Four-point Bending Test on Micropile Threaded Connections

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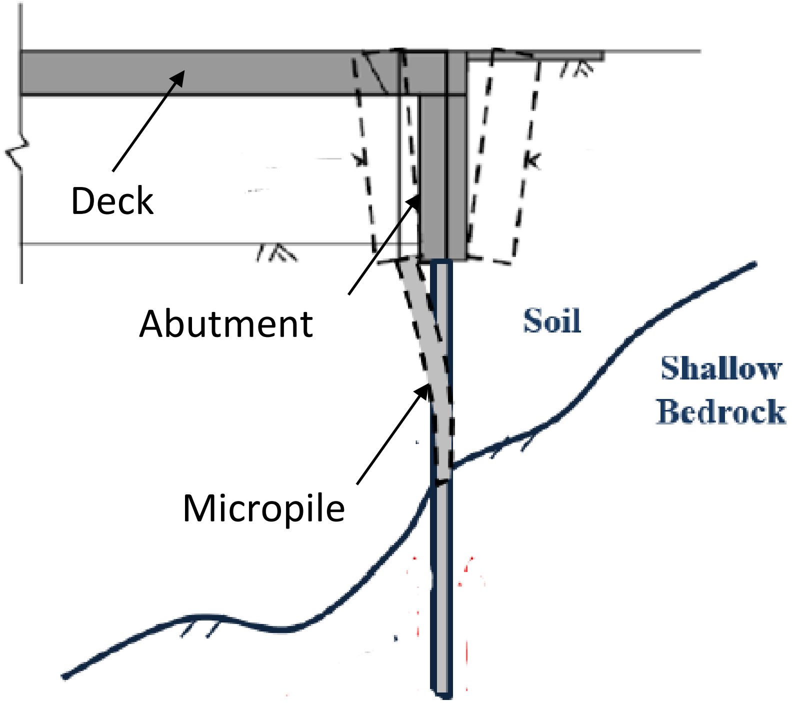
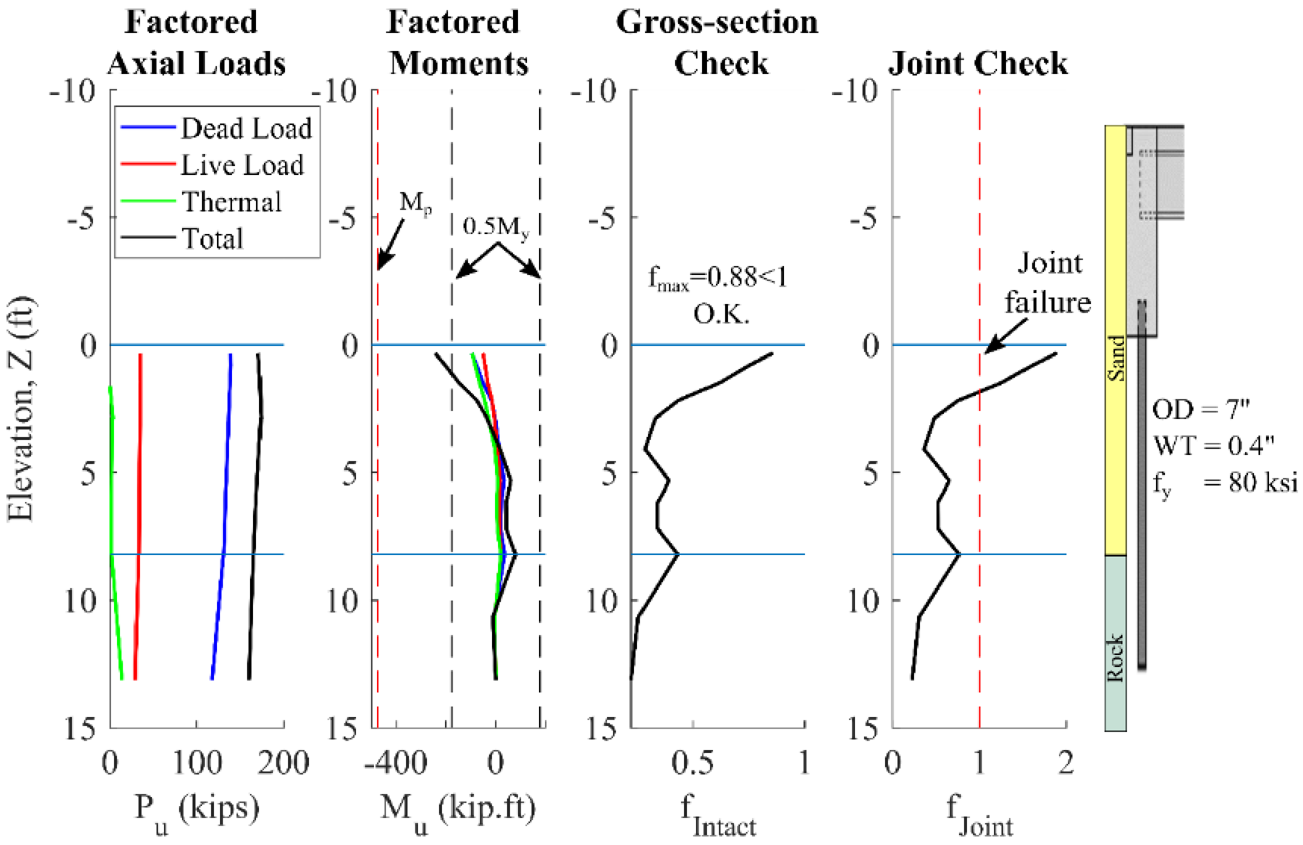
Micropile supported IABs at shallow bedrock sites: Joint capacity under combined load controls the design

IABs subjected to thermal deformations





FHWA Provisions (Sabaini et al., 2005)

$$f = \frac{P_u}{\phi_a P_n} + \frac{8}{9}\frac{M_u}{\phi_b M_n} < 1$$

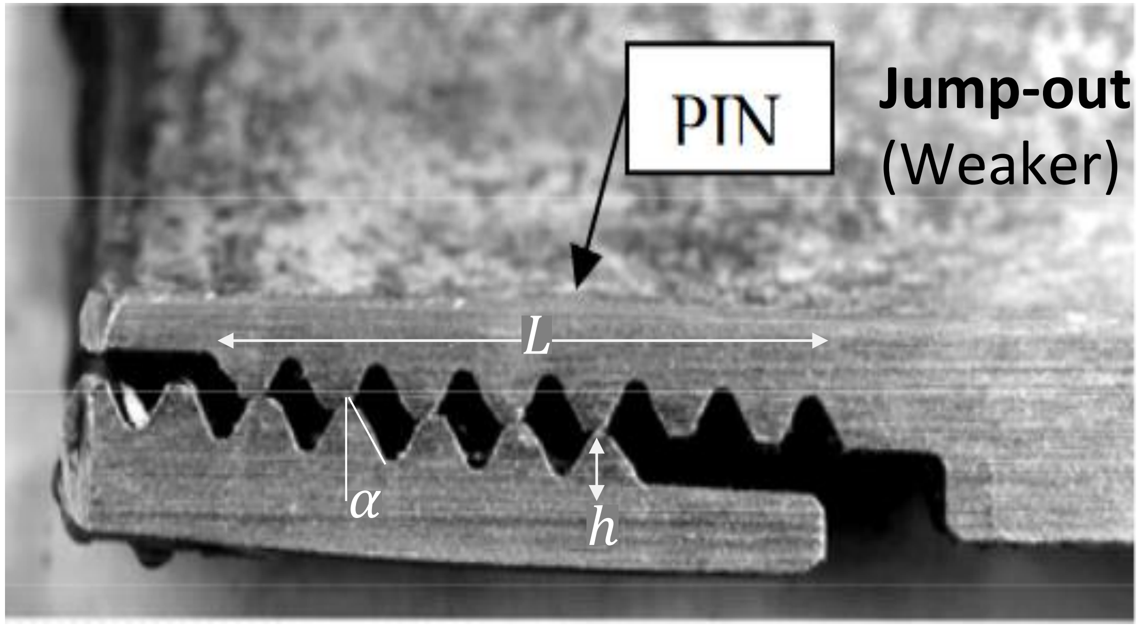
$$P_n = 0.8 f_y A$$

$$M_{njoint} = \frac{1}{2} M_y = 0.5 f_y S$$

Joint strength depends on the thread details

Clinedinst (1965) explained jump-out mechanism for pure tension loads as a consequence of thread slip and plastic radial deformations of the pin end.

