

Influence of Shelf Angle Orientations, Connections, and Ties on the Serviceability of Masonry Veneer Systems

The Masonry Society's 2025 Annual Meeting
Oklahoma City
October 16, 2025

Cory Scott
M.Sc. Student
University of Alberta

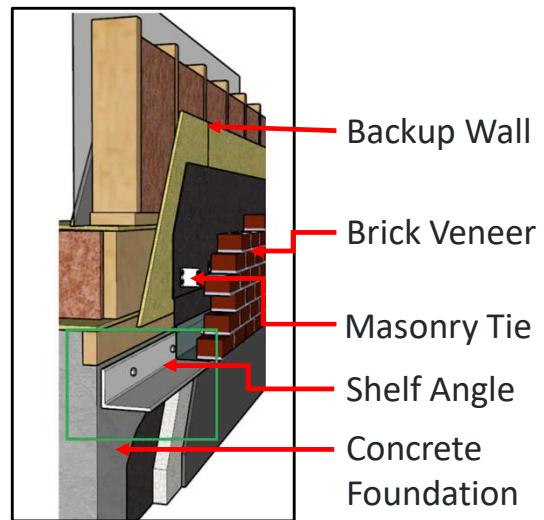


1

Brick Masonry Veneer Systems



Credit: Alberta Masonry Council

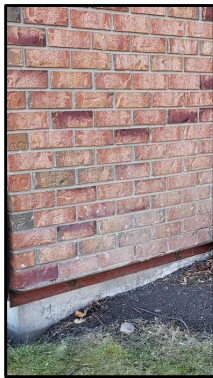


2

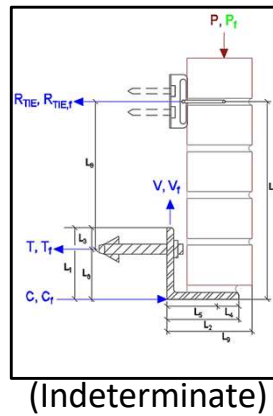
Design Challenges

Masonry veneer shelf angle connection design has proved challenging due to:

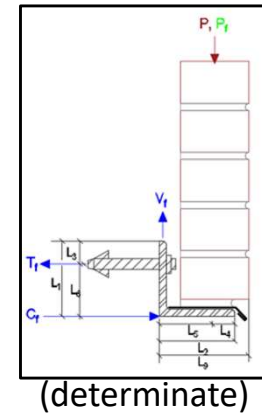
- Limited Experimental Data
- No Standardized Design Provisions
- Use of Mechanics-Based Approach



Simplify



Simplify



3

Configurations & Orientations

To further complicate developing a standardized design provision, many options for masonry veneer connections exist:



Knife Plate



Inverted Knife Plate



Directly Bolted

4

Veneer Connection Experimental Program

To address the lack of experimental data, we have embarked on a preliminary experimental program involving:

- 24 masonry veneer shelf angles connected to concrete foundations.
- Varied tie type, backup wall, veneer presence, and connection detail.



5

Veneer Connection Variation

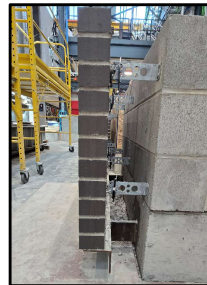
Specimen Variation Nomenclature: Connection Type-Tie Type-Backup Wall



KP-HRT-CMU



DB-CST-SPF



KPI-HRT-CMU



DB-SRT-SPF



KP-NV




DB-NV


6

Veneer Connection Variation

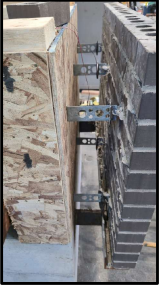
Specimen Variation Nomenclature: Connection Type-Tie Type-Backup Wall




KP-SRT-SS




DB-CST-SPF:NB/FLS




KP-SRT-SPF



DBI-CST-SPF



DB-CST-SPF:NB



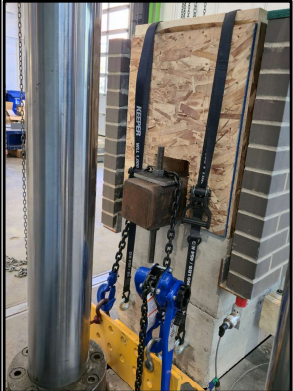
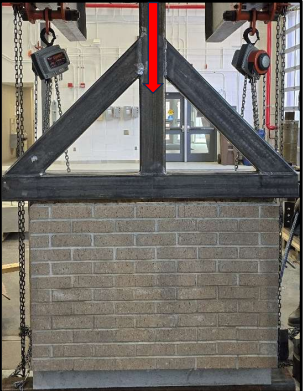
DB-CST-SPF:FLS

