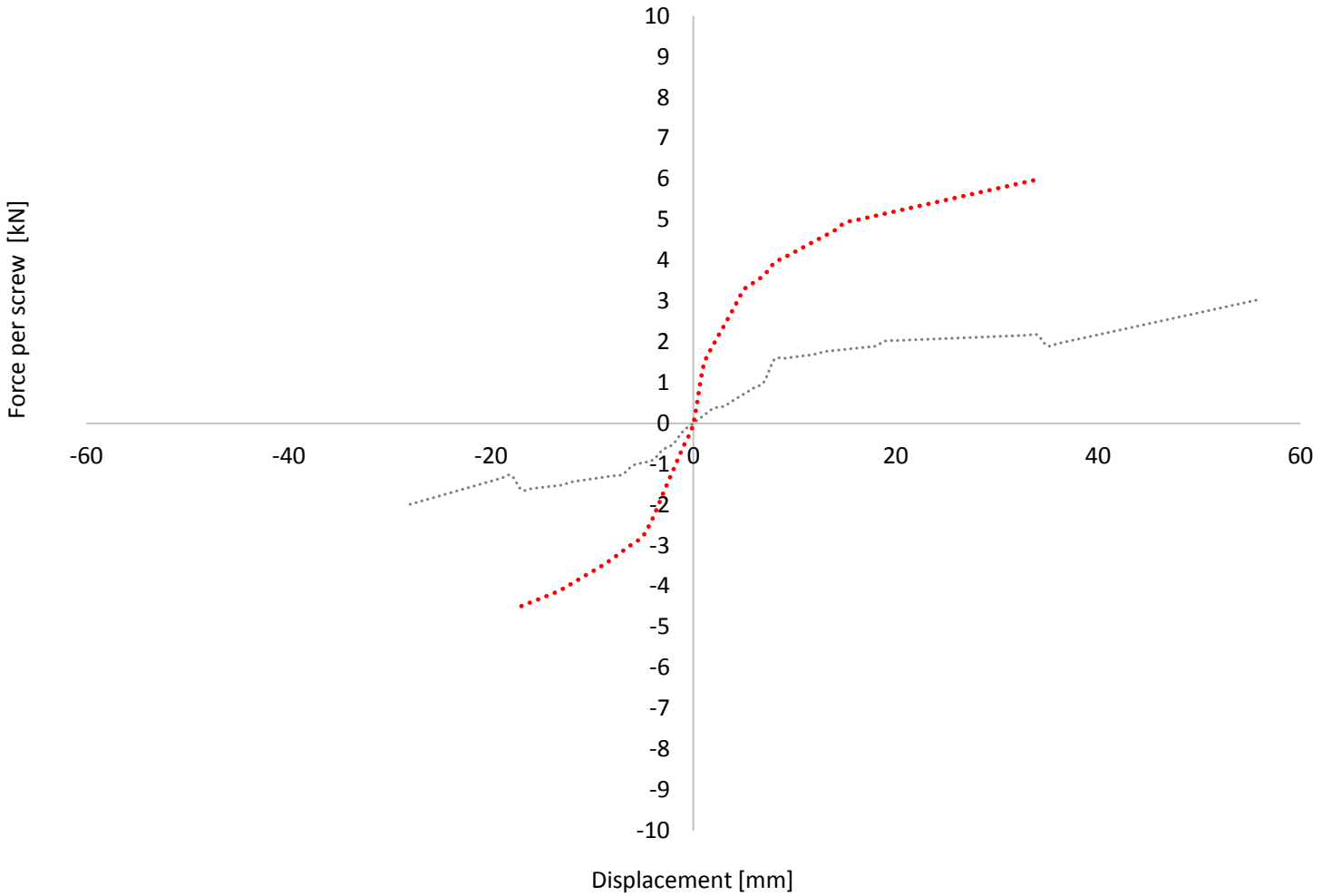
Series 1 - Surface Spline with STS in Shear

