



Influence of geometric scaling on the adaptive behavior of variable curvature friction pendulum bearings

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June 8 , 2026



Background and Motivation

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1 Background and Motivation

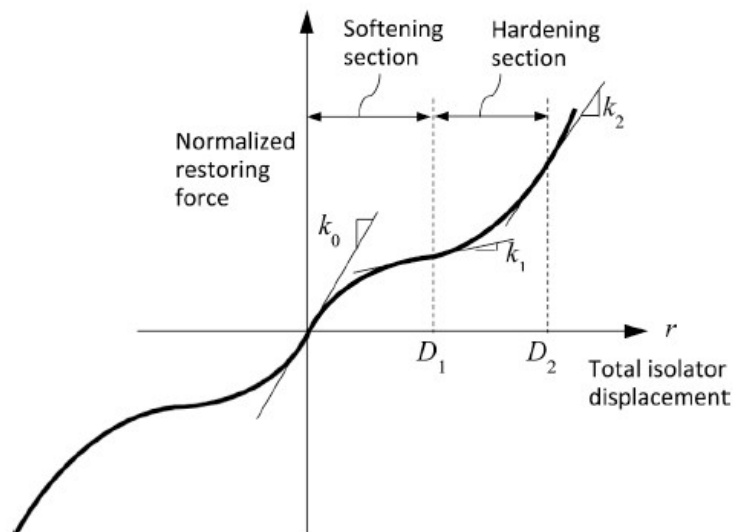
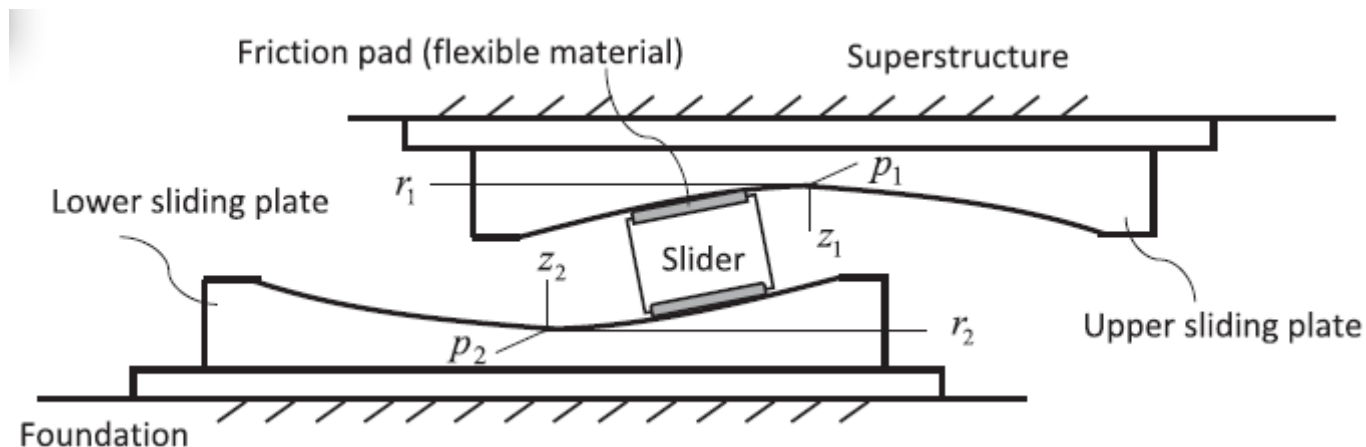
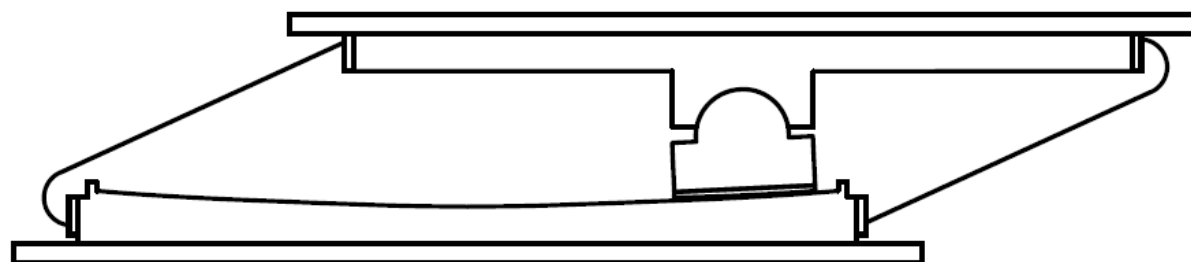


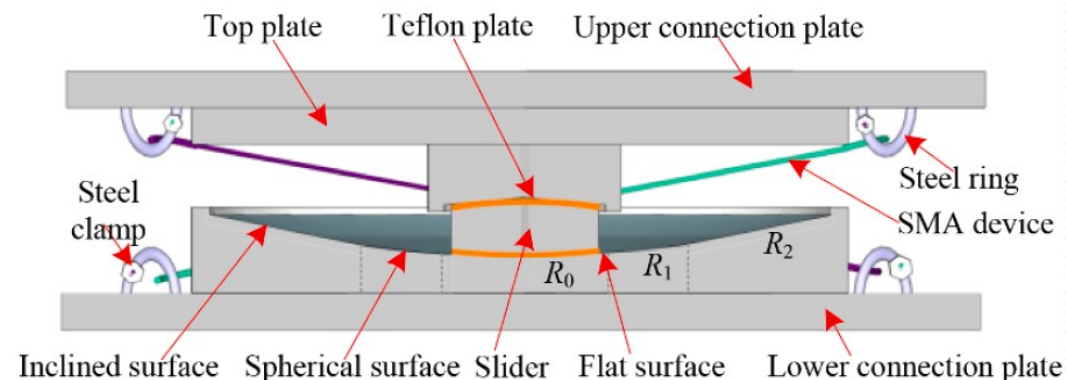
Fig. 5. Design parameters for the restoring force of the DPFP.



Double sliding isolator with variable curvature (DSIVC) (Lu et.al)



Multiple-variable frequency pendulum isolator (MVFPI) (Han et.al)



Superelastic pendulum isolator with multi-stage variable curvature (SPIVC) (Zheng et.al)