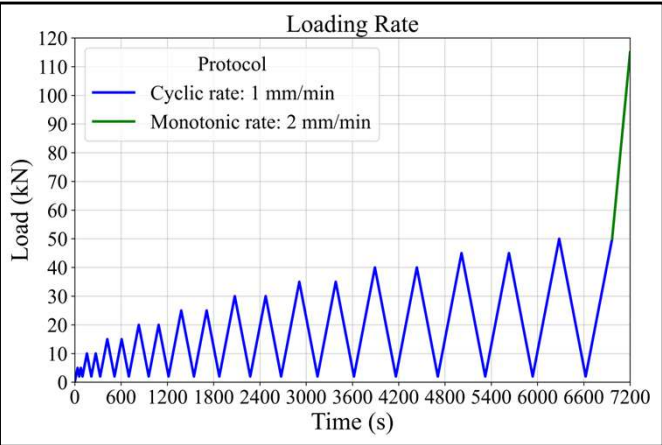
7

Experimental Program

Experimental Testing Involved:

- Concentric Cyclic Axial Load (Applied to Veneer/Shelf Angle)
- Concrete Based Restrained to Strong Floor



Loading Rate

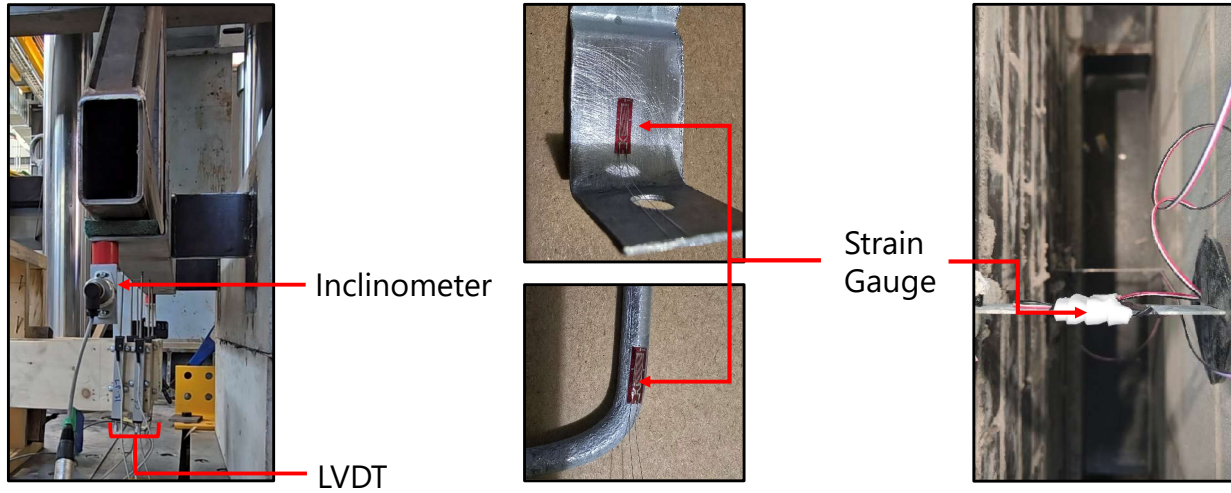
Protocol

- Cyclic rate: 1 mm/min
- Monotonic rate: 2 mm/min

8

Specimen Instrumentation

Specimens were measured using LVDT, Inclinerometers, and strain gauges



9

Results: Directly Bolted-corrugated Strip Tie-SPF



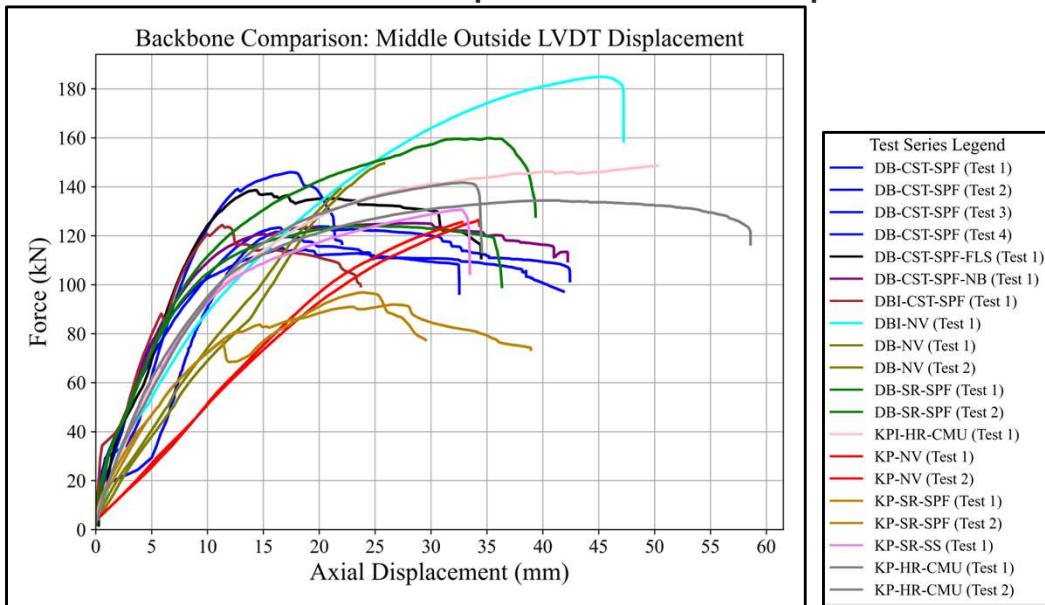
10

Shelf Angle Seating (35 kN)