# Cyclic Backbone Curve Comparison

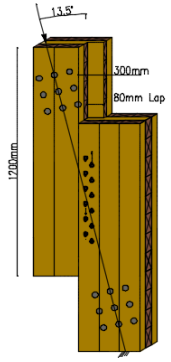



**Dynamic Testing**

Comparison of Backbone Curves for Connections

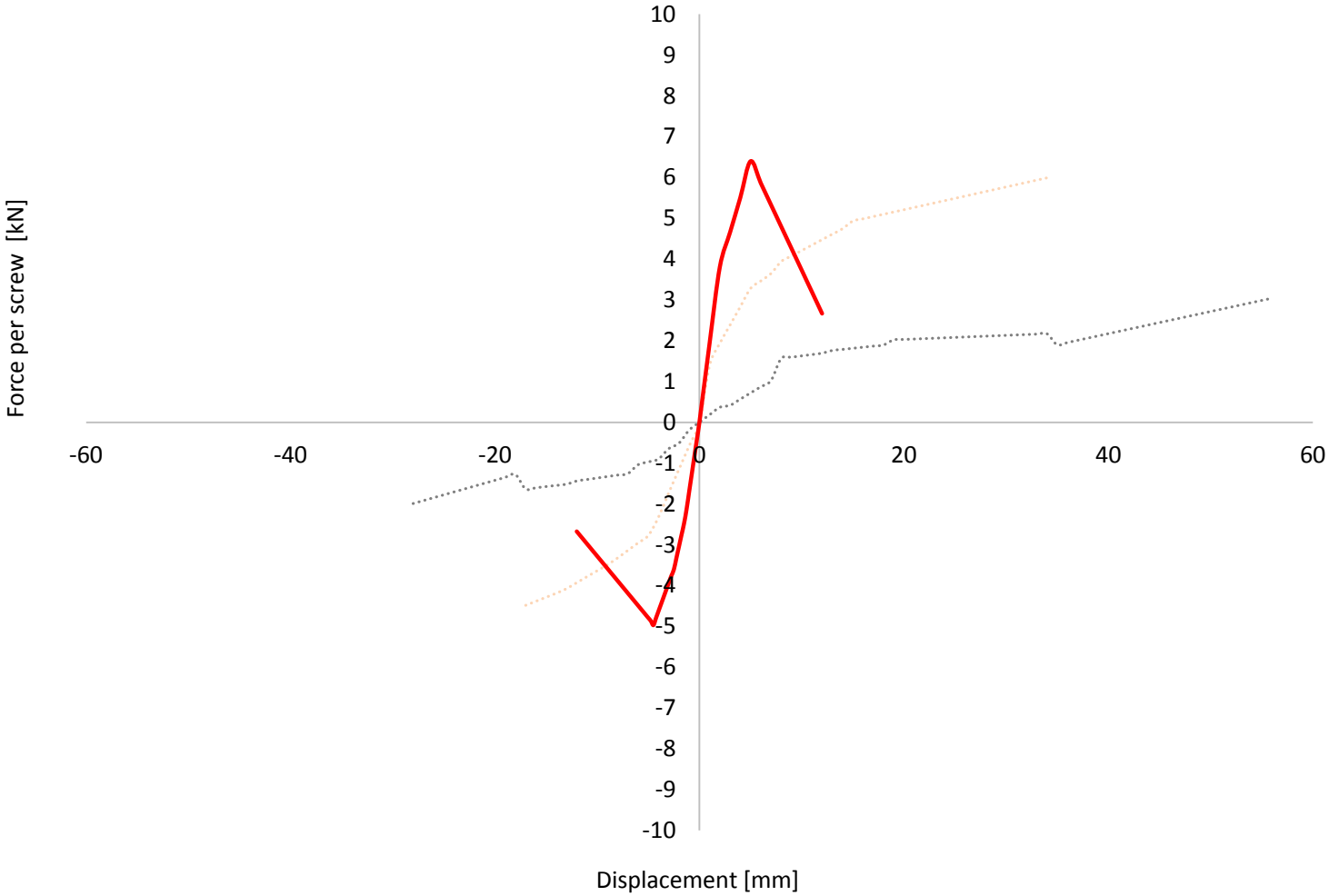


# Cyclic Backbone Curve Comparison

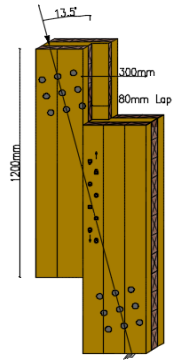



**Dynamic Testing**

Comparison of Backbone Curves for Connections

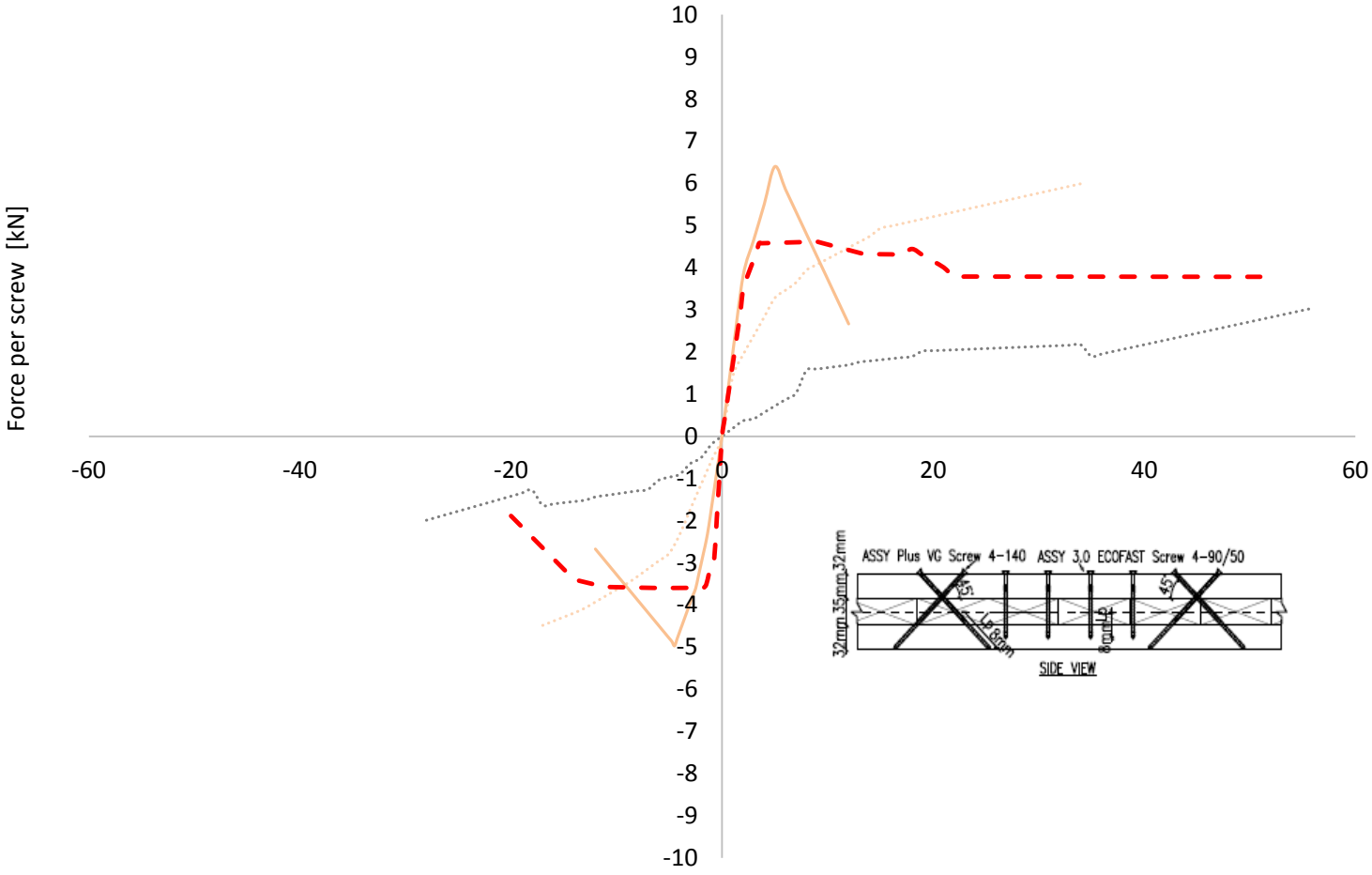


# Cyclic Backbone Curve Comparison




**Dynamic Testing**

Comparison of Backbone Curves for Connections







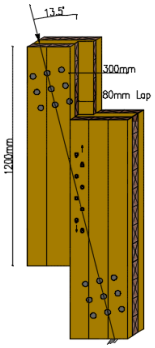
Series 1 - Surface Spline with STS in Shear

Series 2 - Half Lapped with STS in Shear

Series 3 - Half Lapped with STS in Withdr.

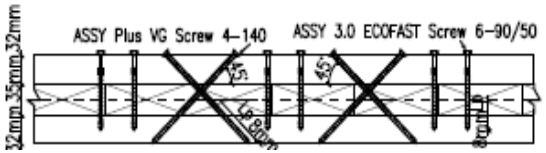
Series 4 - Half Lapped with STS in Shear and Withdr.

# Cyclic Backbone Curve Comparison




**Dynamic Testing**

Comparison of Backbone Curves for Connections




Force per screw [kN]

Displacement [mm]

Series 1 - Surface Spline with STS in Shear

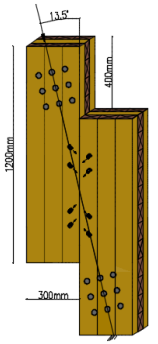
Series 2 - Half Lapped with STS in Shear

Series 3 - Half Lapped with STS in Withdr.