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Background and Motivation



**Full-size
bearing**

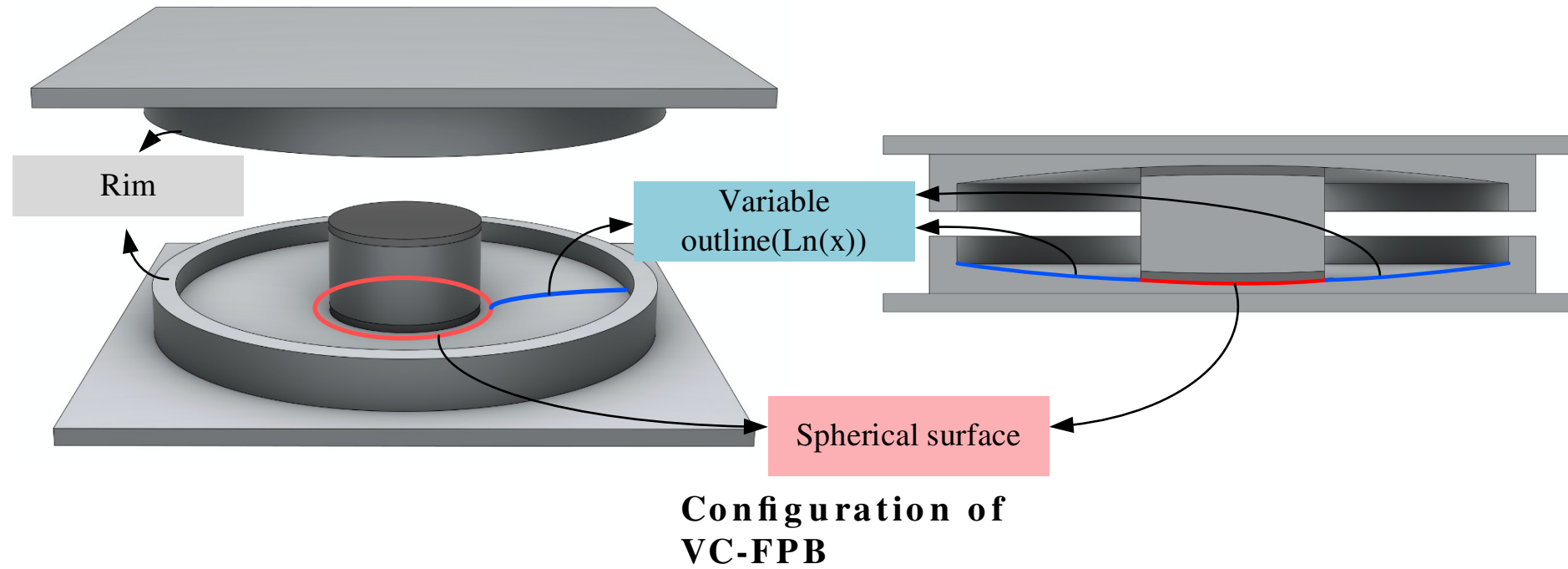


**Shake table
test**

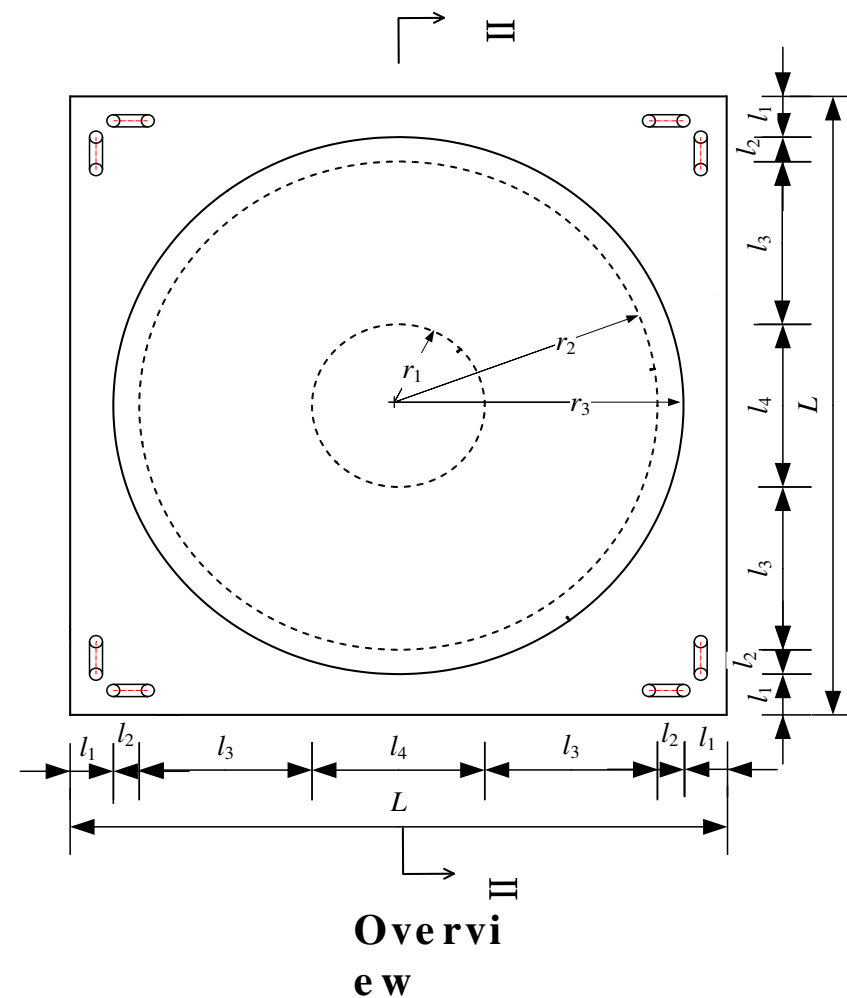
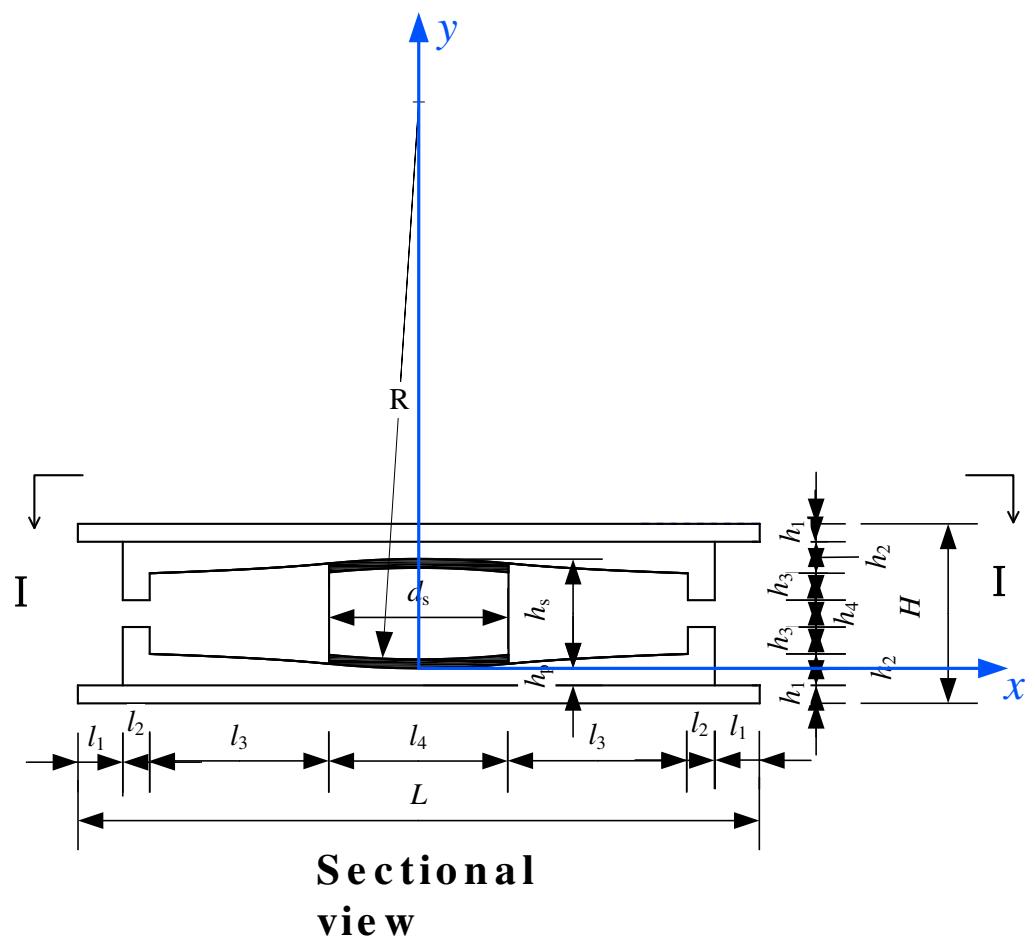