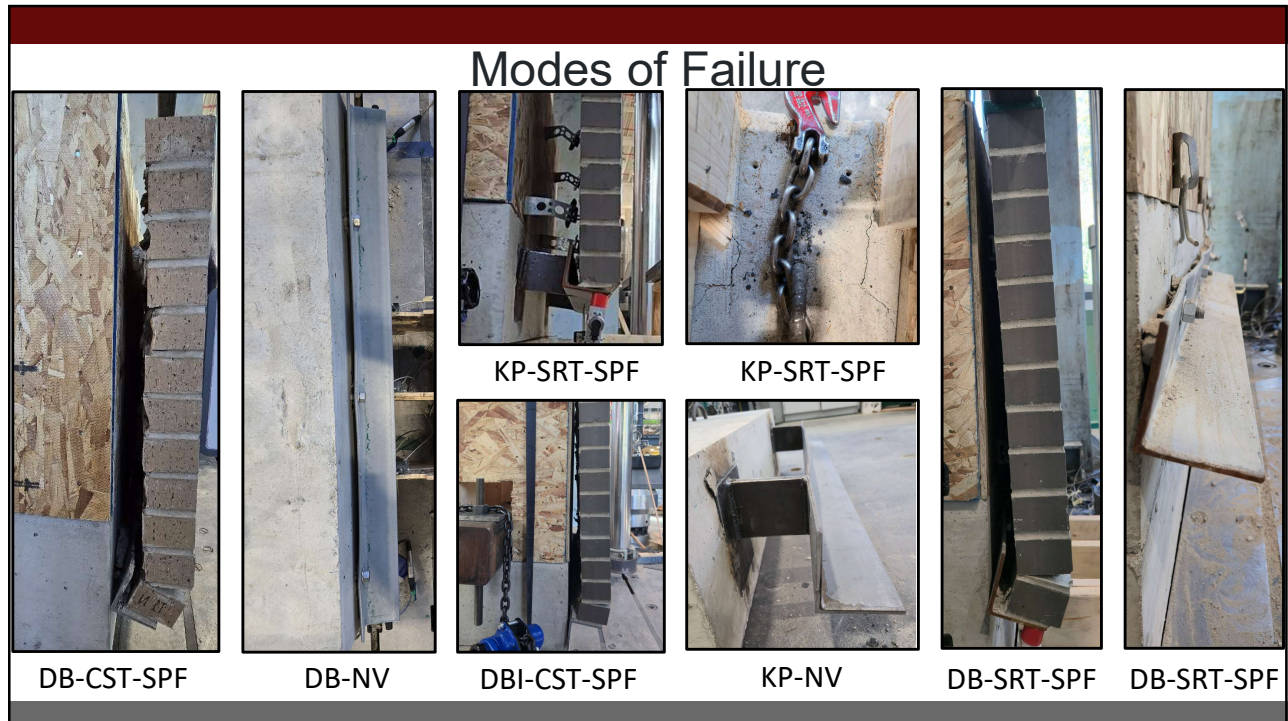


11

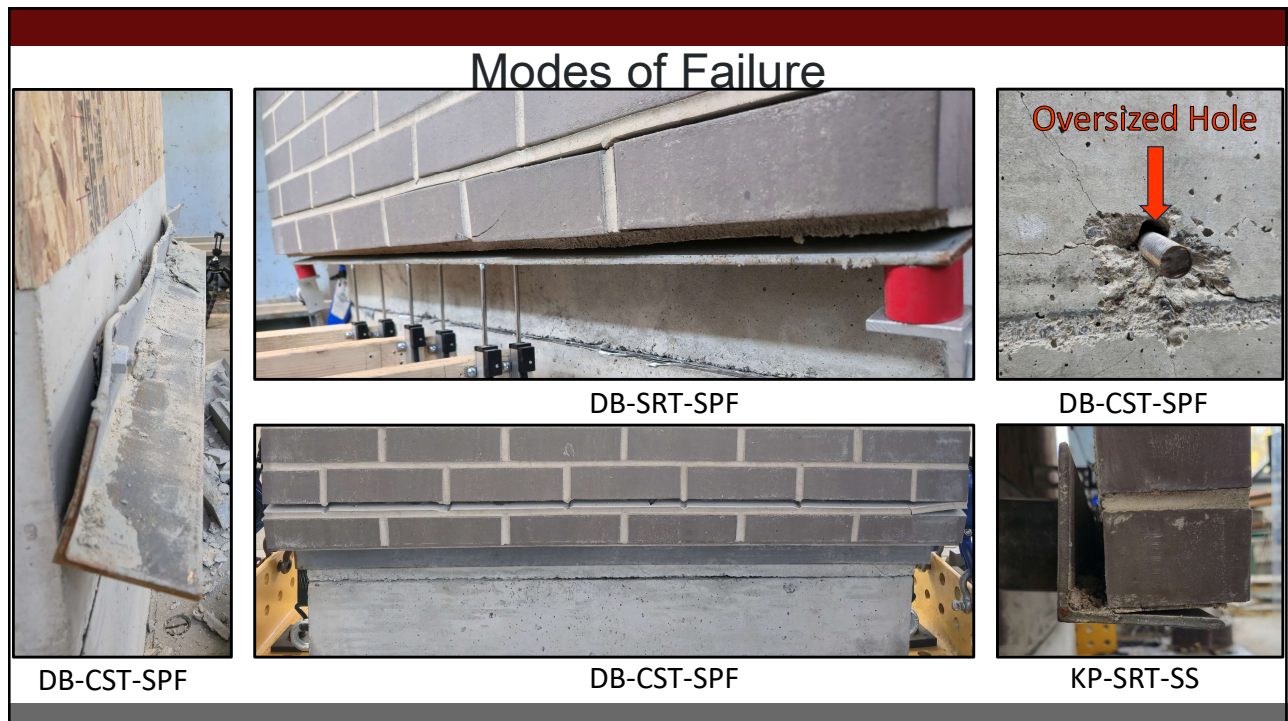
Results: Load Displacement Comparison



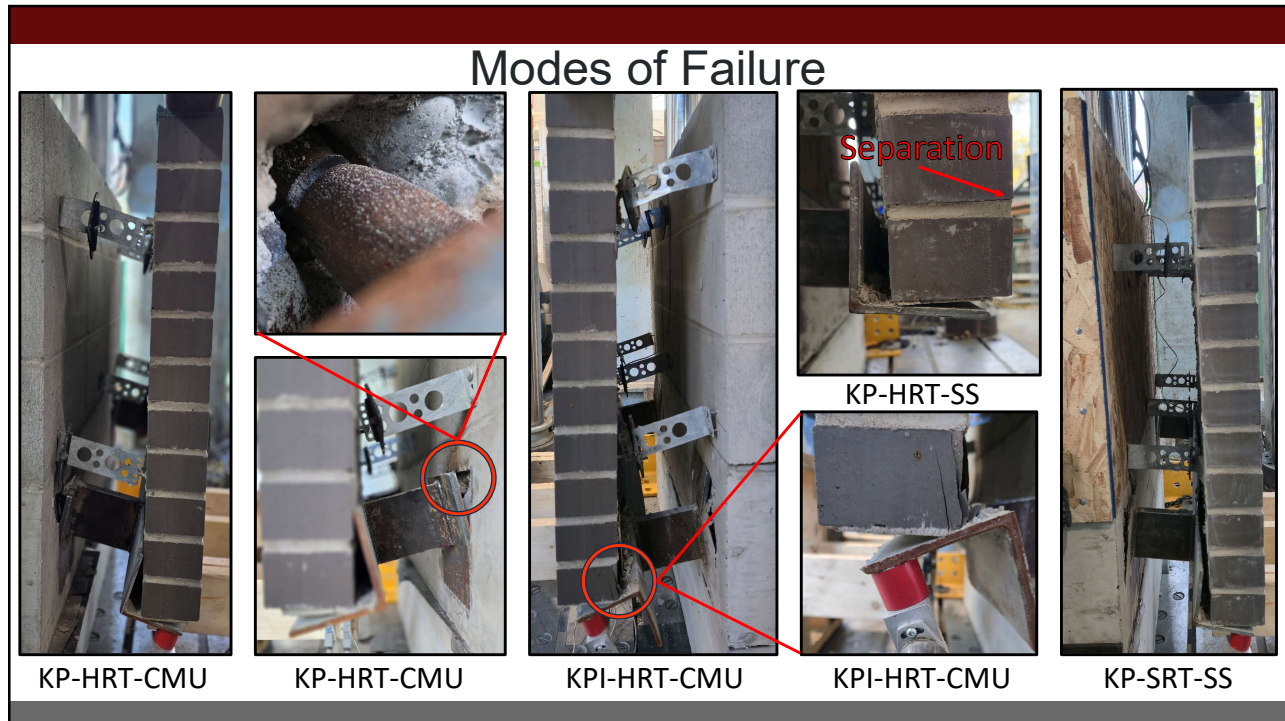
12



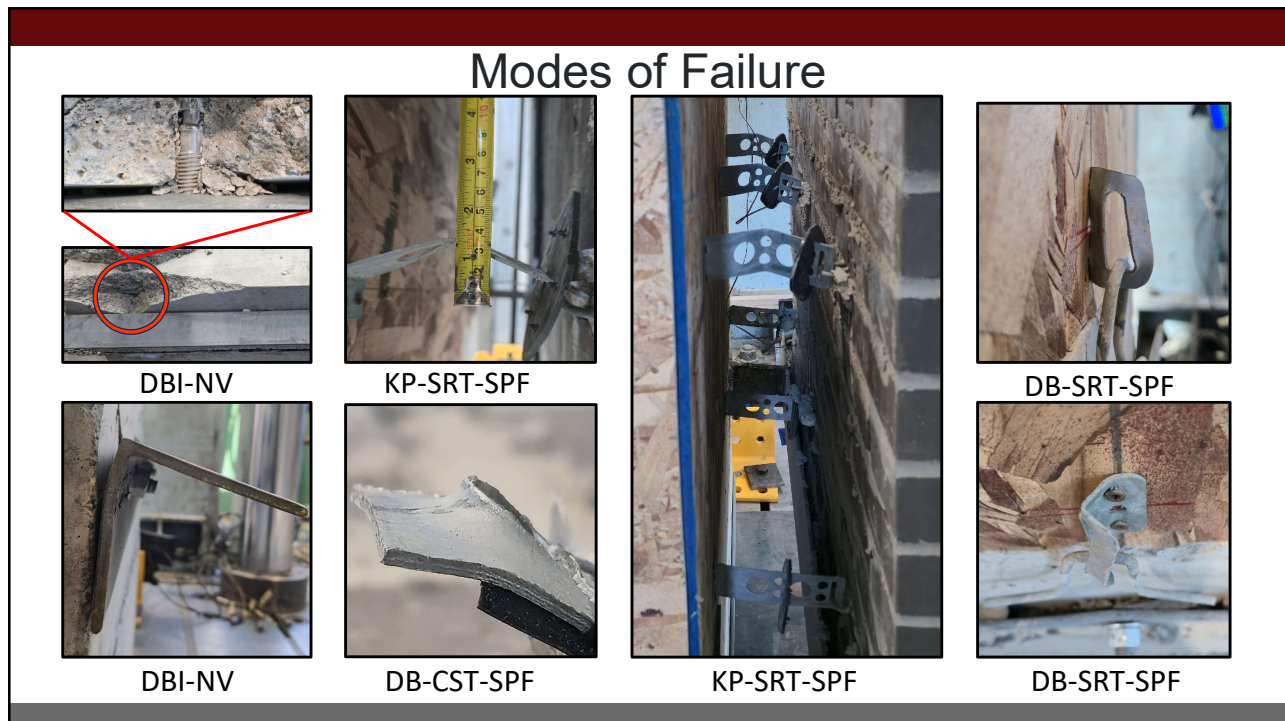
13



14



15



16

Results: Testing Data

2x6 SPF Backup Wall Tests - Directly Bolted and Inverted Angle				
Specimen Test	Specimen Variation	Service Deflection (mm)	Ultimate Load (kN)	Failure Mode
1	Directly Bolted-Corrugated Strip Tie-SPF	0.59	119	Tie Pull out/ Hilti Bolt Pull Out
2				
3	Directly Bolted-No Veneer	1.99	145	Hilti Bolt Pull Out
4				
5	Directly Bolted Slotted Rap Tie-SPF	0.63	141	Tie Buckling/ Hilti Bolt Pull Out
6				
7	Directly Bolted Inverted- No Veneer	1.27	184	Hilti Bolt Pull Out
8				