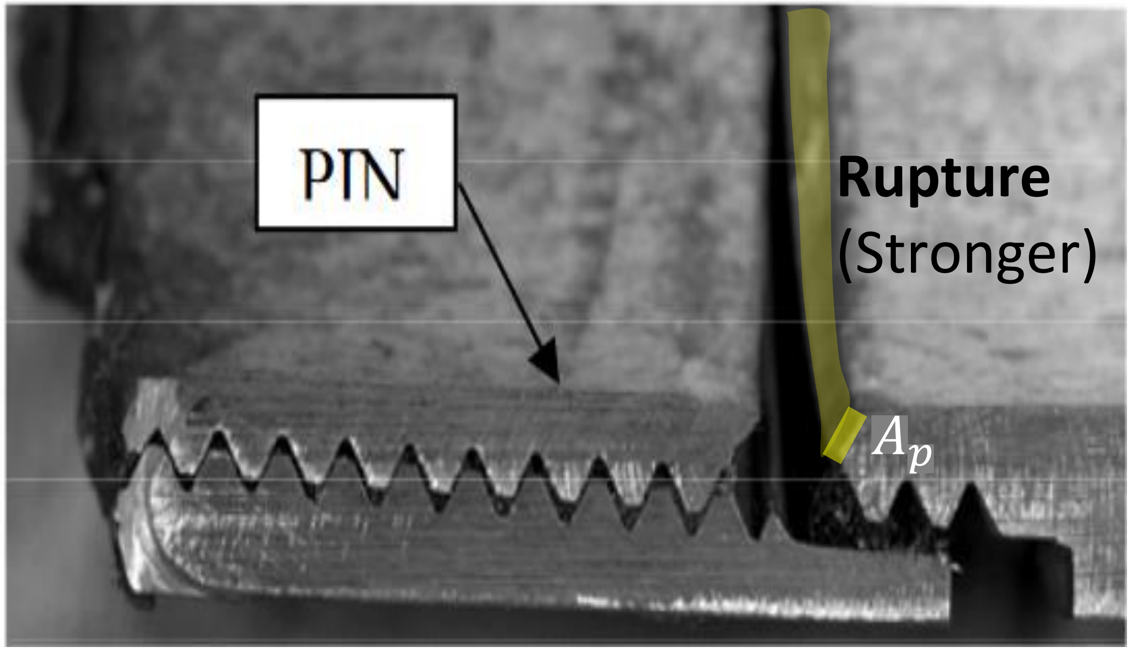
$$P_j = \left[\frac{a\left(\frac{2h}{D}\right)^b f_u}{\frac{1}{2} + \frac{D}{2L}tan(\alpha - \phi)} + \frac{f_y}{1 + \frac{D}{2L}tan\,(\alpha - \phi)} \right] A_p$$



(Musselman at al, 2007)

Longer threaded connections fail in rupture. Clinedinst (1965) indicates failure takes place at the “critical section” (root of the thread) where the wall gets thinner.

$$P_r = f_u A_p$$



(Musselman at al, 2007)

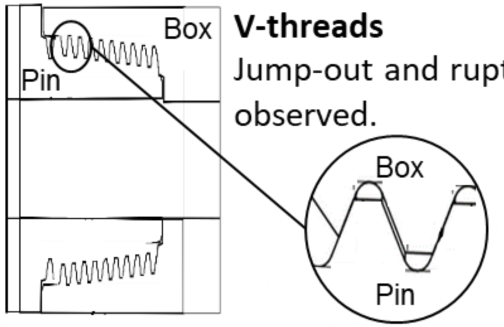
There is no analytical model that incorporates the thread effect/details in a physically consistent way

MALCOLM (1995); NICHOLSON (2005); Musselman et al (2007); AETESS (2009); Babalola (2011); Anderson & Babalola (2012); Zanuy et al (2012).

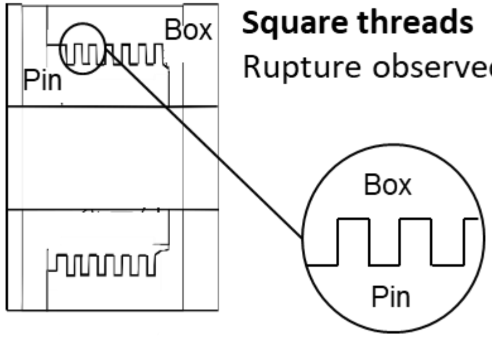
M_u: Joint capacity
M_y: Continuous casing yield moment

Thread shape

V-threads (API like) and square threads



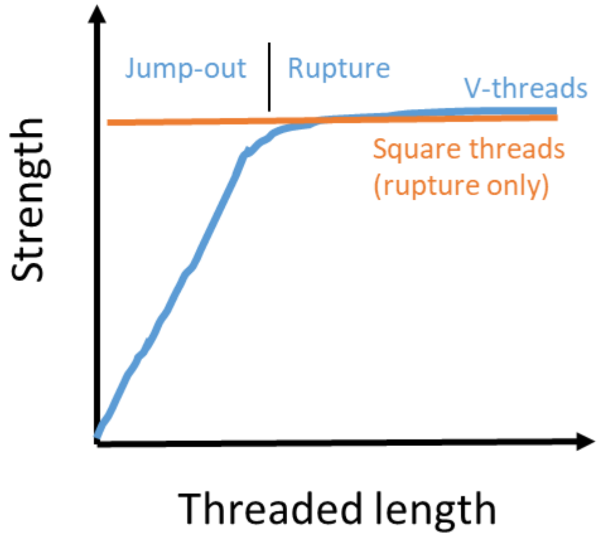
V-threads
Jump-out and rupture observed.



Square threads
Rupture observed only.

Threaded length

Depending on thread shape, it controls the failure mode and strength.

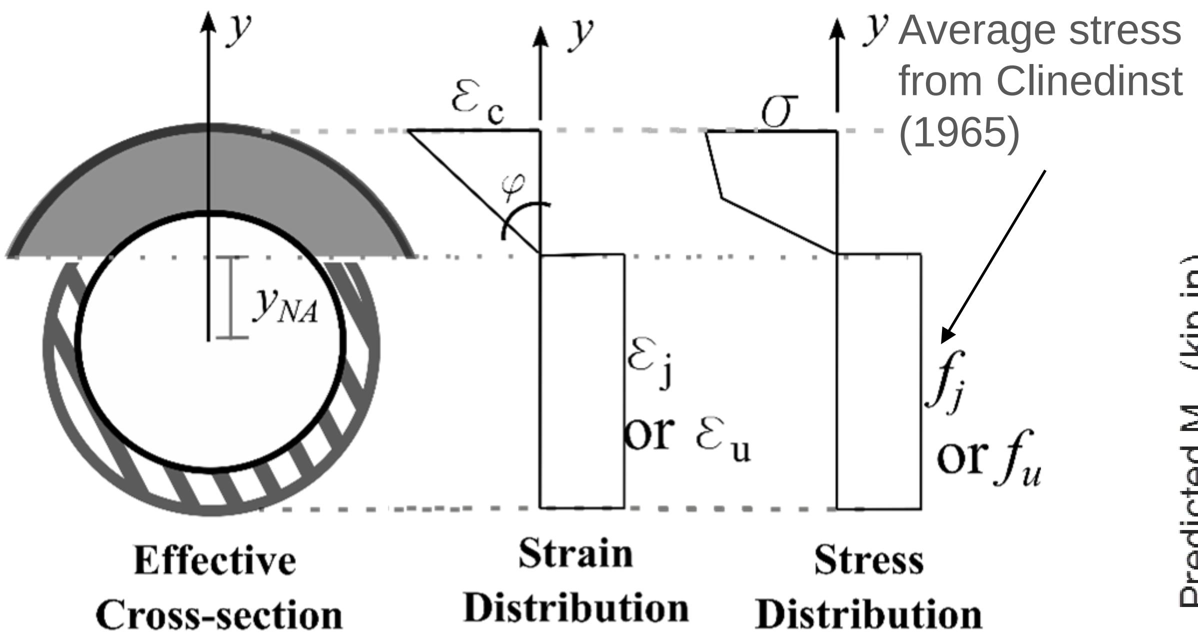


Predicting Strength

Industry: For API N80 sections assume thickness of the connection is 50% of the 'intact' casing (Sabatini et al, 2005)