**Small-scale
specimen**

2 Experimental Testing of VC-FPBs



2 Experimental Testing of VC-FPBs



Specimen dimensions

2 Experimental Testing of VC-FPBs

Table.1. Dimensions of specimens (Unit: mm)

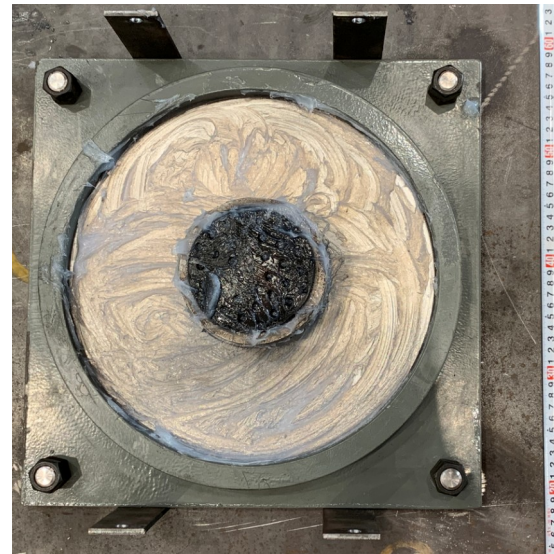
Specimen	R	d _s	h _s	r ₁	r ₂	L	l ₁	l ₂	l ₃	l ₄	H	h ₁	h ₂	h ₃	h ₄	h _p
S1	1000	200	122	100	200	760	50	30	200	200	200	20	31.7	30	36.6	19
S2	500	100	72	50	100	400	20	20	100	120	130.6	20	17.9	20	15	9.4
S3	250	50	40	25	75	310	30	15	85	50	110	20	20	10	10	15
S2M	500	100	81	70	100	400	20	20	90	140	121.2	20	17.9	20	5.5	4.7
S3M	250	50	57	50	75	310	30	15	60	100	110.8	20	20	10	10.8	6.9