Series 4 - Half Lapped with STS in Shear and Withdr.

Series 5 - Half Lapped with STS in Shear and Withdr.

# Cyclic Backbone Curve Comparison




**Dynamic Testing**

Comparison of Backbone Curves for Connections

Force per screw [kN]

Displacement [mm]

Series 1 - Surface Spline with STS in Shear

Series 2 - Half Lapped with STS in Shear

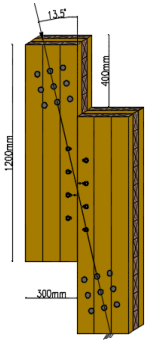
Series 3 - Half Lapped with STS in Withdr.

Series 4 - Half Lapped with STS in Shear and Withdr.

Series 5 - Half Lapped with STS in Shear and Withdr.

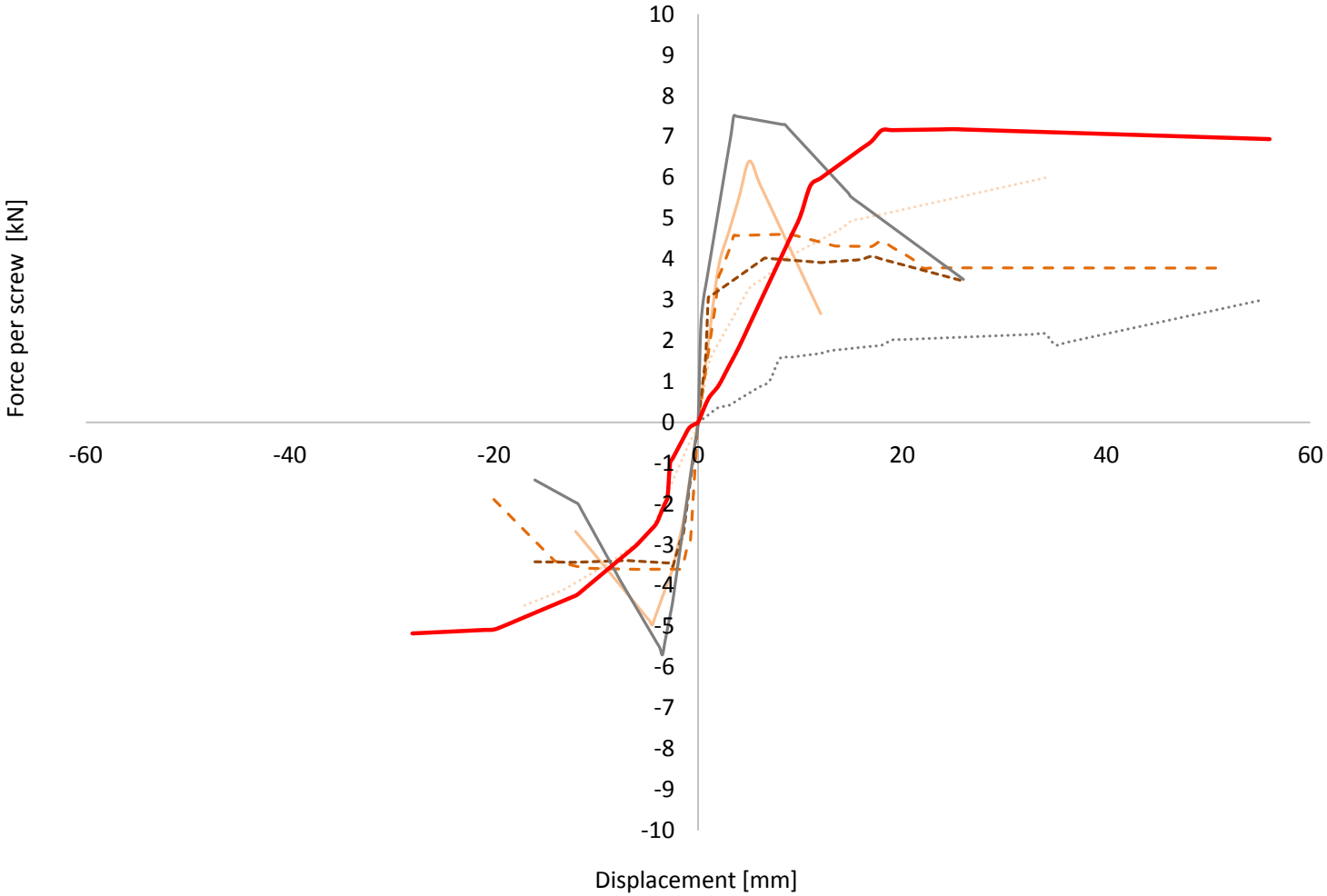
Series 6 - Butt Joint with STS in Withdr.

# Cyclic Backbone Curve Comparison




**Dynamic Testing**

Comparison of Backbone Curves for Connections



# Test Campaign #2 : Cyclic Test Results

## Average Test Results for POSITIVE envelope

| Series | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | Max. Displacement $\Delta_{MAX}$ [mm] | Disp. @ Yield $\Delta_Y$ [mm] | Ductility $\mu$ | Stiffness (10%-90%) $F_Y$ [kN/mm] | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS @ 90 - 3ply | 40.8 | 5.1 | 4.3 | 35.0 | 6.2 | 5.5 | 0.4 | 0.9 |
| Series 2 – LJ @ 90 - 3ply | 44 | 5.5 | 3.9 | 25.3 | 3.5 | 8.8 | 0.5 | 0.6 |
| Series 3 – LJ @ 45 - 3ply | 76.8 | 6.4 | 5.7 | 4.2 | 2.7 | 1.6 | 1.8 | 2.1 |
| Series 4 – LJ @ 45&90 (1) - 3ply | 38.4 | 4.8 | 4.3 | 21.0 | 1.6 | 14.2 | 2.2 | 2.2 |
| Series 5 – LJ @ 45&90 (2) - 3ply | 42 | 4.2 | 3.8 | 11.4 | 1.3 | 8.4 | 2.7 | 3.4 |
| Series 6 – BJ @ 33&45 - 3ply | 63.2 | 7.9 | 7.0 | 5.5 | 2.0 | 3.1 | 2.1 | 2.7 |
| Series 7 – BJ @ 45 - 3ply | 59.2 | 7.4 | 6.5 | 34 | 10 | 3.8 | 0.5 | 0.7 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimens
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Cyclic Test Results