9	Directly Bolted-Corrugated Strip Tie-SPF (Shelf Angle Seating Excluded)	0.52	145	Tie Pull out/ Hilti Bolt Pull Out
10				

2x6 SPF Backup Wall Tests - On Stand-Off				
Specimen Test	Specimen Variation	Service Deflection (mm)	Ultimate Load (kN)	Failure Mode
11	Knife Plate-Slotted Rap Tie-SPF	1.31	94	Ties buckling/ Embed Plate Out-of- Plane (OOP) Bending/ Concrete Breakout
12				
13	Knife Plate-No Veneer	3.64	124	Embed Plate Out-of- Plane (OOP) Bending
14				

17

Results: Testing Data

20 cm Concrete Block Backup Wall Tests - On Stand-Off				
Specimen Test	Specimen Variation	Service Deflection (mm)	Ultimate Load (kN)	Failure Mode
15	Knife Plate-Holed Rap Tie-CMU	1.04	137	Tie Buckling/Embed Plate OOP Bending
16				
17	Knife Plate Inverted-Holed Rap Tie-CMU	1.28	148	Tie Buckling/Embed Plate OOP Bending
18				

18 ga. 152 mm Steel Stud Backup Wall Tests - On Stand-Off				
Specimen Test	Specimen Variation	Service Deflection (mm)	Ultimate Load (kN)	Failure Mode
19	Knife Plate-Slotted Rap Tie-Steel Stud	1.19	130	Embed Plate OOP Bending
20				

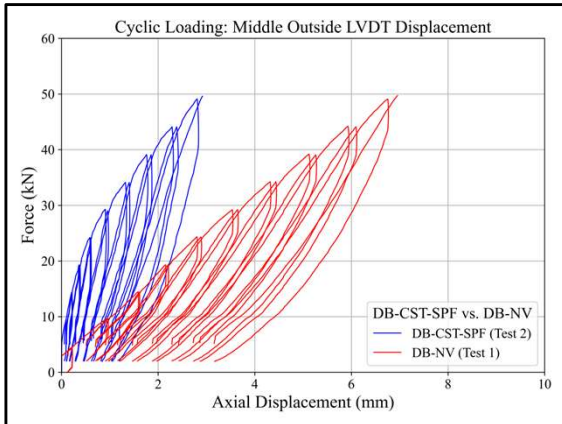
2x6 SPF Backup Wall Tests - Shelf Angle Variations				
Specimen Test	Specimen Variation	Service Deflection (mm)	Ultimate Load (kN)	Failure Mode
21	Directly Bolted-Corrugated Strip Tie-SPF- With Flashing	1.05	138	Tie Pull out/ Hilti Bolt Pull Out
22	Directly Bolted-Corrugated Strip Tie-SPF-No Mortar Bond W/ Shelf angle	0.72	125	Tie Pull out/ Hilti Bolt Pull Out
23	Directly Bolted Inverted-corrugated Strip Tie-SPF	0.27	124	Tie Pull out/ Shelf Angle yielding
24				