2

Experimental Testing of VC-FPBs



(a) Encased steel plate



(b) Apply silicon oil

Assembly process



(c) Installed specimen

2 Experimental Testing of VC-FPBs



**S
1**

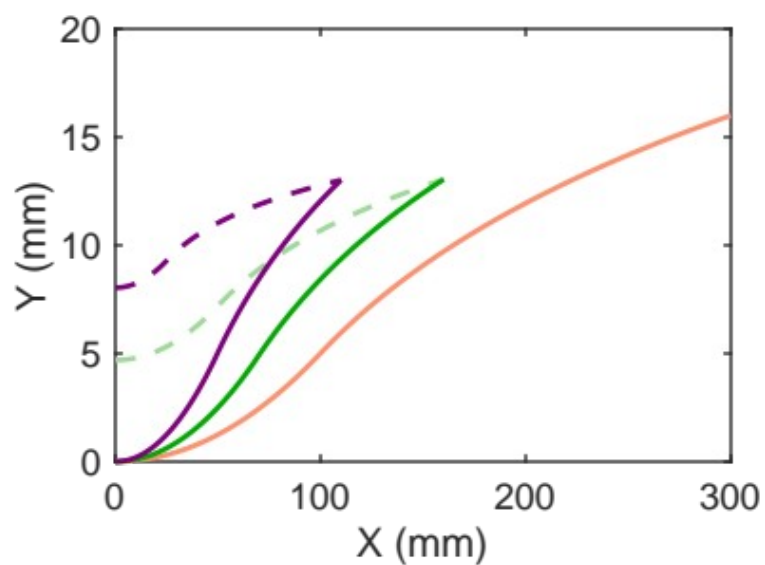


**S2 and
S3**

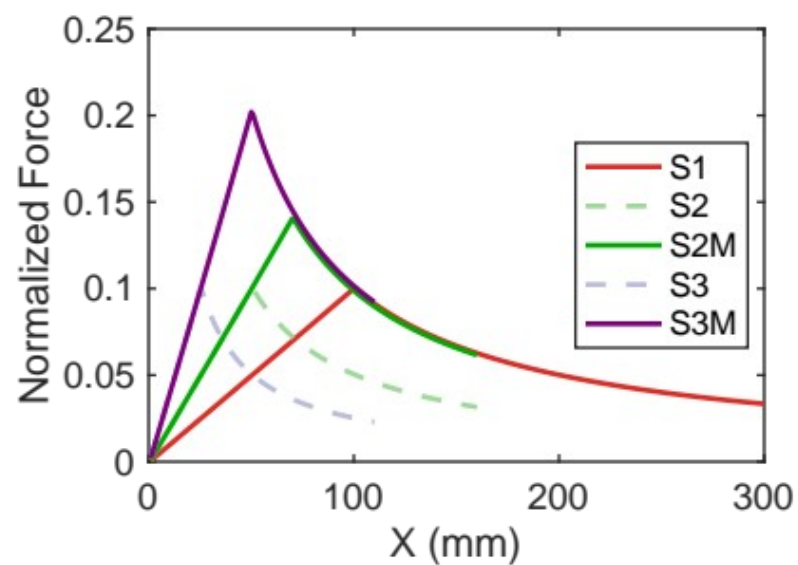


**S2 M and
S3 M**

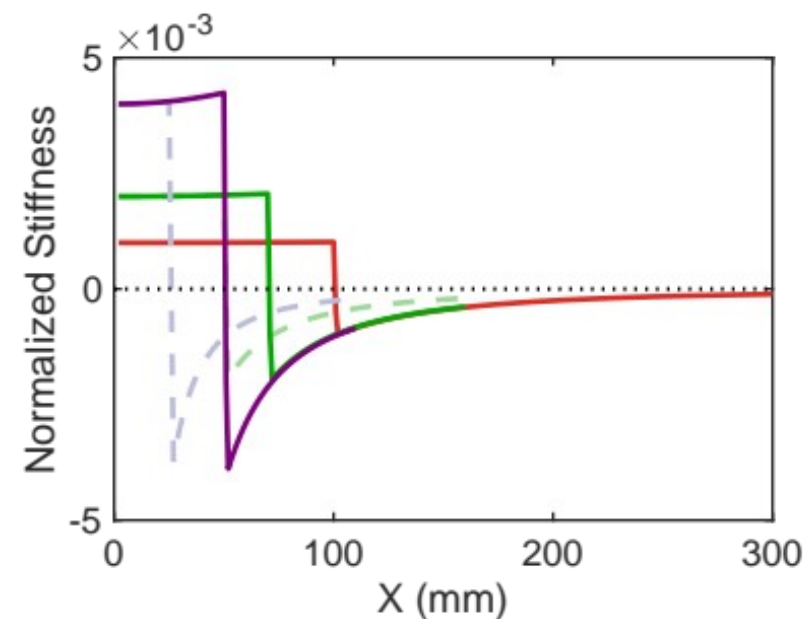
2 Experimental Testing of VC-FPBs



(a) Geometrical shape of variable curved surface



(b) Normalized force of VC surface



(c) Normalized stiffness of VC surface

Comparison of the specimens

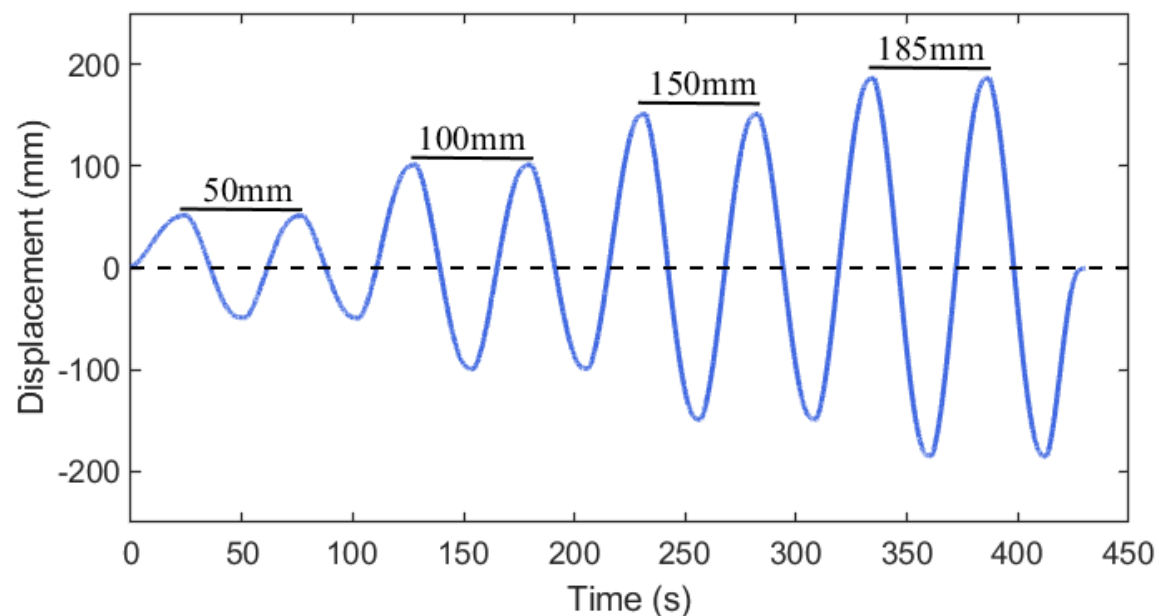
2 Experimental Testing of VC-FPBs



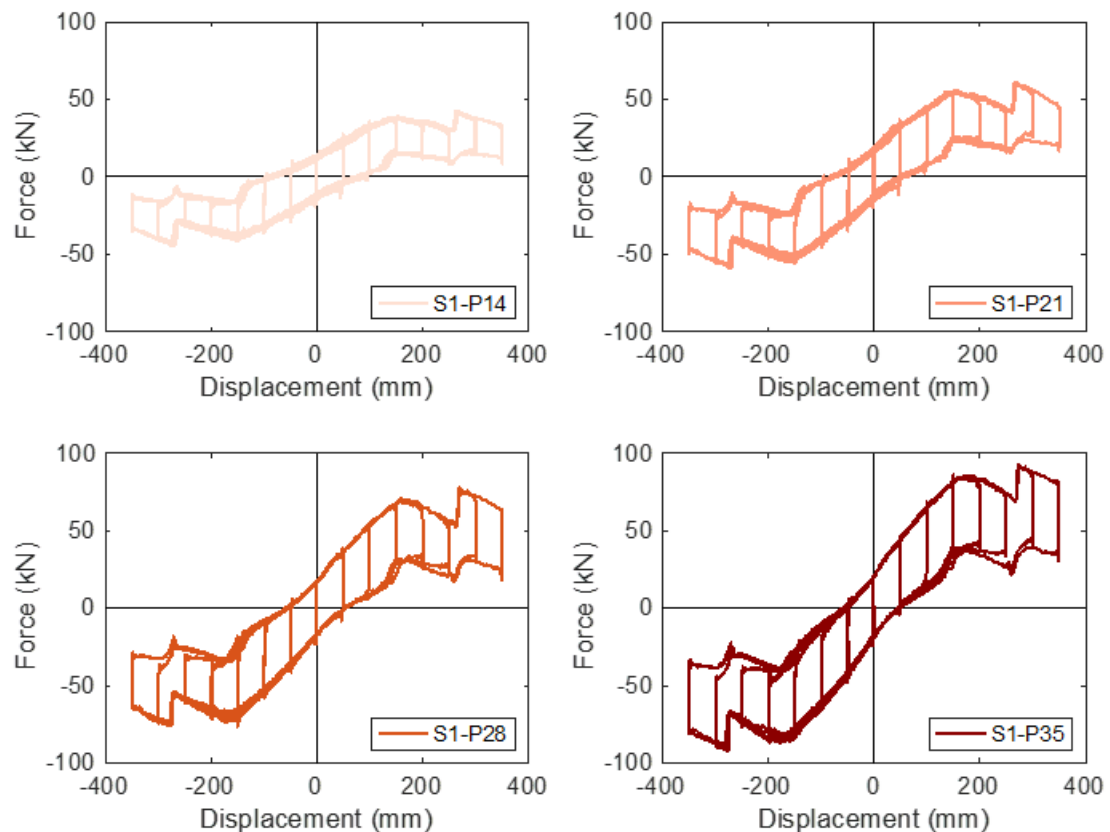