## Average Test Results for NEGATIVE envelope

| Series | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | Max. Displacement $\Delta_{MAX}$ [mm] | Disp. @ Yield $\Delta_Y$ [mm] | Ductility $\mu$ | Stiffness (10%-90%) $F_Y$ [kN/mm] | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS @ 90 - 3ply | 30.4 | 3.8 | 3.1 | 23 | 6.5 | 3.8 | 0.3 | 0.5 |
| Series 2 – LJ @ 90 - 3ply | 35.2 | 4.4 | 3.6 | 18 | 4.8 | 3.7 | 0.4 | 0.7 |
| Series 3 – LJ @ 45 - 3ply | 62.4 | 5.2 | 4.7 | 3.9 | 1.6 | 2.3 | 2.7 | 2.4 |
| Series 4 – LJ @ 45&90 (1) - 3ply | 32 | 4.0 | 3.4 | 14 | 1.1 | 11.4 | 2.9 | 3.9 |
| Series 5 – LJ @ 45&90 (2) - 3ply | 35 | 3.5 | 3.2 | 14 | 1.3 | 11.7 | 1.8 | 1.6 |
| Series 6 – BJ @ 33&45 - 3ply | 40 | 5.5 | 4.5 | 2.9 | 1.6 | 2.3 | 2.1 | 2.3 |
| Series 7 – BJ @ 45 - 3ply | 41.6 | 5.2 | 5.7 | 27.0 | 7.0 | 3.8 | 0.4 | 0.7 |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimens
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Cyclic Test Results

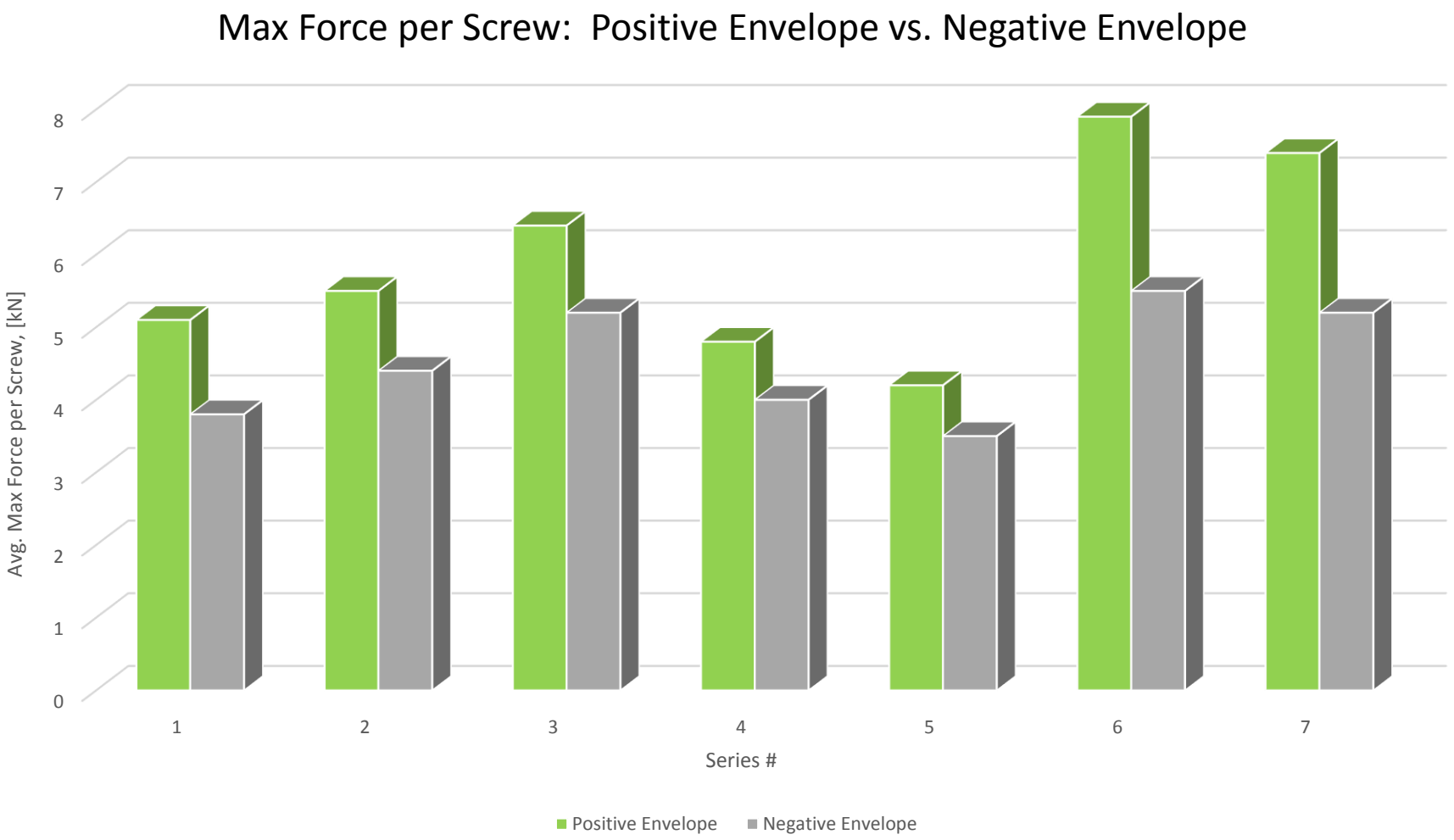
## AVERAGE Test Results

| Series | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | Max. Displacement $\Delta_{MAX}$ [mm] | Disp. @ Yield $\Delta_Y$ [mm] | Ductility $\mu$ | Stiffness (10%-90%) $F_Y$ [kN/mm] | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] |
|---|---|---|---|---|---|---|---|---|
| Series 1 – SS @ 90 - 3ply | 35.6 | 4.5 | 3.7 | 28.9 | 6.4 | 4.7 | 0.4 | 0.7 |
| Series 2 – LJ @ 90 - 3ply | 40 | 5.0 | 3.8 | 21.5 | 4.2 | 5.5 | 0.5 | 0.7 |
| Series 3 – LJ @ 45 - 3ply | 69.6 | 5.8 | 5.2 | 4.1 | 2.2 | 2.0 | 2.3 | 2.3 |
| Series 4 – LJ @ 45&90 (1) - 3ply | 35.2 | 4.4 | 3.9 | 17.4 | 1.4 | 12.1 | 2.6 | 3.1 |
| Series 5 – LJ @ 45&90 (2) - 3ply | 38 | 3.8 | 3.5 | 12.7 | 1.3 | 9.9 | 2.3 | 2.5 |
| Series 6 – BJ @ 33&45 - 3ply | 53.6 | 6.7 | 5.8 | 4.2 | 1.8 | 2.5 | 2.1 | 2.5 |
| Series 7 – BJ @ 45 - 3ply | 50.4 | 6.3 | 5.4 | 30.4 | 8.7 | 3.5 | 0.5 | 0.7 |