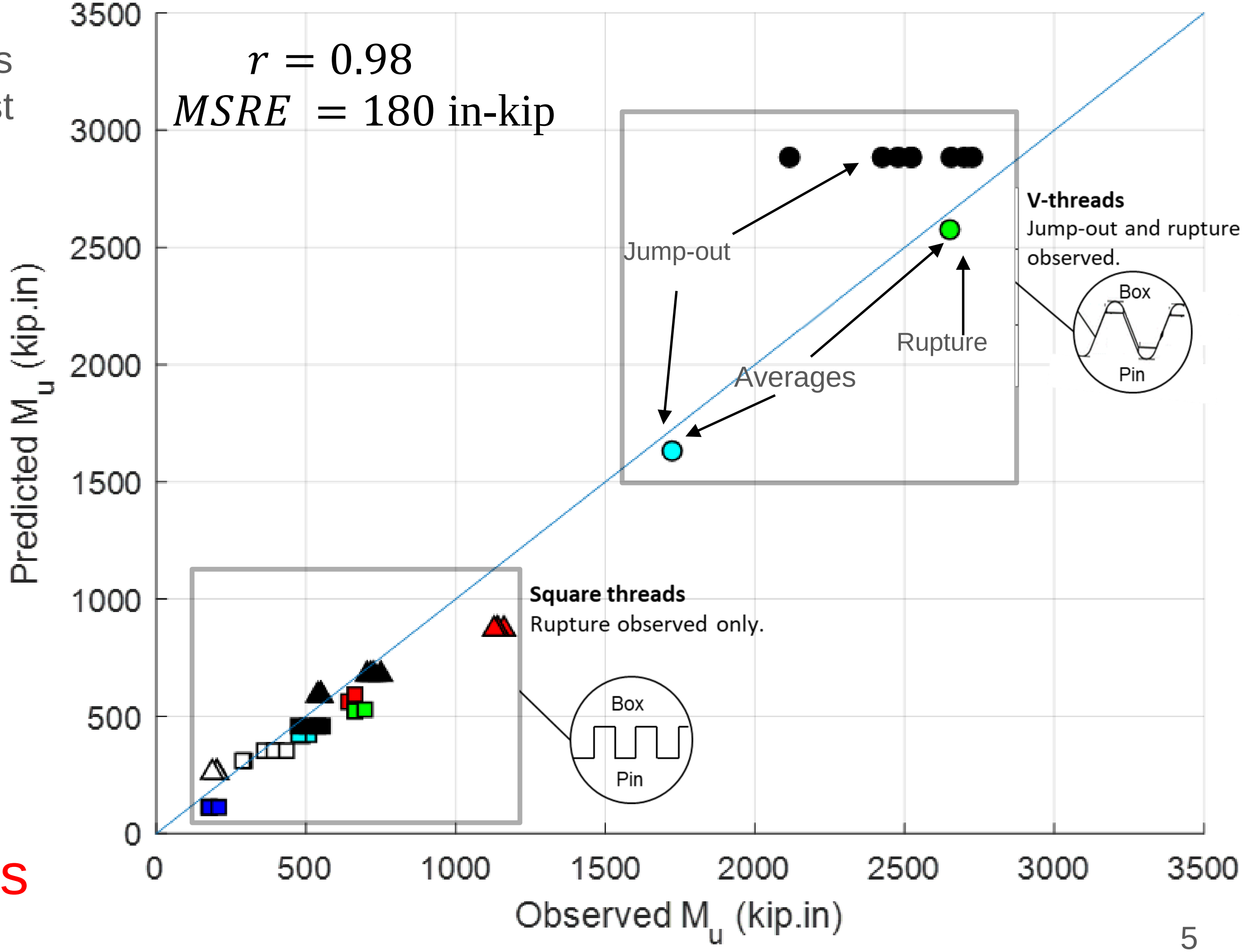
$$M_u/M_y \approx 0.5$$

Unconventional assumptions are required to predict bending capacity



Stress-strain state of the joint at failure according to Musselman et al (2007) developed from a limited number of tests

(Montoya-Vargas et al, 2022)



Need for further investigation

Musselman method predicts failure mode and strength, but:

- Estimation of the neutral axis position is not consistent with the assumed strain profile.
- Physics behind the stress distribution are not understood yet.
- Variability of results had not been verified.
- Contribution from center reinforcing bar not considered.
- No guidance on combined loading (axial+bending).

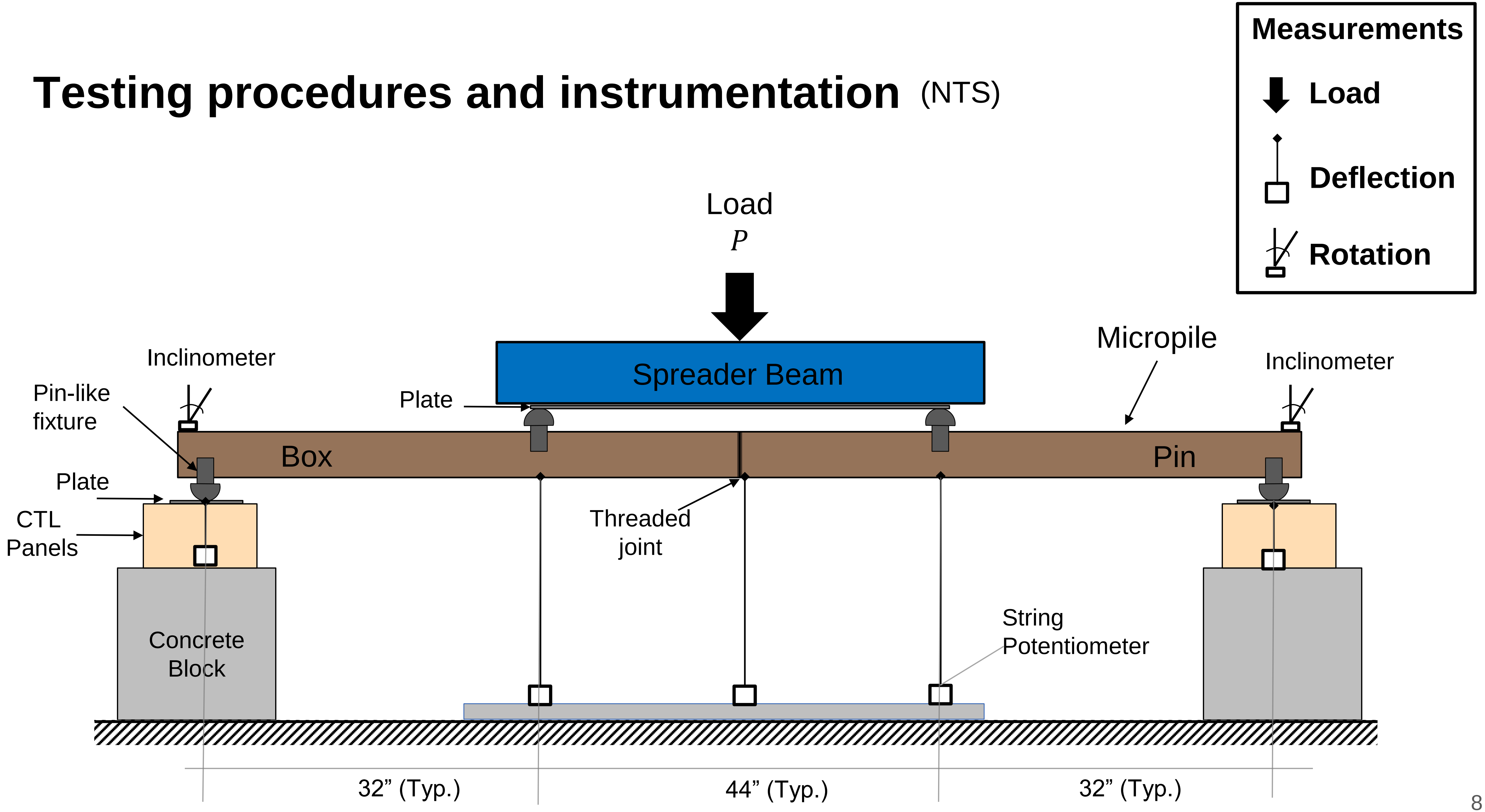
Undergoing research at UMaine

The International Association of Foundation Drilling

Objective: to understand the mechanism governing the flexural failure of micropiles threaded joints.

Goal: Predict strength and stiffness of the joint, including the contribution from the center reinforcing bar and combined loading conditions.