2 Experimental Testing of VC-FPBs

Table.2 Loading

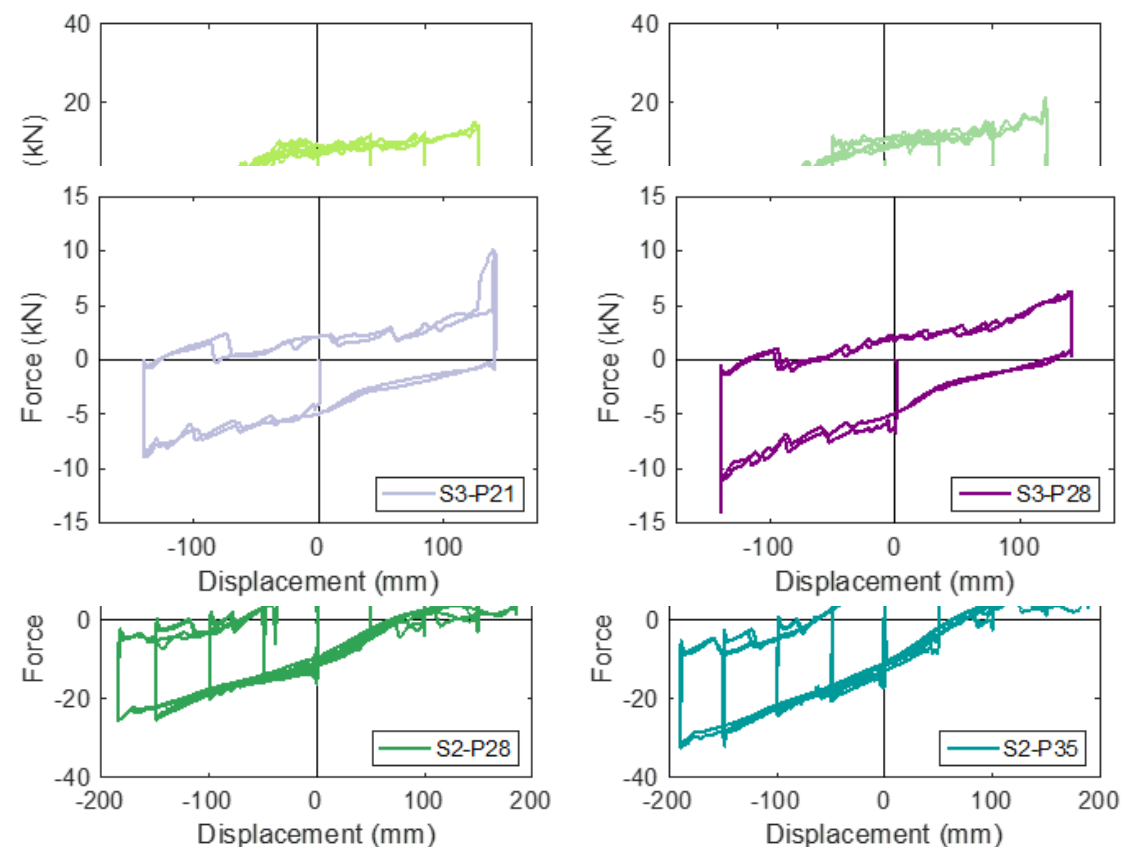
Case	Vertical Load (kN)	Average Pressure (MPa)	Loading Cycles	Loading Frequency (Hz)	Disp. Amplitude (mm)
S1-P14	400	14.1	2	0.005	50-350
S1-P21	600				
S1-P28	800				
S1-P35	1000				
S2-P14	75				
S2-P21	100				
S2-P28	150				
S2-P35	200				
S3-P21	37.5				
S3-P28	50				
S2M-P14	100				
S2M-P21	150				
S2M-P28	200				
S2M-P35	250				
S3M-P14	25	14.1	2	0.002	50-135
S3M-P21	37.5	21.2	2	0.002	50-135
S3M-P28	50	28.2	2	0.002	50-135
S3M-P35	62.5	35.3	2	0.002	50-135



2 Experimental Testing of VC-FPBs

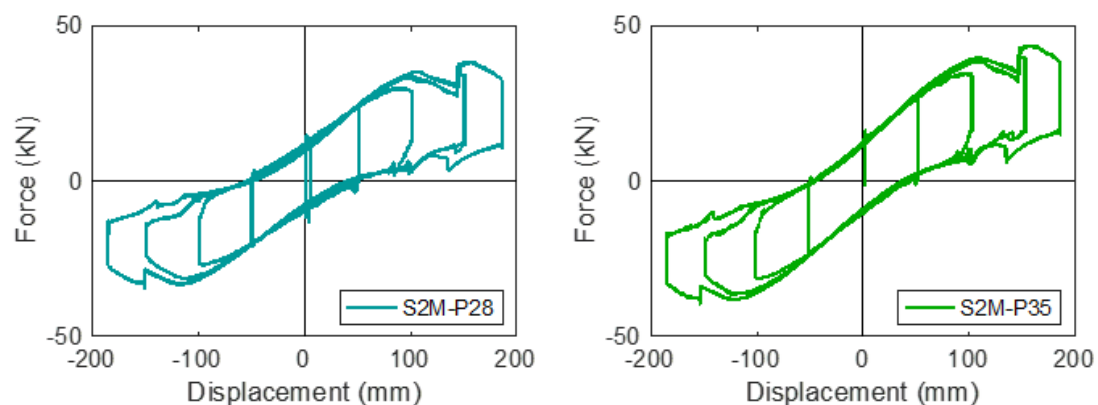
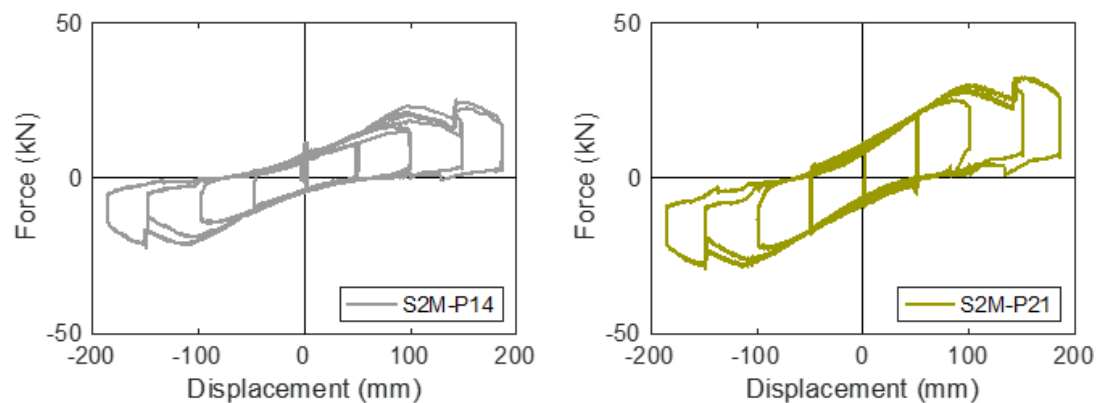