18

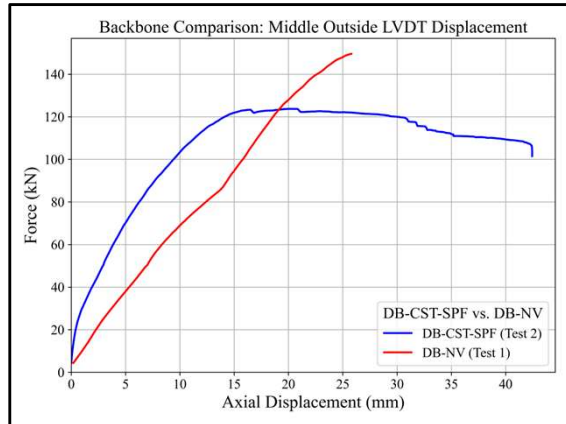
Comparison 1 - Veneer Presence

Directly Bolted-Corrugated Strip Tie-SPF vs. Directly Bolted-No Veneer

- **Service Deflection:** 0.59 mm (w/ Veneer) & 1.99 mm (w/o Veneer)
- **Failure Load:** 134 kN (w/ Veneer) & 145 kN (w/o Veneer)



Service State



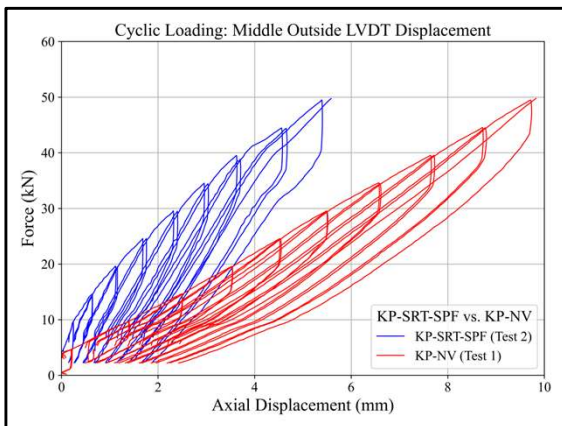
Ultimate State

19

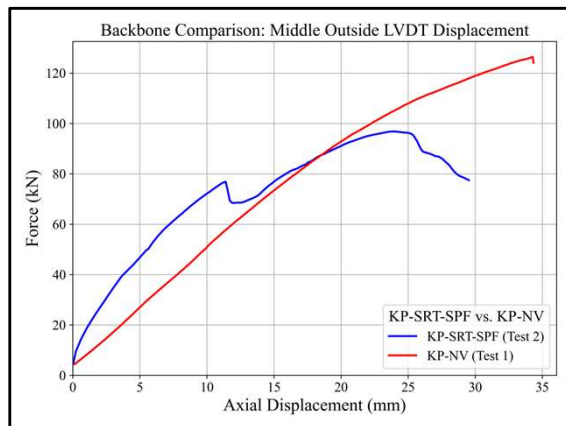
Comparison 2 - Veneer Presence

Knife Plate-Slotted Rap Tie-SPF vs. Knife Plate-No Veneer

- **Service Deflection:** 1.31 mm (w/ Veneer) & 3.64 mm (w/o Veneer)
- **Failure Load:** 94 kN (w/ Veneer) & 124 kN (w/o Veneer)



Service State



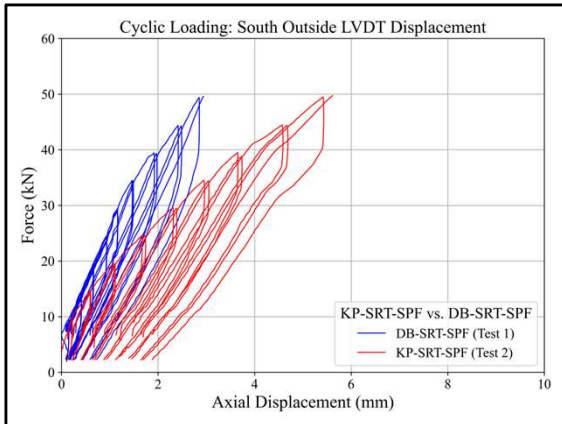
Ultimate State

20

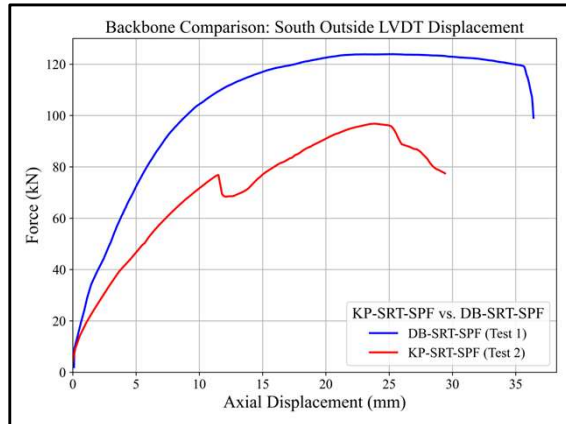
Comparison 3 - Connection Type

Directly Bolted-Slotted Rap Tie-SPF vs. Knife Plate-Slotted Rap Tie-SPF

- **Service Deflection:** 0.63 mm (w/ Directly Bolted) & 1.29 mm (w/ Knife Plate)
- **Failure Load:** 141 kN (w/ Directly Bolted) & 94 kN (w/ Knife Plate)