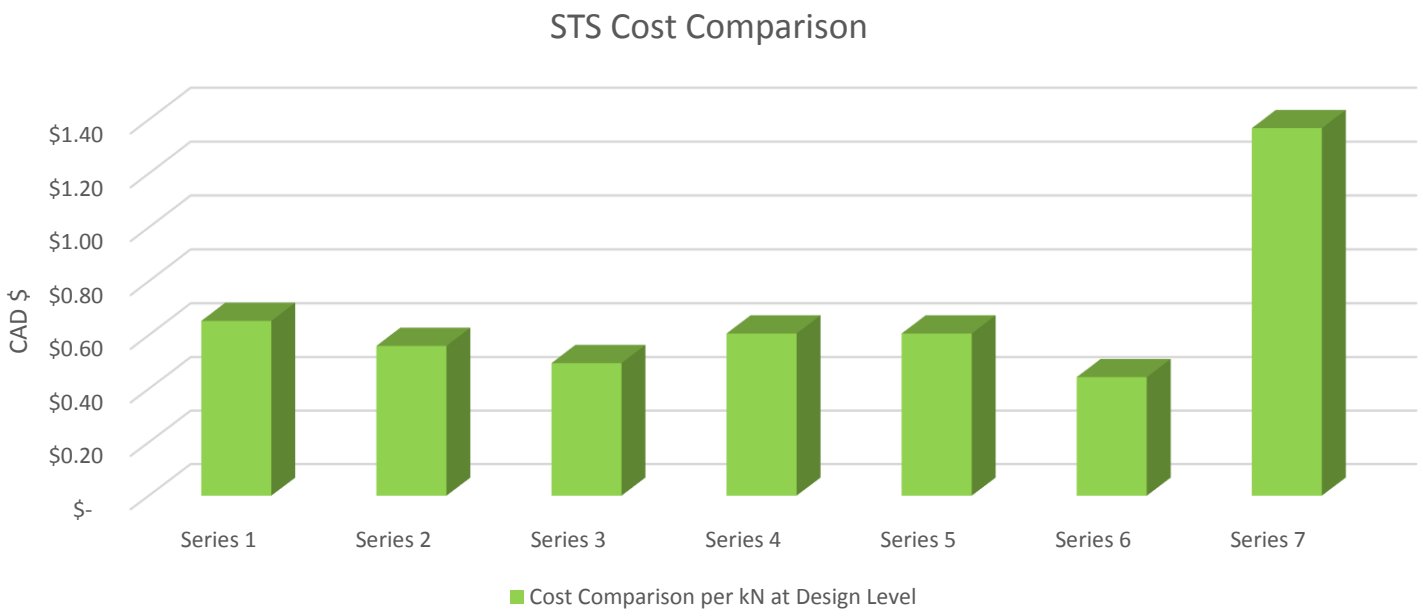
- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimens
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

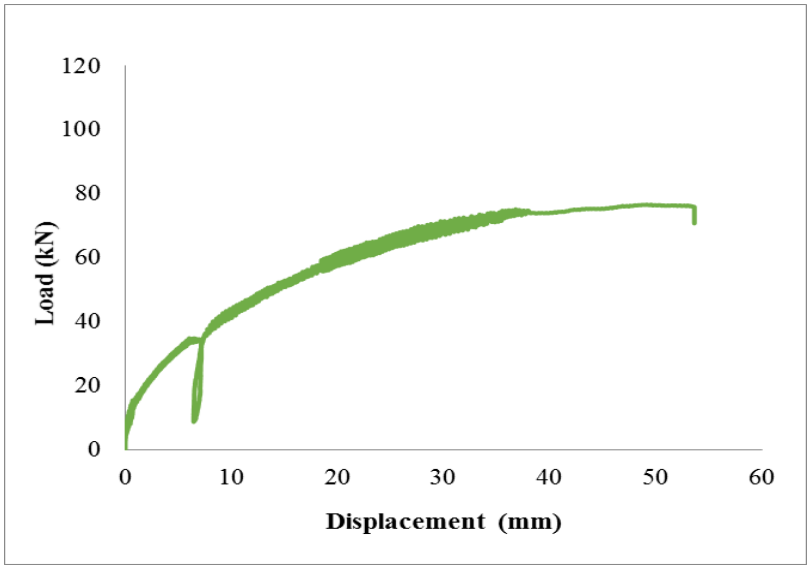
# Test Campaign #2 : Cyclic Test Results