**Hysteretic curves
of S1**

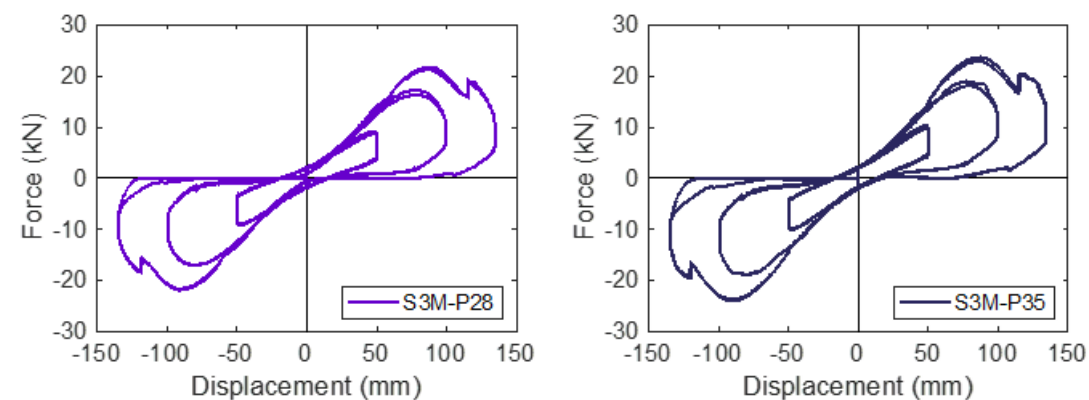
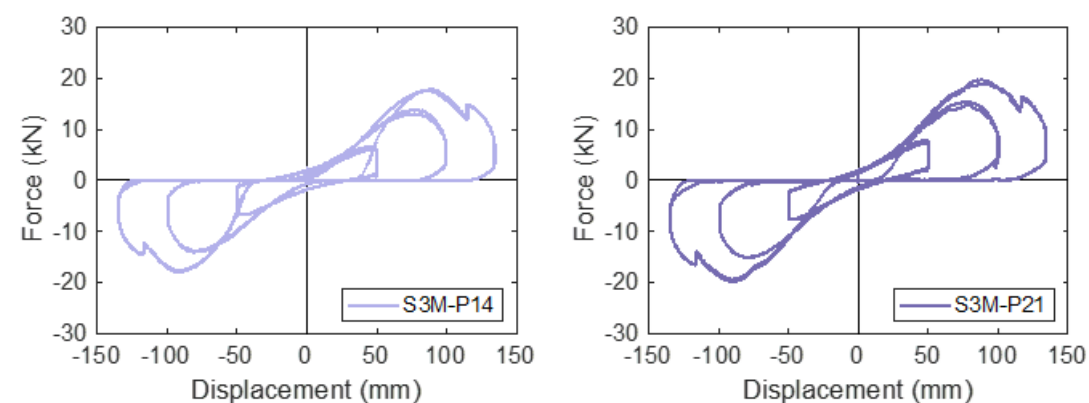