Service State



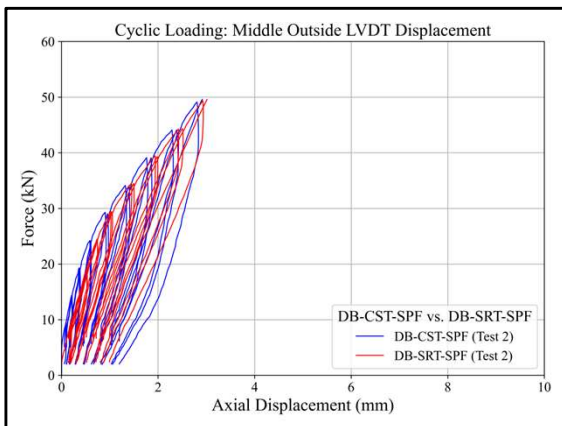
Ultimate State

21

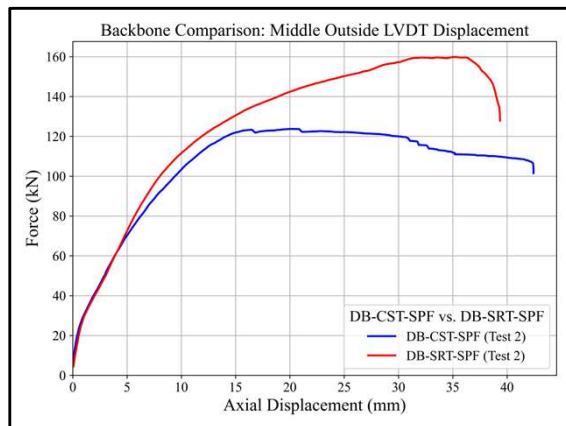
Comparison 4 – Tie Type

Directly Bolted-Corrugated Strip Tie-SPF vs. Directly Bolted-Slotted Rap Tie-SPF

- **Service Deflection:** 0.59 mm (w/ Strip Tie) & 0.63 mm (w/ Rap Tie)
- **Failure Load:** 123 kN (w/ Strip Tie) & 141 kN (w/ Rap Tie)



Service State



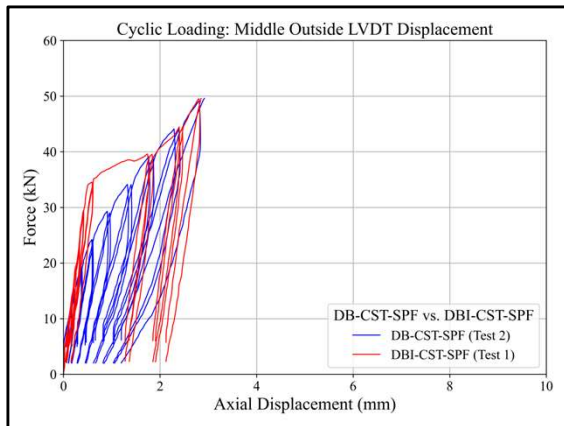
Ultimate State

22

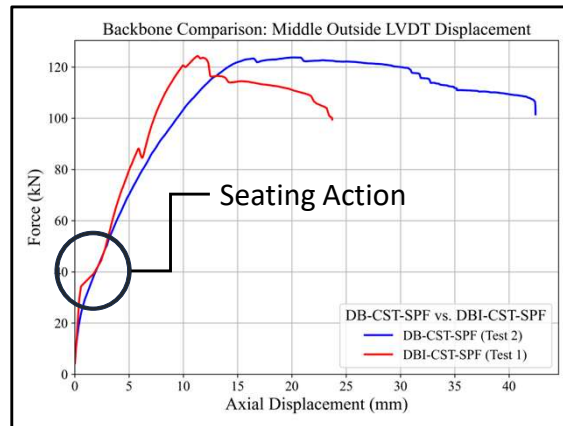
Comparison 5 – Shelf Angle Orientation

Directly Bolted-Corrugated Strip Tie-SPF vs Directly Bolted Inverted-Corrugated Strip Tie-SPF

- **Service Deflection:** 0.59 mm (w/ Directly Bolted) & 0.27 mm (w/ Inverted)
- **Failure Load:** 124 kN (w/ Directly Bolted) & 124 kN (w/ Inverted)