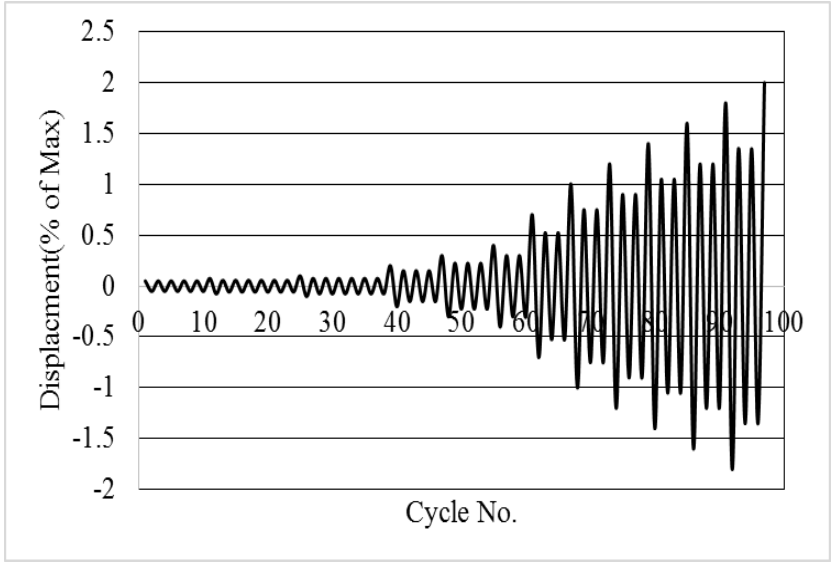
# Test Campaign #2: STS Cost Analysis



# Static vs Cyclic Performance




VS



# Test Campaign #2 : Static vs Cyclic

## Comparison of Connection Capacity

| Series | STATIC LOADING | | | CYCLIC LOADING | | | **Reduction** of Capacity due to Cyclic Loading | |
|---|---|---|---|---|---|---|---|---|
| | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | $F_{MAX}$ | $F_Y$ |
| Series 1 – SS @ 90 - 3ply | 52.0 | 6.5 | 5.5 | 35.6 | 4.5 | 3.7 | 31% | 33% |
| Series 2 – LJ @ 90 - 3ply | 53.6 | 6.8 | 5.0 | 39.6 | 5.0 | 3.8 | 26% | 24% |
| Series 3 – LJ @ 45 - 3ply | 86.4 | 7.2 | 5.8 | 69.6 | 5.8 | 5.2 | 19% | 10% |
| Series 4 – LJ @ 45&90 (1) - 3ply | 53.6 | 6.7 | 4.4 | 35.2 | 4.4 | 3.9 | 34% | 11% |
| Series 5 – LJ @ 45&90 (2) - 3ply | 49 | 4.9 | 3.8 | 38.5 | 3.8 | 3.5 | 22% | 8% |
| Series 6 – BJ @ 33&45 - 3ply | 62.4 | 7.8 | 6.7 | 53.6 | 6.7 | 5.8 | 14% | 13% |
| Series 7 – BJ @ 45 - 3ply | 54.4 | 6.8 | 6.5 | 50.4 | 6.3 | 5.4 | 7% | 17% |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimen
- $F_{max}$= Max. Force ; $F_Y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_Y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Static vs Cyclic

## Comparison of Connection Capacity

| Series | STATIC LOADING | | | CYCLIC LOADING | | | **Reduction** of Capacity due to Cyclic Loading | |
|---|---|---|---|---|---|---|---|---|
| | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | Total Max Force $F_{MAX}$ [kN] | Max Force $F_{MAX}$ [kN] | Yield Force $F_Y$ [kN] | $F_{MAX}$ | $F_Y$ |
| Series 1 – SS @ 90 - 3ply | 52.0 | 6.5 | 5.5 | 35.6 | 4.5 | 3.7 | 31% | 33% |
| Series 2 – LJ @ 90 - 3ply | 53.6 | 6.8 | 5.0 | 39.6 | 5.0 | 3.8 | 26% | 24% |
| Series 3 – LJ @ 45 - 3ply | 86.4 | 7.2 | 5.8 | 69.6 | 5.8 | 5.2 | 19% | 10% |
| Series 4 – LJ @ 45&90 (1) - 3ply | 53.6 | 6.7 | 4.4 | 35.2 | 4.4 | 3.9 | 34% | 11% |
| Series 5 – LJ @ 45&90 (2) - 3ply | 49 | 4.9 | 3.8 | 38.5 | 3.9 | 3.5 | 22% | 8% |
| Series 6 – BJ @ 33&45 - 3ply | 62.4 | 7.8 | 6.7 | 53.6 | 6.7 | 5.8 | 14% | 13% |
| Series 7 – BJ @ 45 - 3ply | 54.4 | 6.8 | 6.5 | 50.4 | 6.3 | 5.4 | 7% | 17% |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimens
- $F_{max}$= Max. Force ; $F_Y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; μ= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_Y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Static vs Cyclic

## Comparison of Connection Performance

| Series | STATIC LOADING | | | CYCLIC LOADING | | | **Reduction** of Ductility and Stiffness due to Cyclic Loading | |
|---|---|---|---|---|---|---|---|---|
| | Max. Displacement $\Delta_{MAX}$ [mm] | Ductility $\mu$ | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] | Max. Displacement $\Delta_{MAX}$ [mm] | Ductility $\mu$ | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] | Ductility | $K_{0.4}$ |
| Series 1 – SS @ 90 - 3ply | 46.8 | 5.4 | 1.3 | 28.9 | 4.6 | 0.7 | 15% | 46% |
| Series 2 – LJ @ 90 - 3ply | 25.7 | 7.1 | 2.2 | 21.5 | 5.5 | 0.7 | 23% | 68% |
| Series 3 – LJ @ 45 - 3ply | 4.1 | 3.4 | 14.4 | 4.1 | 2.0 | 2.3 | 41% | 84% |
| Series 4 – LJ @ 45&90 (1) - 3ply | 19.5 | 19.5 | 11.4 | 17.4 | 12.8 | 3.1 | 34% | 73% |
| Series 5 – LJ @ 45&90 (2) - 3ply | 24.7 | 17.6 | 8.3 | 12.7 | 9.7 | 2.5 | 45% | 70% |
| Series 6 – BJ @ 33&45 - 3ply | 6.5 | 6.5 | 10.4 | 4.2 | 2.3 | 2.5 | 65% | 76% |
| Series 7 – BJ @ 45 - 3ply | 39.2 | 3.8 | 1 | 30.4 | 3.6 | 0.7 | 6% | 30% |

- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimen
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Static vs Cyclic

## Comparison of Connection Performance

| Series | STATIC LOADING | | | CYCLIC LOADING | | | **Reduction** of Ductility and Stiffness due to Cyclic Loading | |
|---|---|---|---|---|---|---|---|---|
| | Max. Displacement $\Delta_{MAX}$ [mm] | Ductility $\mu$ | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] | Max. Displacement $\Delta_{MAX}$ [mm] | Ductility $\mu$ | Stiffness $K_{0.4}$ (10%-40%) $F_{MAX}$ [kN/mm] | Ductility | $K_{0.4}$ |
| Series 1 – SS @ 90 - 3ply | 46.8 | 5.4 | 1.3 | 28.9 | 4.6 | 0.7 | 15% | 46% |
| Series 2 – LJ @ 90 - 3ply | 25.7 | 7.1 | 2.2 | 21.5 | 5.5 | 0.7 | 23% | 68% |
| Series 3 – LJ @ 45 - 3ply | 4.1 | 3.4 | 14.4 | 4.1 | 2.0 | 2.3 | 41% | 84% |
| Series 4 – LJ @ 45&90 (1) - 3ply | 19.5 | 19.5 | 11.4 | 17.4 | 12.8 | 3.1 | 34% | 73% |
| Series 5 – LJ @ 45&90 (2) - 3ply | 24.7 | 17.6 | 8.3 | 12.7 | 9.7 | 2.5 | 45% | 70% |
| Series 6 – BJ @ 33&45 - 3ply | 6.5 | 6.5 | 10.4 | 4.2 | 2.3 | 2.5 | 65% | 76% |
| Series 7 – BJ @ 45 - 3ply | 39.2 | 3.8 | 1 | 30.4 | 3.6 | 0.7 | 6% | 30% |