**Hysteretic curves
of S2**

2 Experimental Testing of VC-FPBs

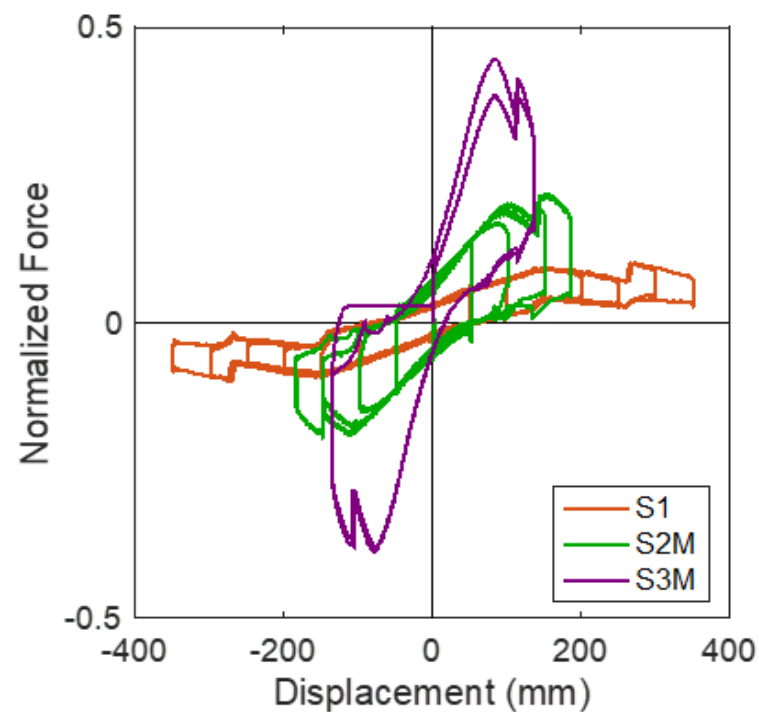


**Hysteretic curves of
S2M**

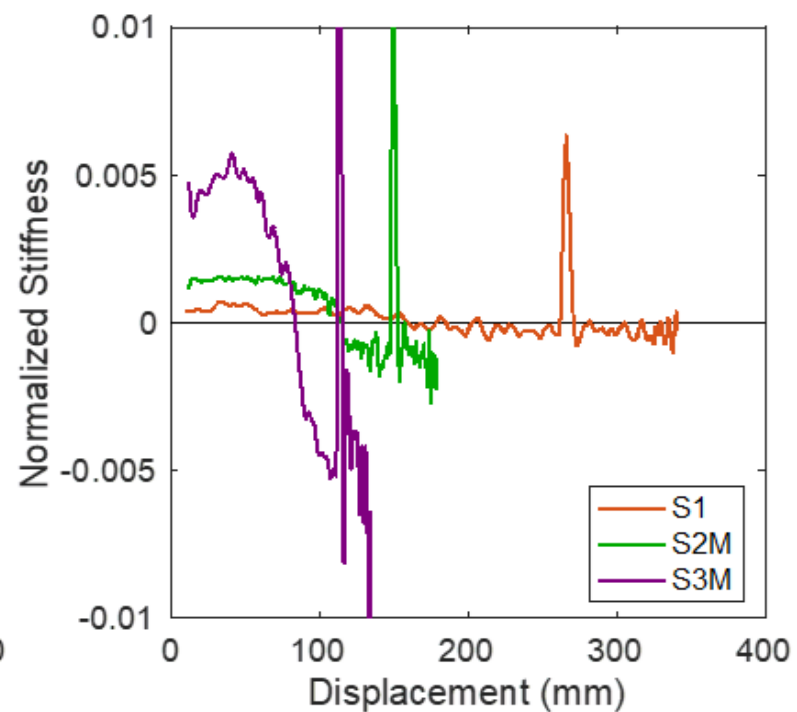


**Hysteretic curves of
S3M**

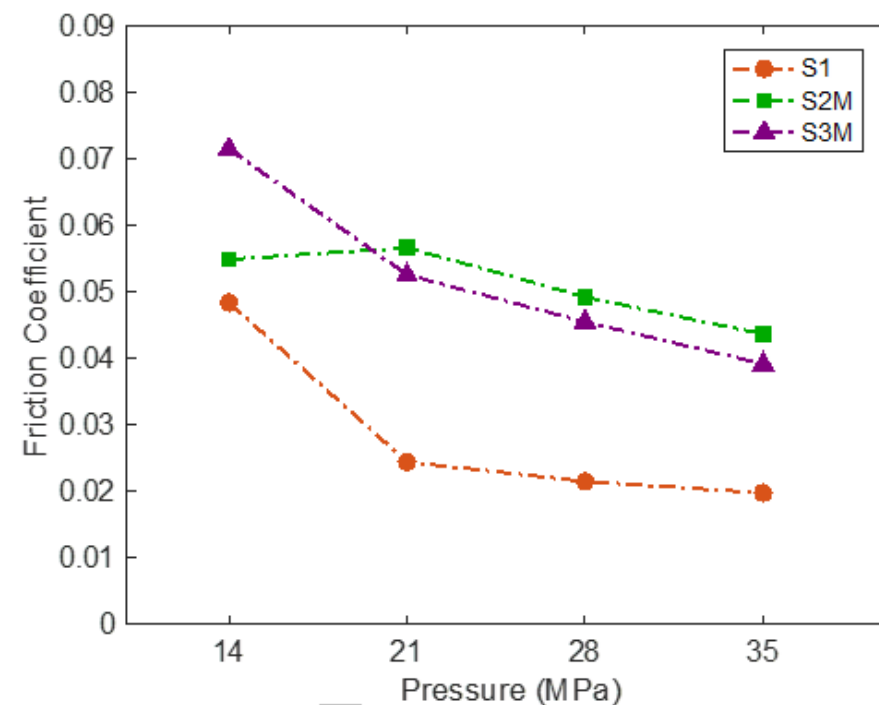
2 Experimental Testing of VC-FPBs



**Normalized
force**



**Normalized
stiffness**

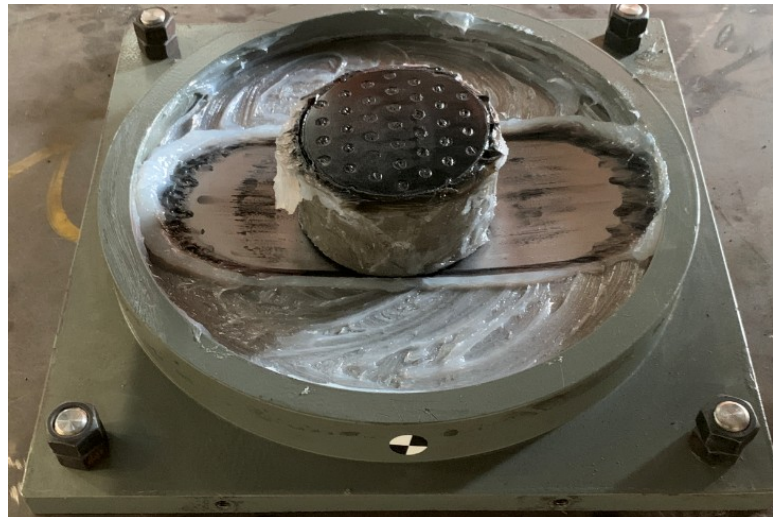


**Friction
coefficient**

2 Experimental Testing of VC-FPBs



S1



S2M

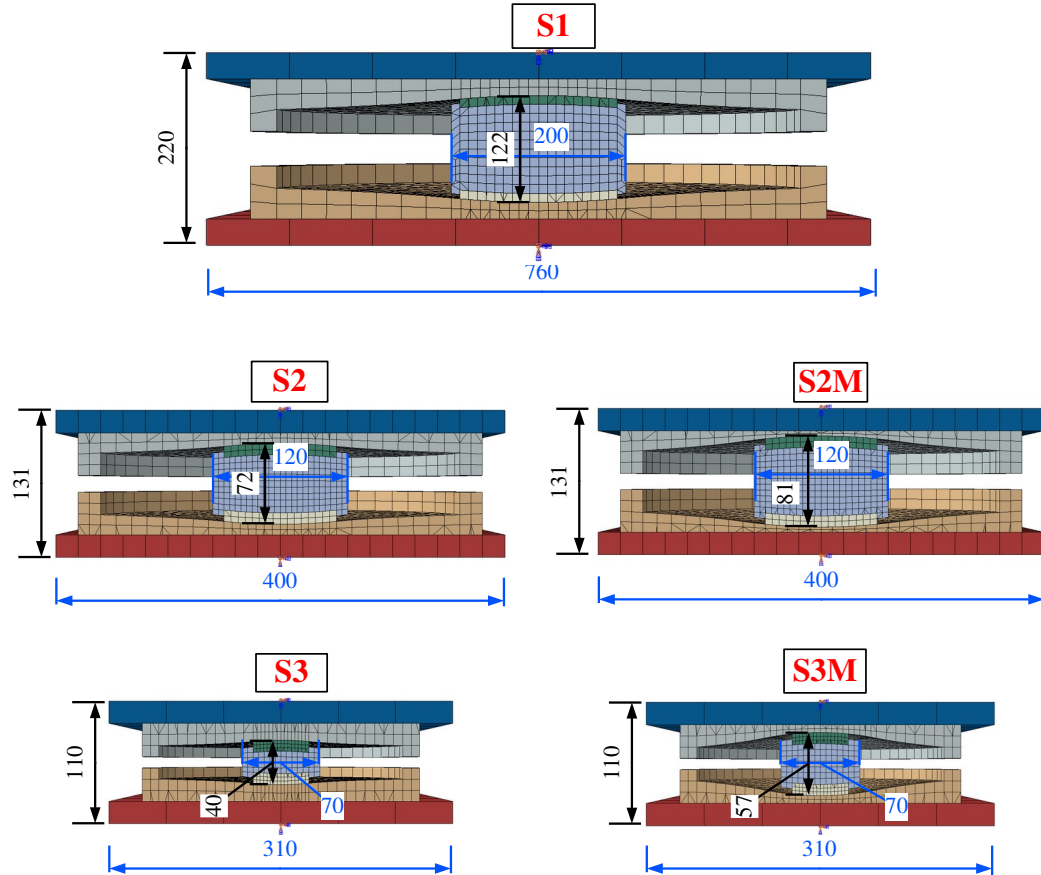


S3
M

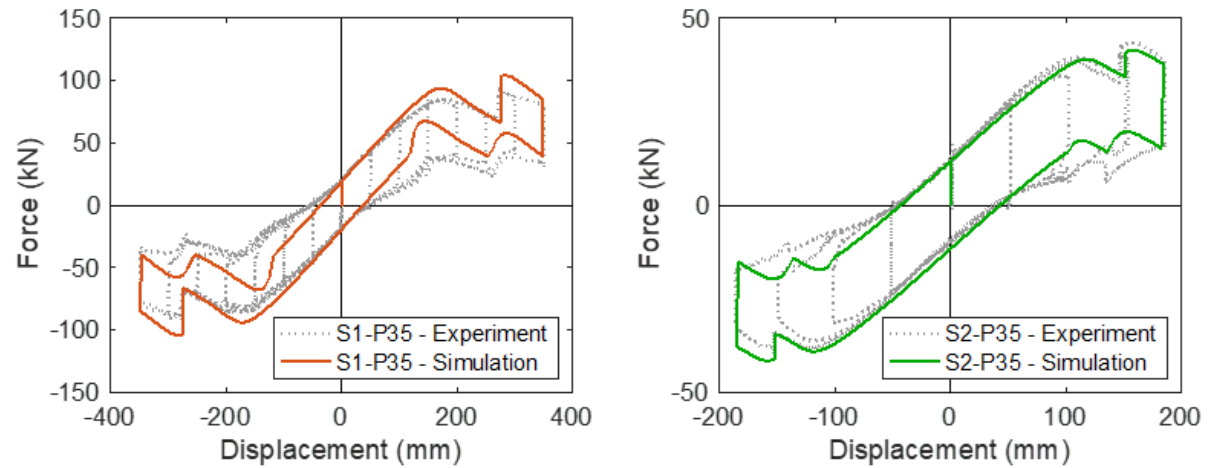
State of friction pads after all
the tests