Service State



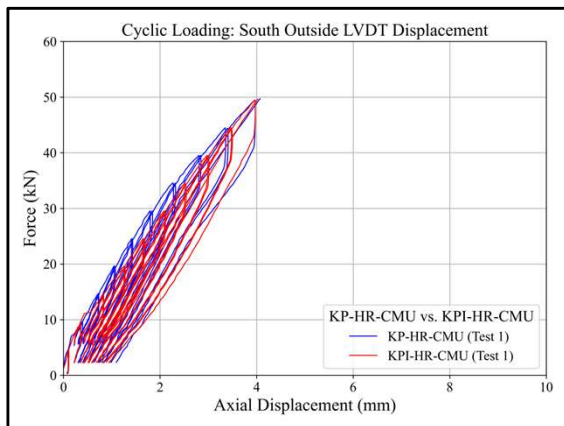
Ultimate State

23

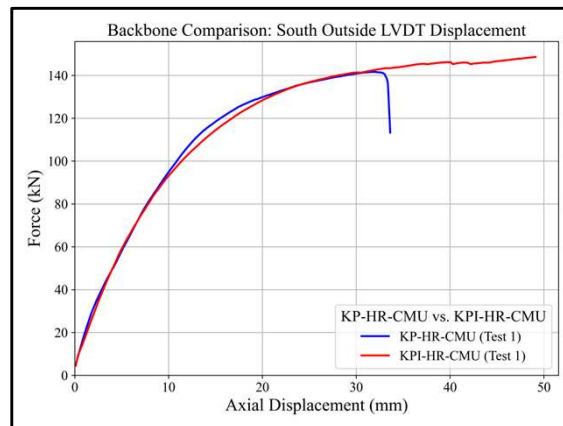
Comparison 6 – Shelf Angle Orientation

Knife Plate-Holed Rap Tie-CMU vs Knife Plate Inverted-Holed Rap Tie-CMU

- **Service Deflection:** 1.04 mm (w/ Knife Plate) & 1.28 mm (w/ Inverted)
- **Failure Load:** 137 kN (w/ Knife Plate) & 148 kN (w/ Inverted)



Service State



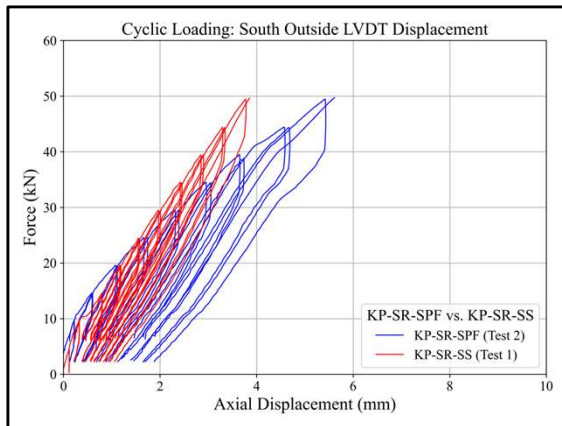
Ultimate State

24

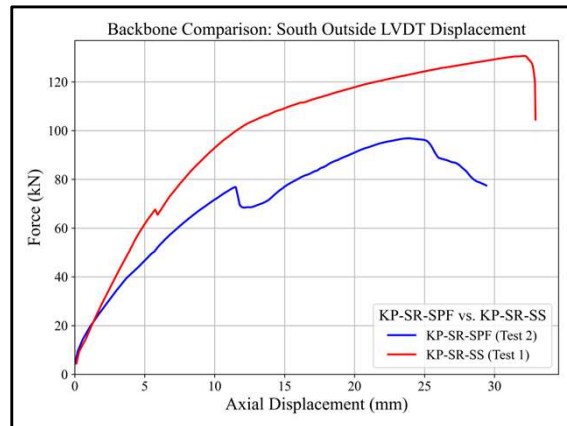
Comparison 7 – Backup Wall Connection

Knife Plate-Slotted Rap Tie-SPF vs Knife Plate-Slotted Rap Tie-Steel Stud

- **Service Deflection:** 1.29 mm (w/ SPF) & 1.19 mm (w/ Steel Stud)
- **Failure Load:** 93 kN (w/ SPF) & 130 kN (w/ Steel Stud)



Service State



Ultimate State

25

Conclusion

Veneer presence influences serviceability :

With veneer, service deflection drops for both systems—DB: **0.52-0.59 mm** (with veneer) vs **1.99 mm** (no veneer) and KP: **1.29-1.31 mm** vs **3.64 mm**. (*Comparisons 1–3*)

Connection type influences stiffness, capacity, and failure mode:

For the same tie and SPF backup, DB-SRT-SPF outperforms KP-SRT-SPF at service (**0.52-0.59 mm** vs **1.29-1.31 mm**); DB failures are governed by Hilti anchor and tie pull-out, while KP failures are dominated by embed-plate out-of-plane bending with tie buckling. (*Comparison 3*)

Service deflection drops remain high despite tie variation and shelf angle orientation:

Service deflection drops remained high despite tie variation and shelf angle orientation change . (*Comparison 4,5, and 6*)

Backup Wall type has little Influence:

The back up wall contributes little when examining serviceability deflection (1.29 mm w/ SPF & 1.19 mm w/ Steel Stud). (*Comparison 7*)

26

Future testing

Future Testing to expand experimental program:

- Full Scale Testing
- Beam Action of Veneers
- Different Boundary Condition
- Adhered Veneers



Beam Action



No Shelf Angle Supporting Vener



27

27

Contact Information

Cory Scott, E.I.T. - MSc Student, University of Alberta

Cory1@ualberta.ca

Mark Hagel, PhD, P.Eng. - Executive Director, Alberta Masonry Council

markhagel@albertamasonrycouncil.ca

Clayton Pettit, PhD, P.Eng. - Assistant Professor, University of Alberta

cpettit@ualberta.ca

28