Testing procedures and instrumentation (NTS)



Testing specimens cover the range of micropile diameters and threaded lengths typically implemented in the practice

Casing diameter

7”, 7-5/8”, 9-5/8”, and 13-5/8”

Thread shape

V-thread, square threads

Threaded length

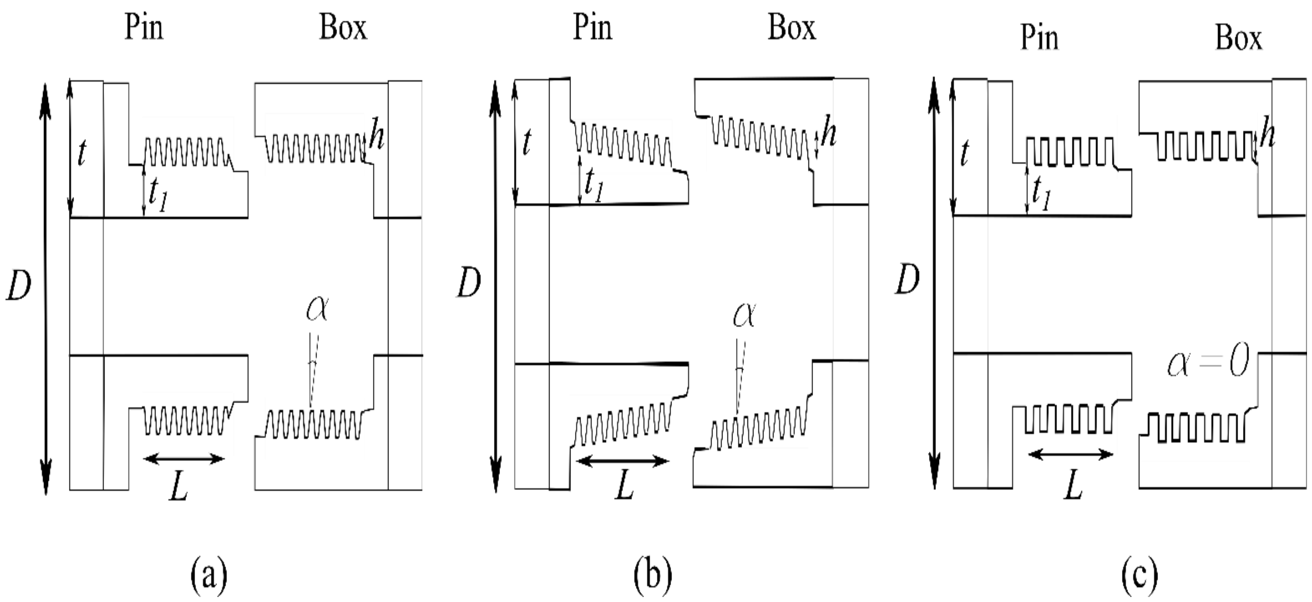
2”, 2.5”, 3” and 5” (nominal values)

Reinforcement

1-3/4” threaded bar

Combined loading

Unbonded dywidag bar for postensioned specimens

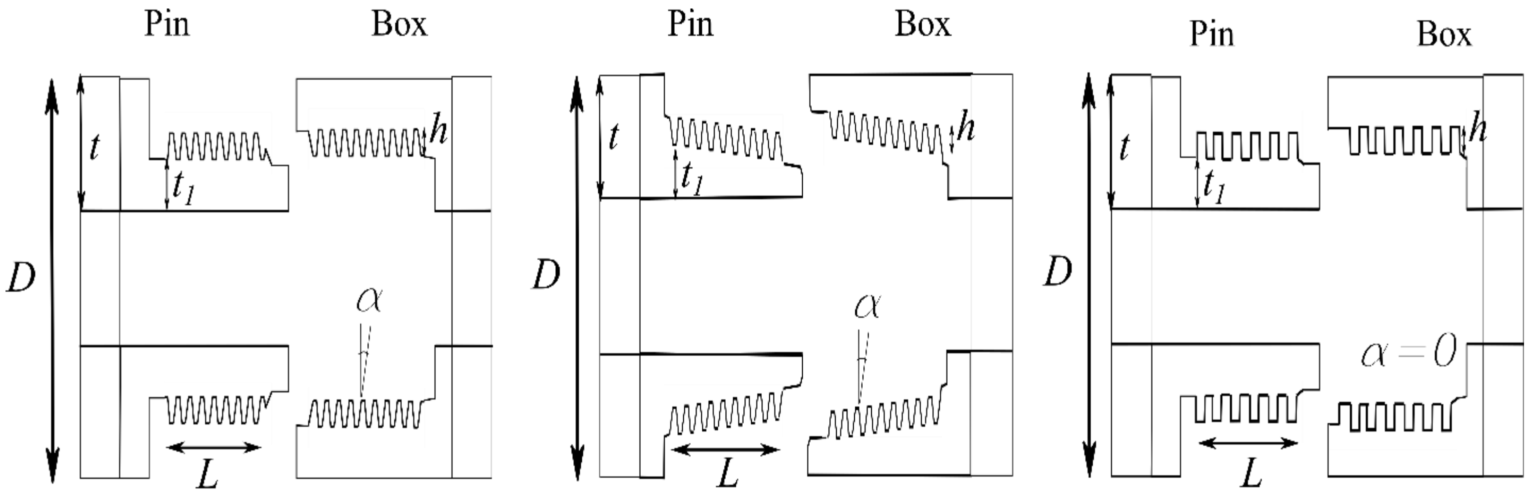


Test ID	Thread type	Outer diameter (in)	Nominal Thread length (in)	Rebar	Post tension
1	a	7	2	No	No
2	b	7 5/8	2.5	No	No
3	a	9 5/8	2	No	No
4	b	7 5/8	2	No	No
5	b	7 5/8	3	No	No
6	b	7 5/8	2.5	Yes	No
7	b	7 5/8	3	Yes	No
8	a	9 5/8	2	Yes	No
9	a	9 5/8	2.75	Yes	No
10	a	9 5/8	3	No	No
11	c	SQ9 5/8	2.5	No	No
12	b	9 5/8	3	No	No
13	a	9 5/8	2	No	Yes
14	a	9 5/8	2.75	No	Yes
15	b	9 5/8	2.5	No	Yes
16	b	9 5/8	3	No	Yes
17	b	13 5/8	3.5	No	No
18	b	13 5/8	3.5	Yes	No
19	b	13 5/8	5	No	No
20	b	13 5/8	5	Yes	No

Selection of threaded lengths was guided by Clinedinst model for pure tension

ID	Outer Diameter*, D (in)	Wall thickness*, t (in)	Connection type	Thread engagement length, L (in)	Thread height, h (in)	Thickness at pin, t_1 (in)	Yield stress, f_y (ksi)	UTS, f_u (ksi)
1	7	0.453	a	1.25	0.121	0.147	128	139.7
2	7.625	0.5	b	1	0.122	0.232	132	143
3	7.625	0.5	b	2.25	0.122	0.232	132	143
4	R7.625	0.5	b	2.25	0.122	0.232	129	145
5	9.625	0.545	a	2	0.122	0.201	104.7	116.8
6	9.625	0.545	b	2.25	0.122	0.27	135.2	143.4
7	SQ9.625	0.545	c	1.25	0.122	0.201	125	135