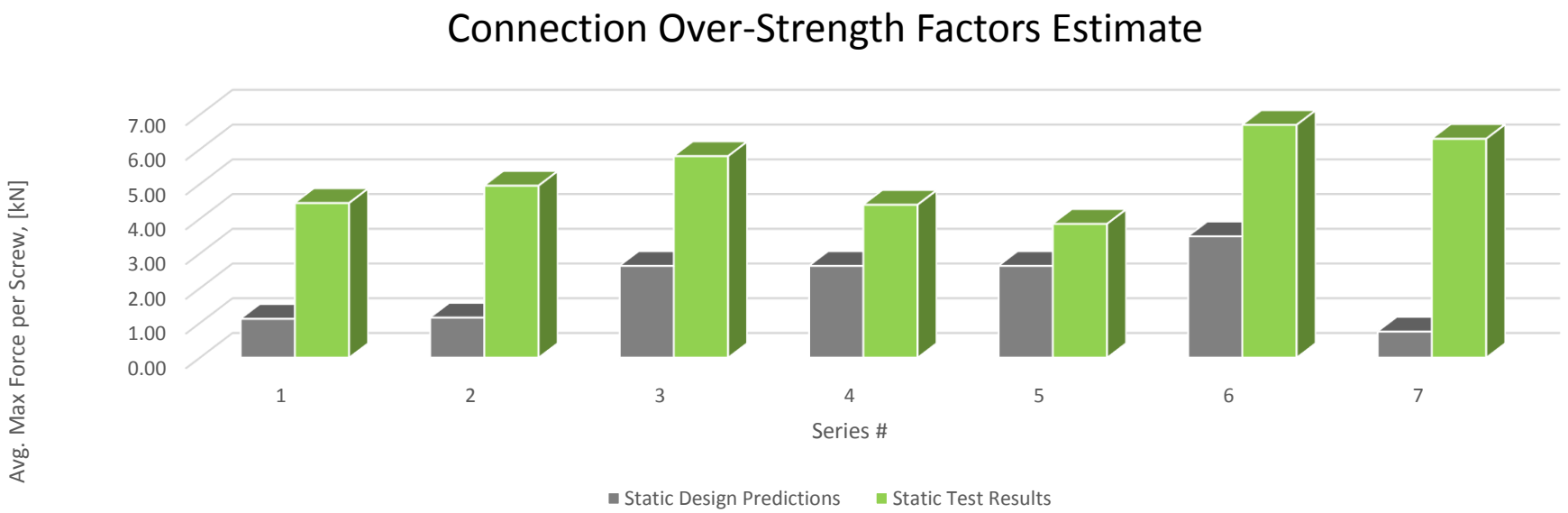
- **Total $F_{MAX}$ value is per shear plane ; All other values are per screw**
- Average measurements out of 3 specimens
- $F_{max}$= Max. Force ; $F_y$= Yield Force ; $\Delta_{MAX}$= Max Displ. ; $\Delta_y$= Displ. at Yield ; $\mu$= Ductility ; $K_{0.4}$= stiffness calculated at 10% - 40% of $F_{max}$
- Ductility = (Displ. @ $F_{max}$) / (Displ. @ $F_y$)
- Yield Force and ductility were calculated following Equivalent Energy Elastic-Plastic

(EEEP) Curves as per ASTM 2126-09

# Test Campaign #2 : Static vs Cyclic

## Comparison between Design & Cyclic Test Data:

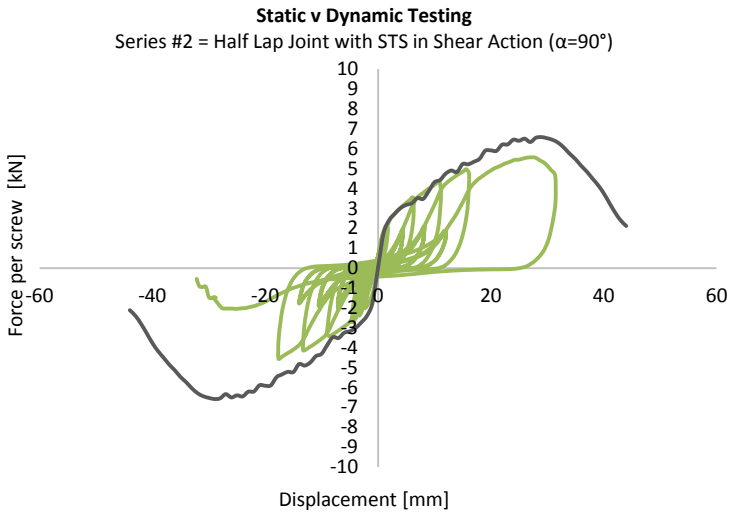
| Label | Type | $F_{MAX}$ [kN] | Predicted* $F_{MAX}$ [kN] | $\Delta_{MAX}$ [mm] | $K_{0.4}$ [kN/mm] | Over-Strength Ratio |
|---|---|---|---|---|---|---|
| Series 1 – SS_90_3ply | Surface Spline Joint | 4.5 | 1.12 | 28.9 | 0.7 | 4.0 |
| Series 2 – LJ_90_3ply | Half Lapped Joint | 5.0 | 1.15 | 21.5 | 0.7 | 4.3 |
| Series 3 – LJ_45_3ply | | 5.8 | 2.64 | 4.1 | 2.3 | 2.2 |
| Series 4 – LJ_45/90_3ply_WSSW | | 4.4 | | 17.4 | 3.1 | 1.7 |
| Series 5 – LJ_45/90_3ply_SWSWS | | 3.8 | | 12.7 | 2.5 | 1.5 |
| Series 6 – BJ_33/45_3ply | Butt Joint | 6.7 | 3.49 | 4.2 | 2.5 | 1.9 |
| Series 7 – BJ_45_3ply | | 6.3 | 0.75 | 30.4 | 0.7 | 8.4 |