* Nominal values

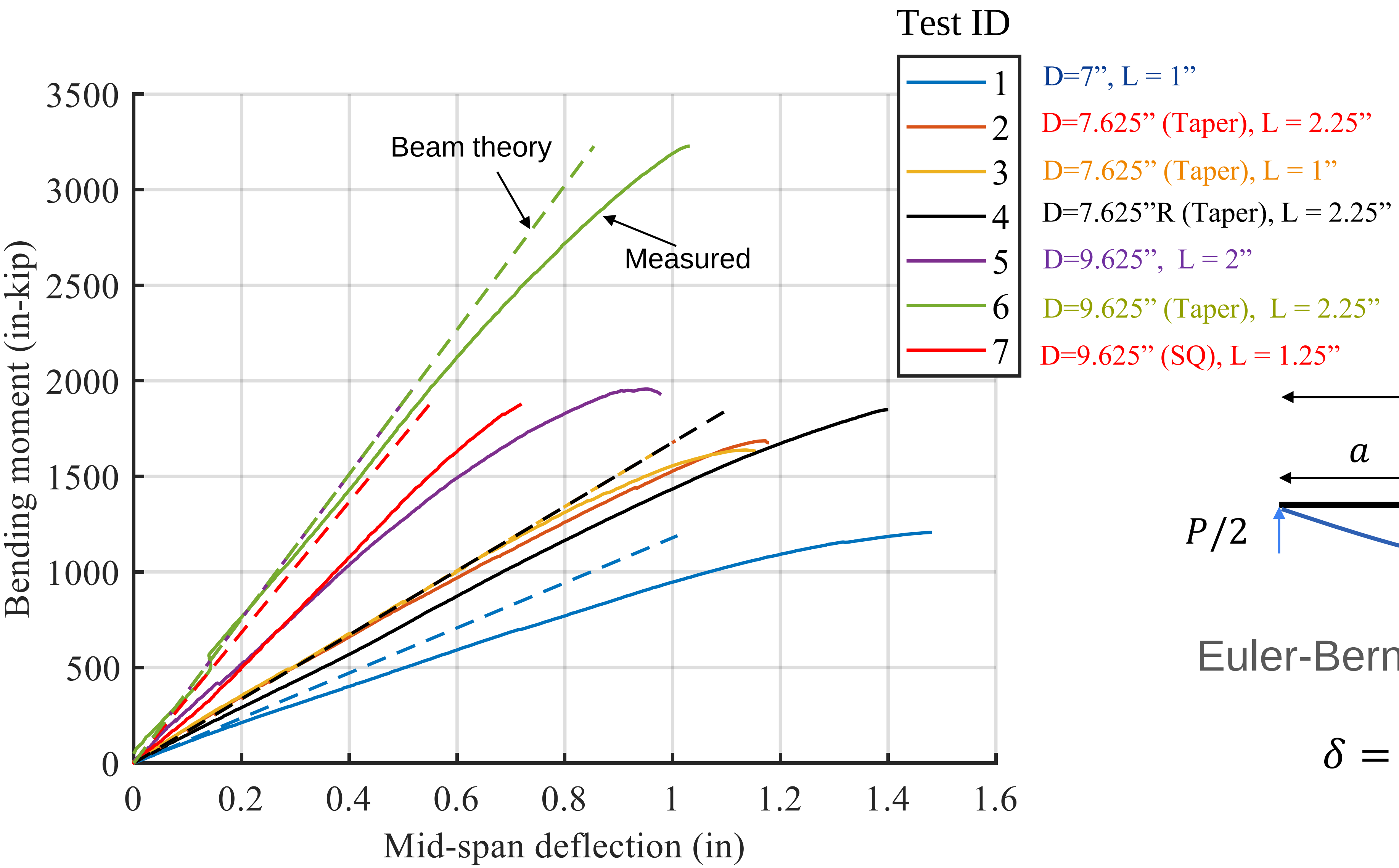


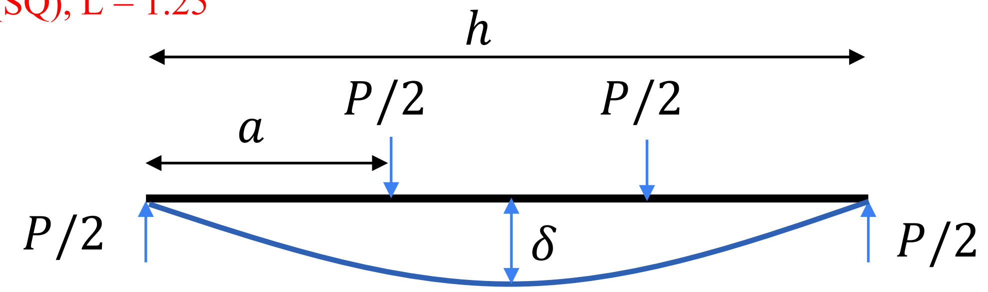
(a) (b) (c)

Assemblage process mimics the installation conditions

ADVANCED STRUCTURES &
composites center

Micropile response is affected by joint stiffness

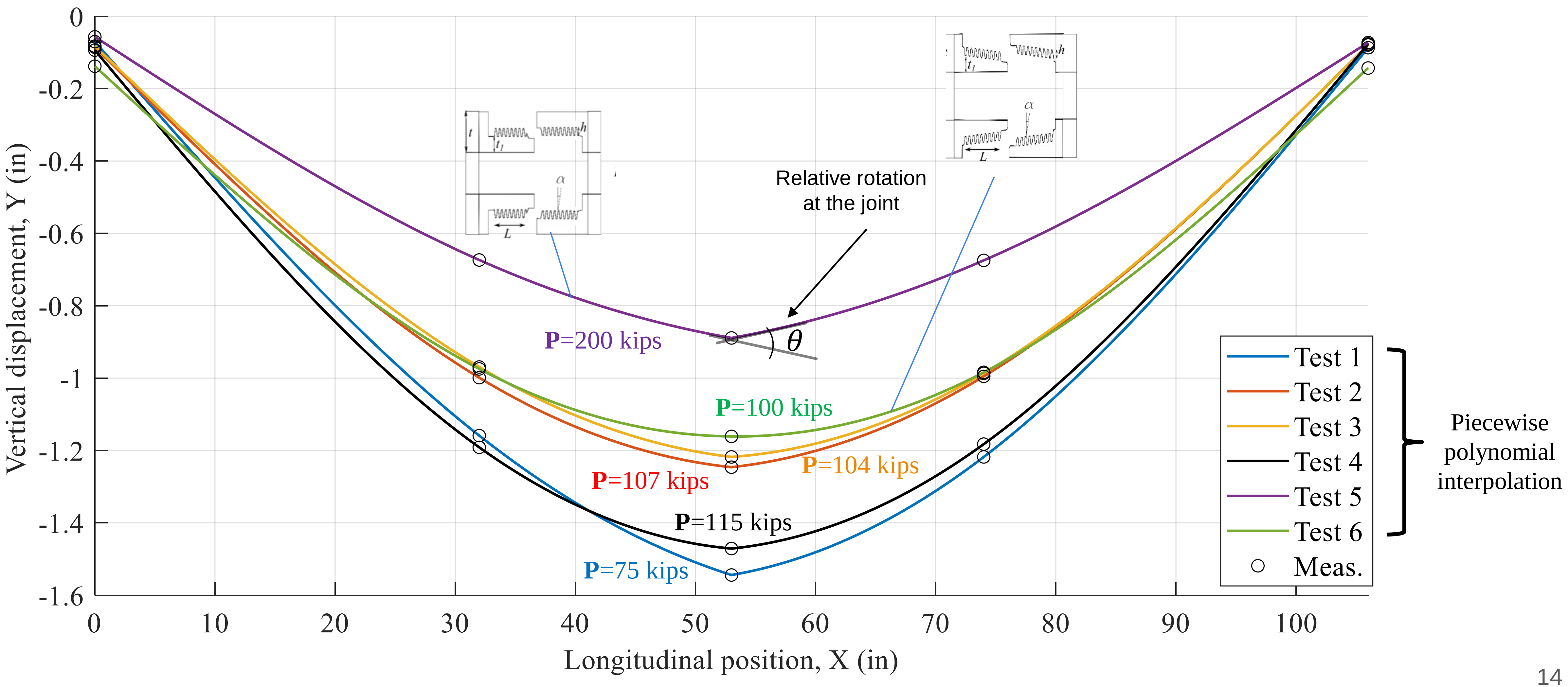




Euler-Bernoulli beam theory:

$$\delta = \frac{Pa}{48EI}(3h^2 - 4a^2)$$

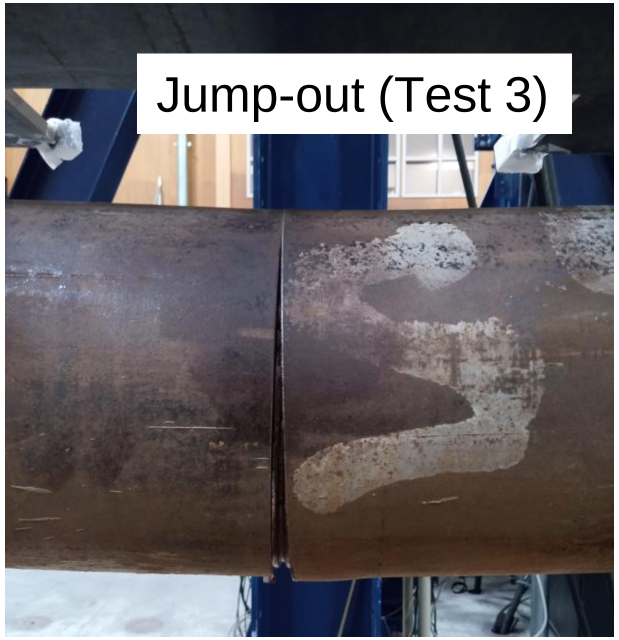
Relative rotations at the joint

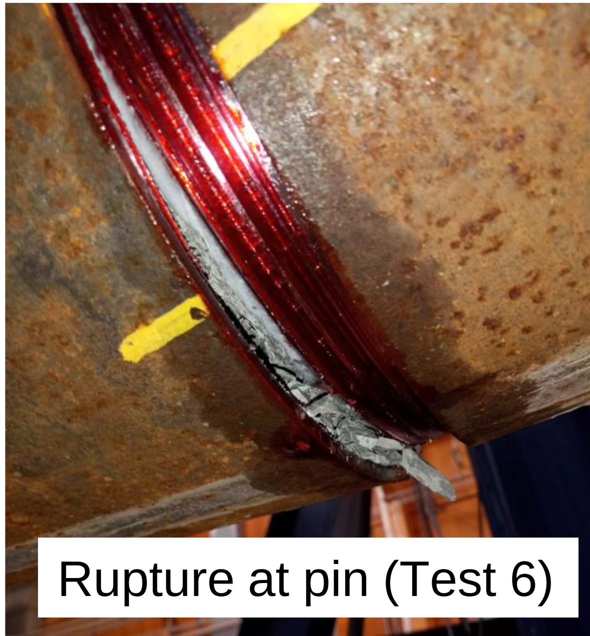


Observation vs. predictions: Failure mode

ID	Outer Diameter*, D (in)	Thread engagement length, L (in)	Predicted Failure mode	Observed Failure mode
1	7	1.25	Rupture[a]	Rupture[b]
2	7.625 (Taper)	1	Jump-out	Jump-out
3	7.625 (Taper)	2.25	Rupture[a]	Jump-out
4	R7.625 (Taper)	2	Rupture[a]	Jump-out
5	9.625 (Taper)	2.25	Rupture[a]	Rupture[a]
6	9.625	2	Rupture[a]	Jump-out
7	SQ9.625	1.25	Rupture[a]	Rupture[a]

(a) Pin-end; (b) Box-end





Observation vs. predictions: Strength

ID	Outer Diameter*, D (in)	Thread engagement length, L (in)	Predicted Failure mode	Observed Failure mode	Predicted bending strength (in-kip)	50% thickness reduction (in-kip)	Observed bending strength (in-kip)
1	7	1.25	Rupture[(a)]	Rupture[(b)]	1012	879	1200
2	7.625 (Taper)	1	Jump-out	Jump-out	1645	1183	1676
3	7.625 (Taper)	2.25	Rupture[(a)]	Jump-out	1935	1183	1620
4	R7.625 (Taper)	2	Rupture[(a)]	Jump-out	-	1156	1850
5	9.625 (Taper)	2.25	Rupture[(a)]	Rupture[(a)]	3113	2179	3440
6	9.625	2	Rupture[(a)]	Jump-out	2259	1687	1950
7	SQ9.625	1.25	Rupture[(a)]	Rupture[(a)]	2611	2015	1880

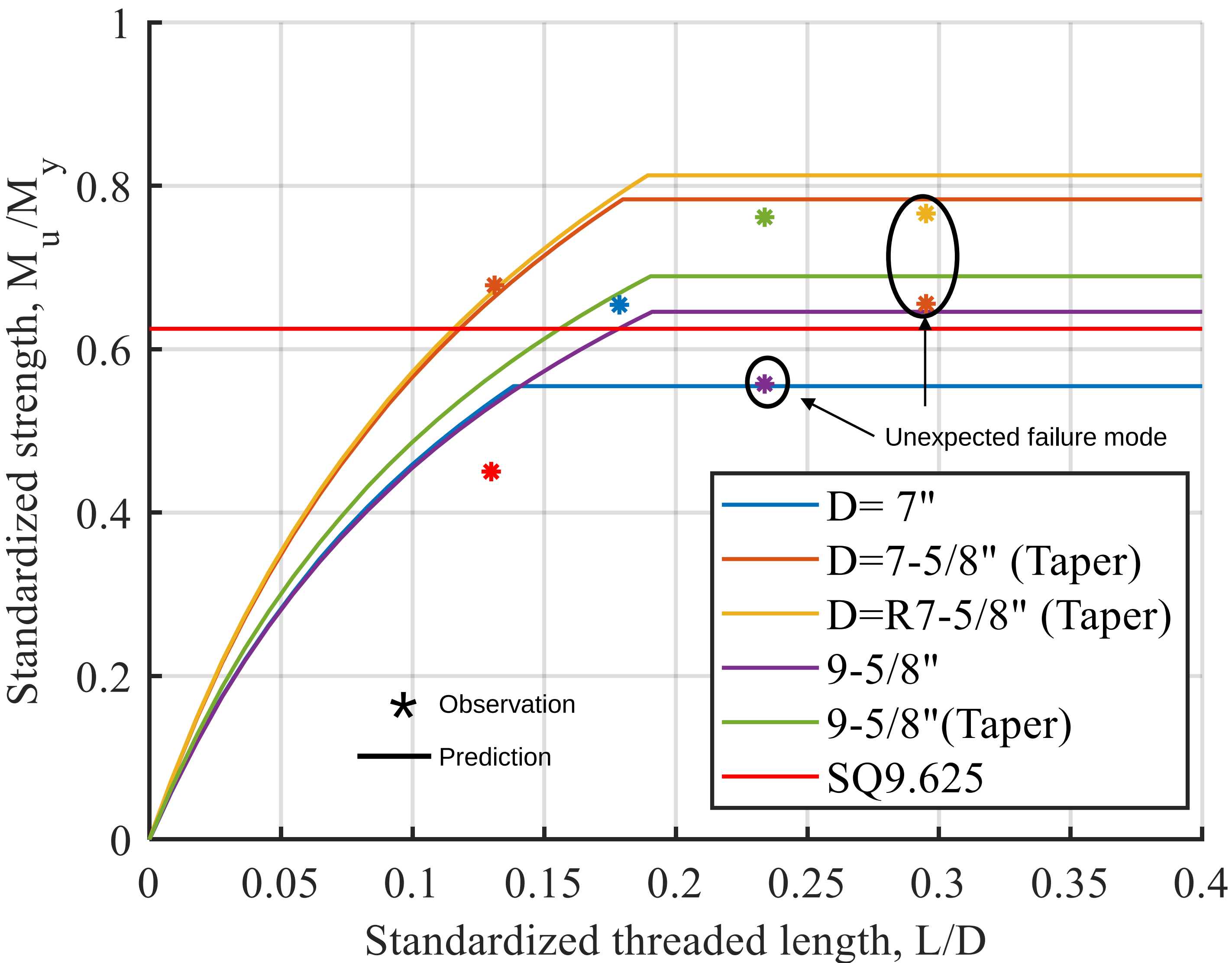
(a) Pin-end; (b) Box-end

Similar accuracy reported on previous studies

Correlation coefficient: $r = 0.87$

Error: $MRSE = 381\ \text{in} \cdot \text{kip}$

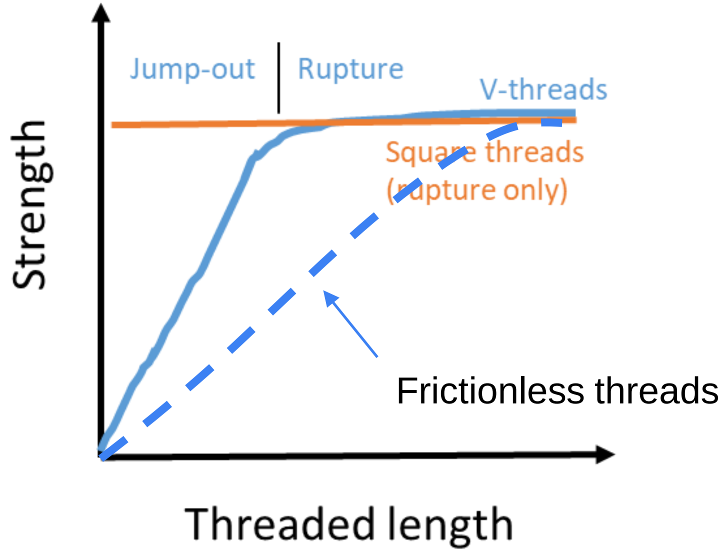
Did thread compounds affected the performance?



Average stress for jump-out:

$$f_j = \frac{a\left(\frac{2h}{D}\right)^b f_u}{\frac{1}{2} + \frac{D}{2L}\tan(\alpha - \phi)} + \frac{f_y}{1 + \frac{D}{2L}\tan(\alpha - \phi)}$$

Friction angle for threads



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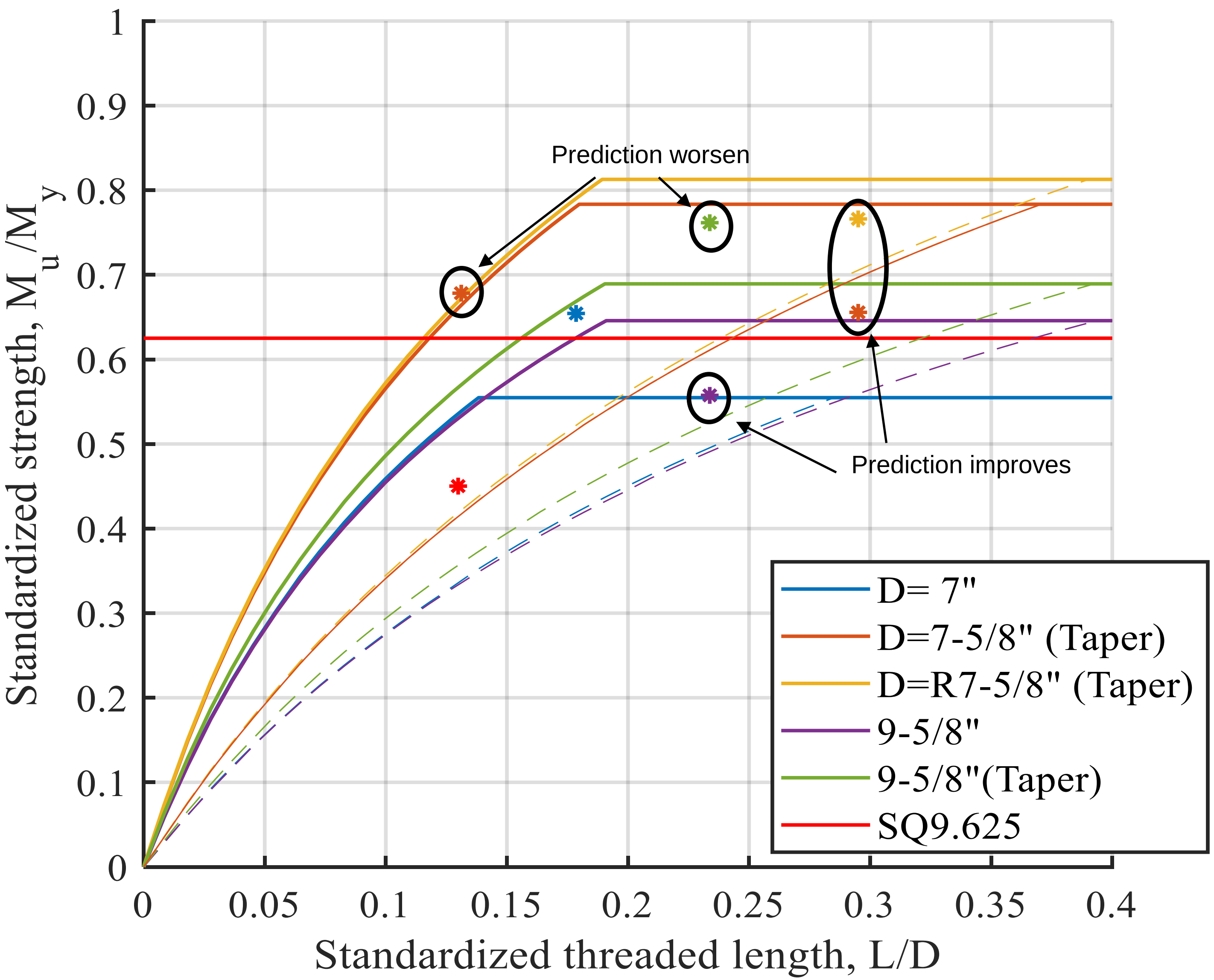
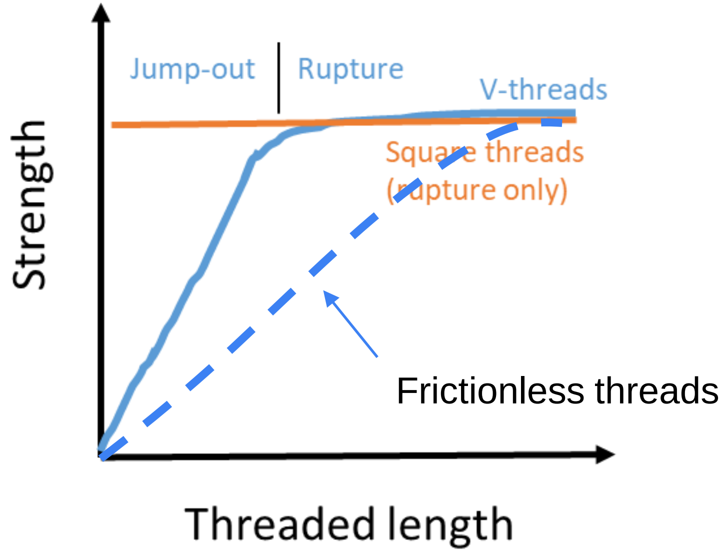


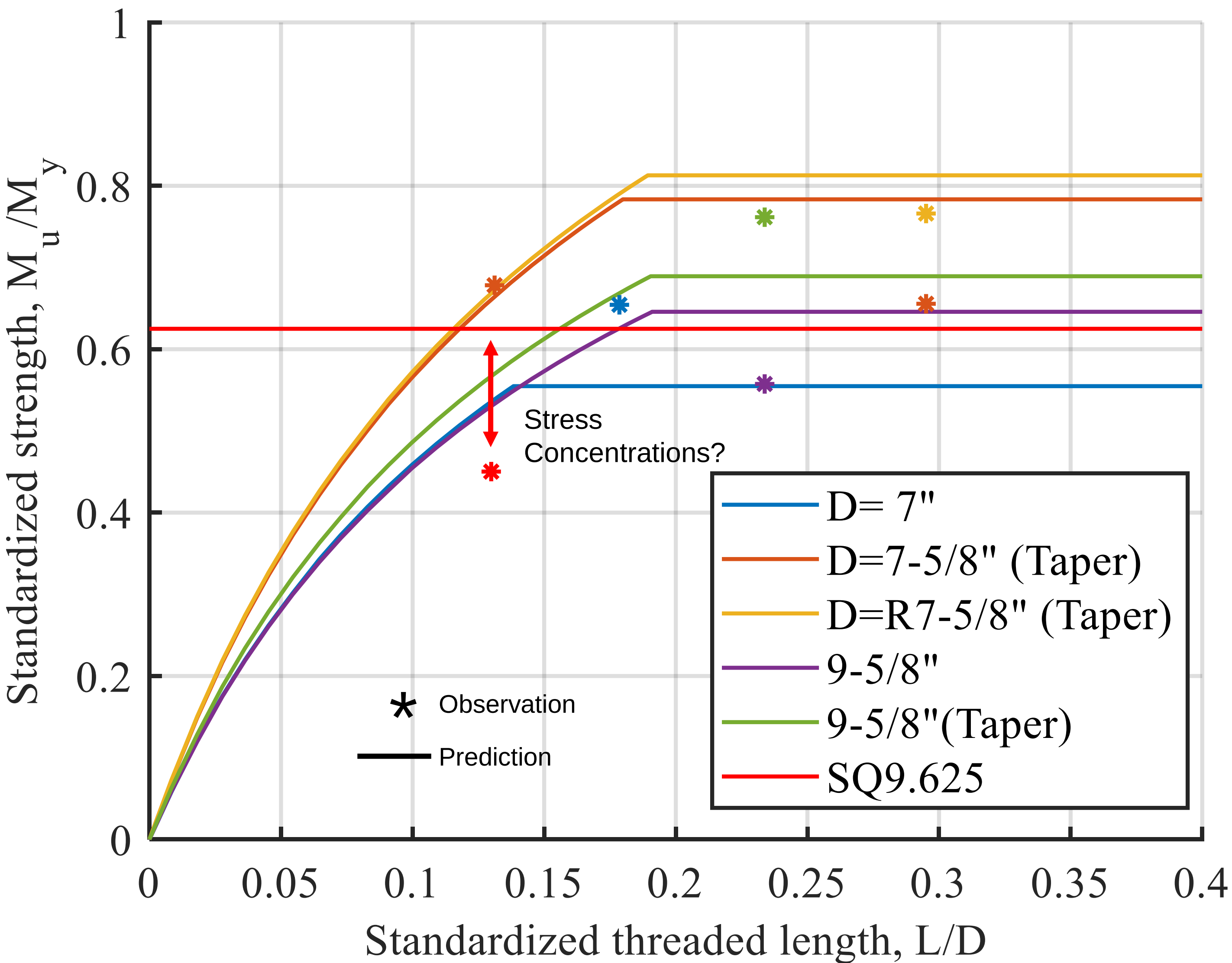
Average stress for jump-out:

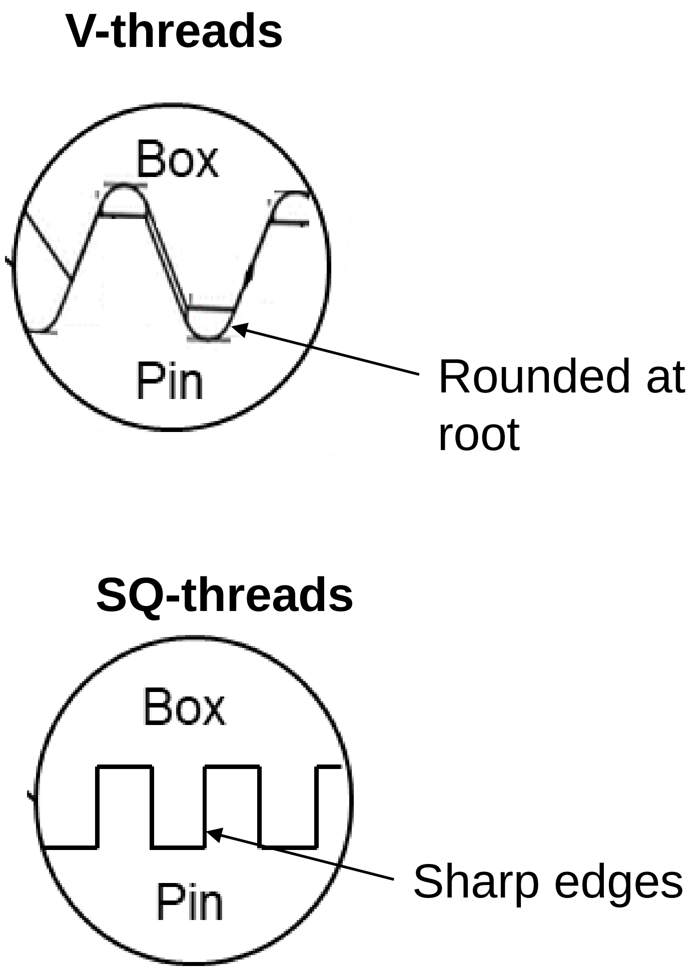
$$f_j = \frac{a\left(\frac{2h}{D}\right)^b f_u}{\frac{1}{2} + \frac{D}{2L}\tan(\alpha - \phi)} + \frac{f_y}{1 + \frac{D}{2L}\tan(\alpha - \phi)}$$

Friction angle for threads



Do stress concentrations affected square threads with thin wall at the pin?



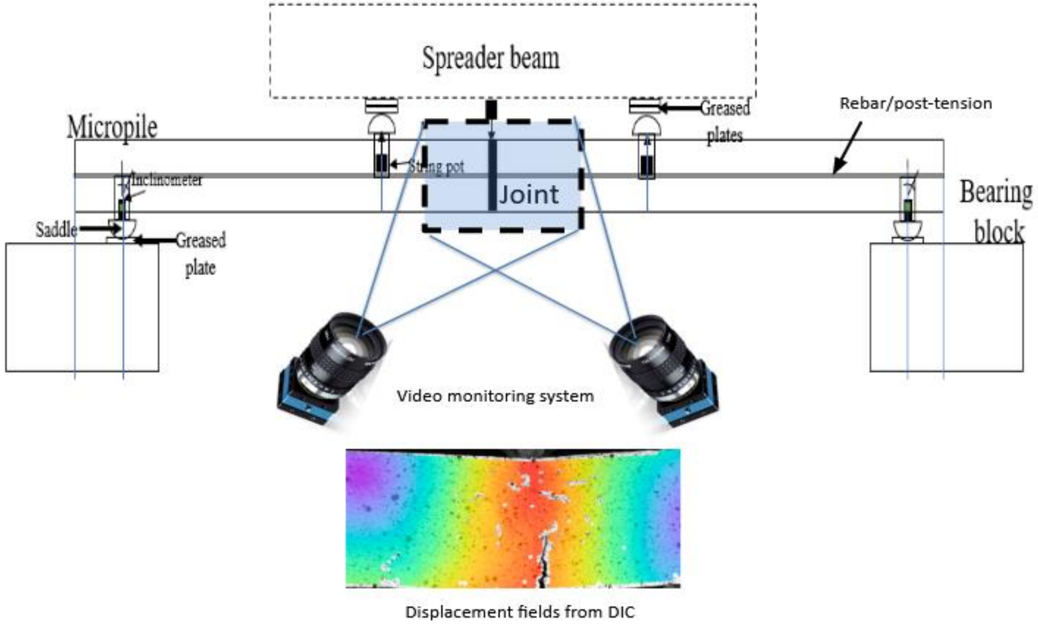


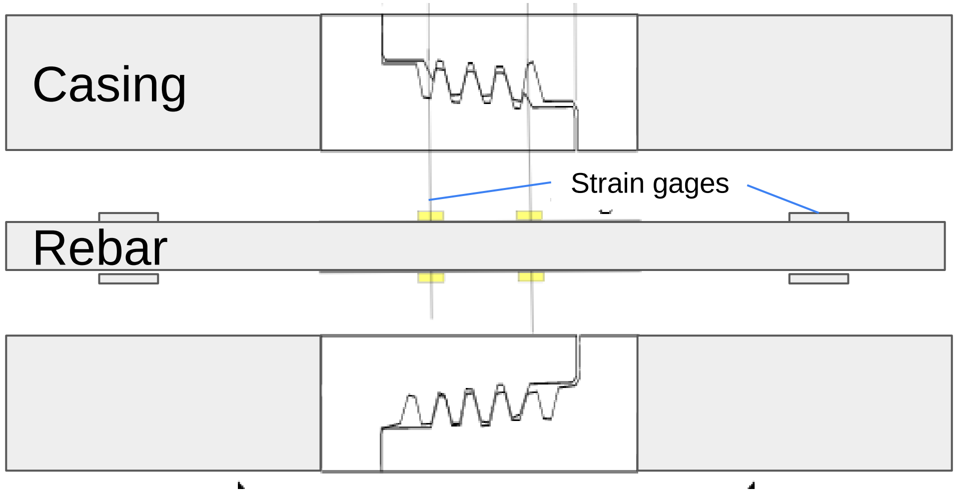
Conclusions

- Influence of joint flexibility on overall response of the micropile.
- Threads with thicker wall at the pin are stiffer and stronger.
- Larger casings require longer threads to ensure that rupture governs.
- Joint strength can be predicted with reasonable accuracy.
- Adopted model tends to overpredict the strength in jump-out, and underpredict strength in rupture. Square threads might be affected by stress concentration.
- Failure mode was successfully predicted for some specimens. Unexpected failure modes might be due to the lost of friction at the threads or inaccurate model. **Need to verify repeatability!**

Undergoing work

- Implementation of digital image correlation to monitor strain fields near the joint.
- Testing on reinforced specimens.
- Testing on post-tensioned specimens (Bending + Compression)





Acknowledgements

TIDC Transportation Infrastructure Durability Center AT THE UNIVERSITY OF MAINE

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References

AETESS. 2009. Structural Behavior of Micro-pile Joints (In spanish: Comportamiento Estructural de Uniones de Micropilotes).

Anderson, B. J., and M. R. Babalola. 2011. “Lateral Load Testing Micropiles to Evaluate the Impact of Threaded Joints and Casing Embedment on Short Micropiles in Shallow Rock.” DFI Journal - The Journal of the Deep Foundations Institute, 5 (2): 23–34. Deep Foundations Institute. https://doi.org/10.1179/dfi.2011.009.

Babalola, M. R. 2011. EVALUATION OF THE LATERAL RESPONSE OF MICROPILES VIA FULL SCALE LOAD TESTING.

Clinedinst, W. O. 1965. “Strength of threaded joints for steel pipe.” Journal of Manufacturing Science and Engineering, Transactions of the ASME, 87 (2): 125–133. American Society of Mechanical Engineers Digital Collection. https://doi.org/10.1115/1.3670774.

MALCOLM. 1995. “7 INCH PIPE TEST.” Sun Valley, California: MALCOLM DRILLING CO., INC.

Montoya-Vargas, S., A. Gallant, and W. G. Davids. 2022. “Flexural Strength of Micropile Threaded Connections.” Geo-Congress 2022. American Society of Civil Engineers (ASCE).

Musselman, S. R., J. H. Long, N. Carroll, and S. Farr. 2007. Bending Strength of Micropile Threaded Connections.

NICHOLSON. 2005. “Report on 9.625" Micropile Casing Thread Bending Tests.” Cuddy, Pennsylvania.

Zanuy, C., P. De La Fuente, and M. Pinilla. 2012. “Bending strength of threaded connections for micropiles.” J Constr Steel Res, 78: 68–78. https://doi.org/10.1016/j.jcsr.2012.06.009