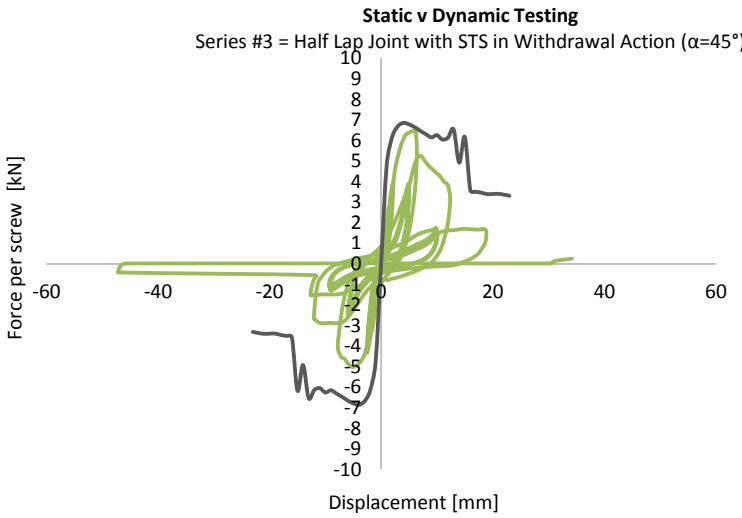


# Conclusions

1. Tests indicate ductile performance with STS in shear action

2. Tests indicate more brittle performance with STS in withdrawal, higher initial stiffness and ultimate capacity



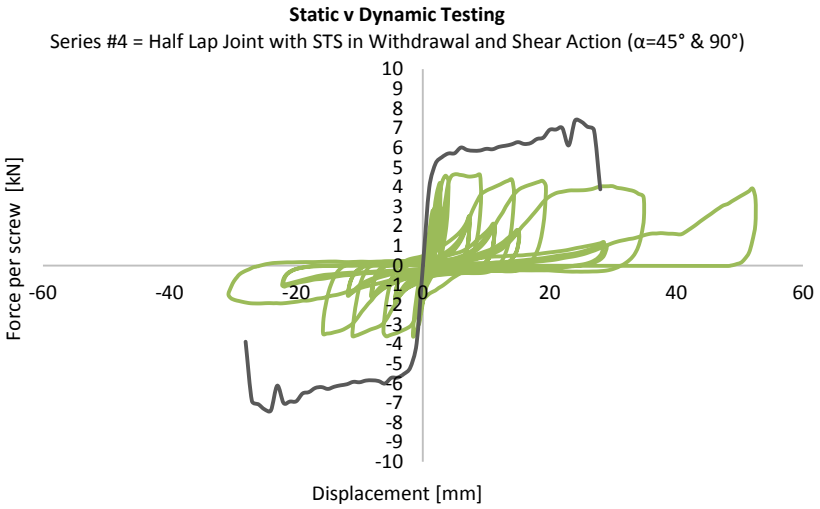



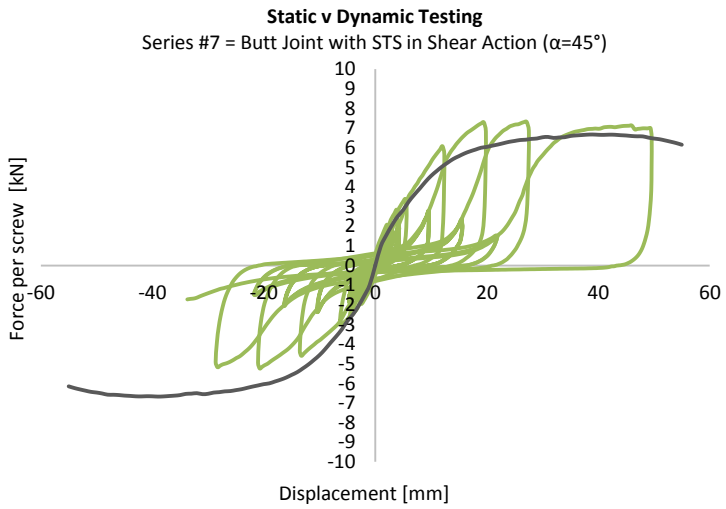
# Conclusions

3. Tests indicate moderate performance with STS in combined action

4. Tests indicate reduction in capacity and stiffness in cyclic tests

5. Tests indicate Butt Joints exhibit good performance under cyclic loading

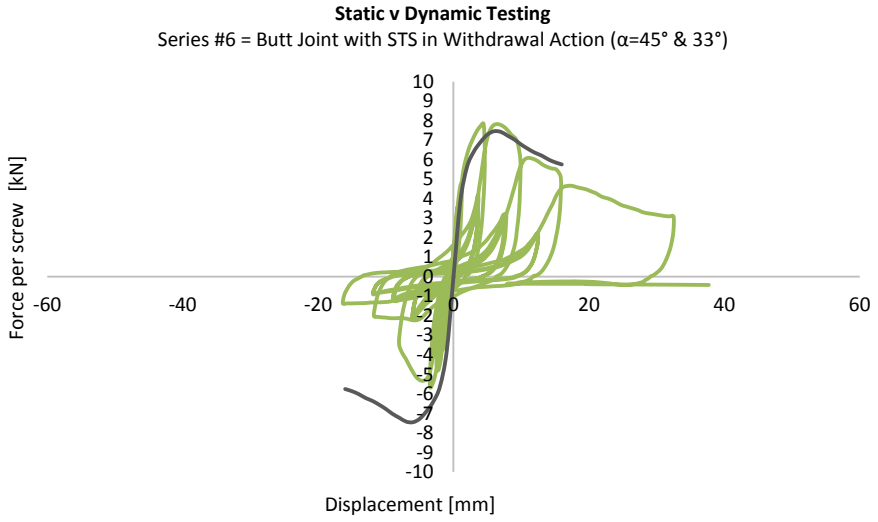


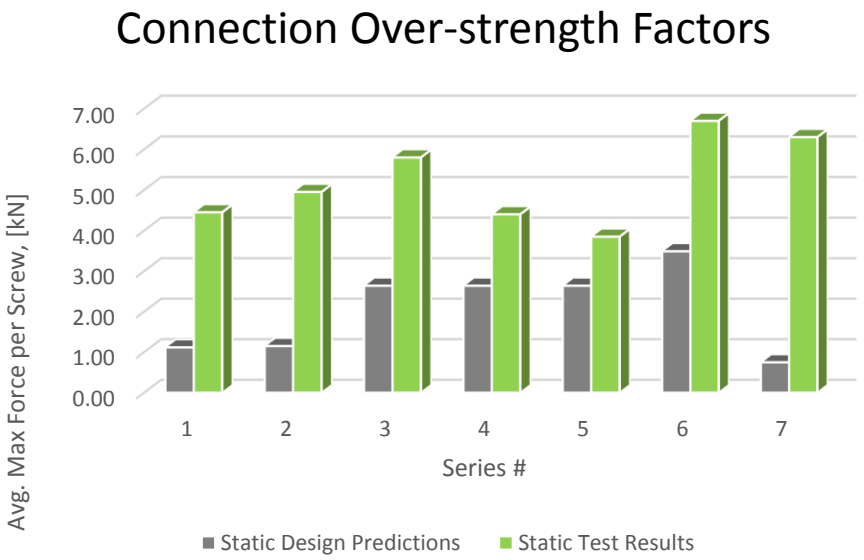



# Conclusions

6. In addition, Butt Joints with tension STS exhibited minimal reduction of capacity and stiffness from static results in linear elastic range

7. Testing indicates the conservative nature of over-strength factors even between static design approach and cyclic results



# Outlook

1. Group action factors need more testing - no conclusive results
2. Dynamic confirmation testing needs to address the created perpendicular force component and its impact
3. Impact of difference in fasteners to butt joint performance, partially threaded or fully threaded, to be investigated
4. Medium scale testing with 4’x8’ CLT panels i.e. shear wall
5. Investigating fastener diameter influence

$$R_k = k_1 \cdot k_2 \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,1,k} \cdot d} + \Delta R_k$$

$\Delta Rk \approx 0.25 \cdot Pwr$

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# THANK YOU for attending

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