3

Numerical Simulations of VC-FPBs

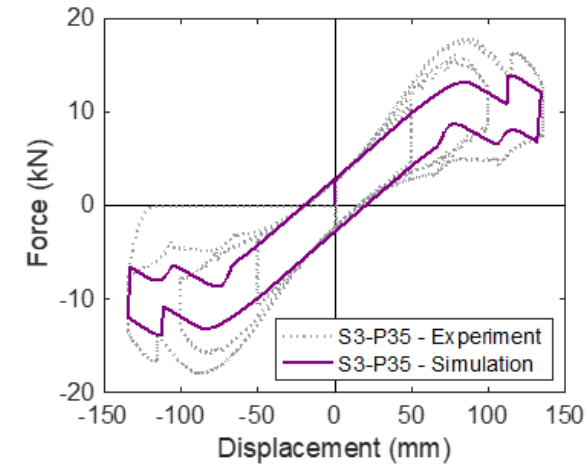


Abaqus Finite element model



(a)

(b)



(c)

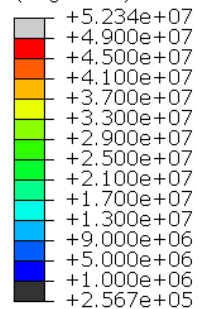
Comparison of numerical and experimental results

3

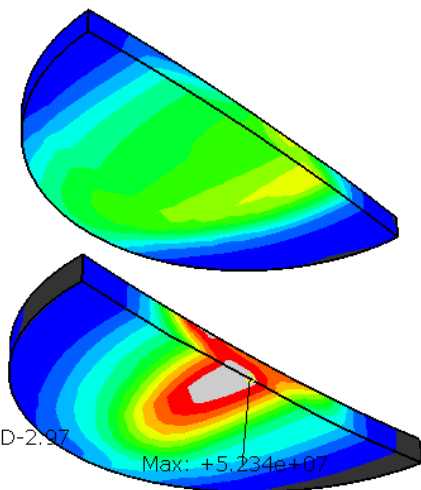
Numerical Simulations of VC-FPBs

Stress

S, Mises
(Avg: 75%)

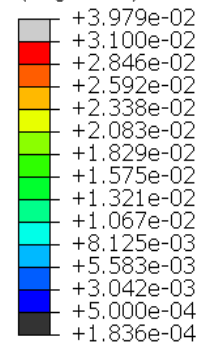


Max: +5.234e+07
Elem: FRICTIONPAD-2.97
Node: 50

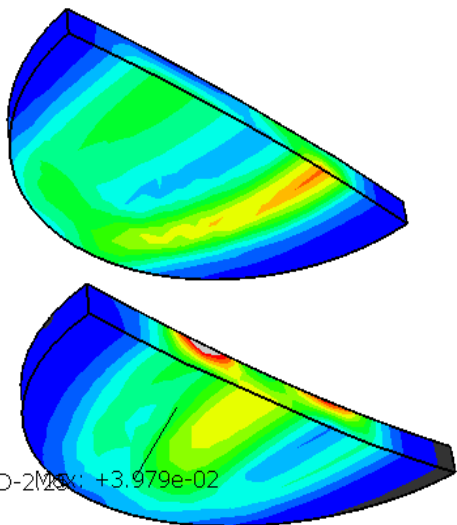


Strain

LE, Max. Principal
(Avg: 75%)

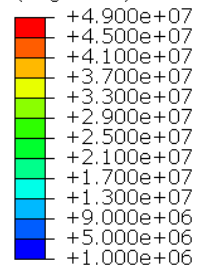


Max: +3.979e-02
Elem: FRICTIONPAD-2.97
Node: 793

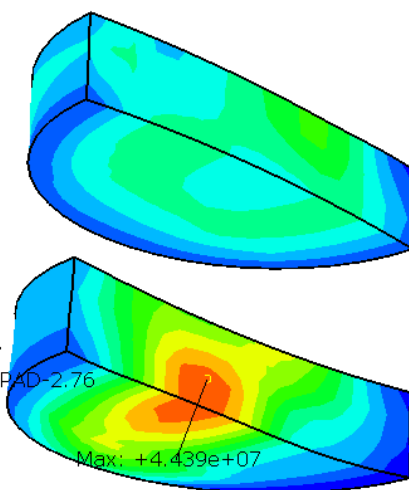


S1

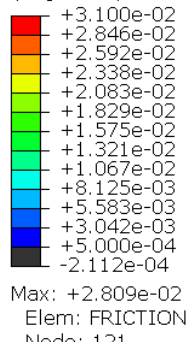
S, Mises
(Avg: 75%)



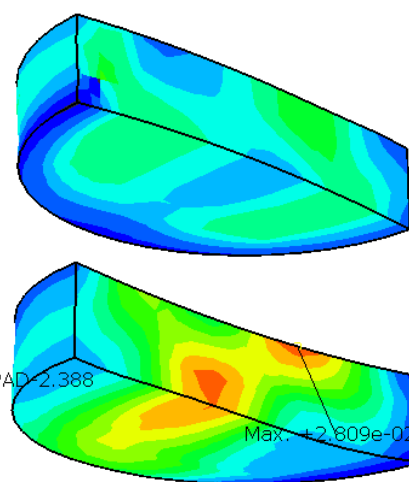
Max: +4.439e+07
Elem: FRICTIONPAD-2.76
Node: 205



LE, Max. Principal
(Avg: 75%)

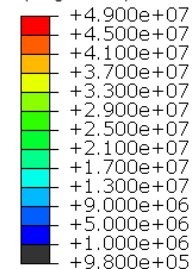


Max: +2.809e-02
Elem: FRICTIONPAD-2.388
Node: 121

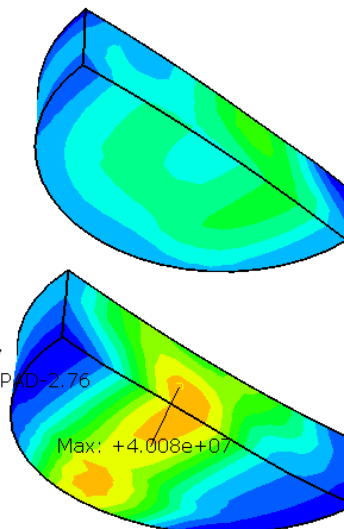


S2
M

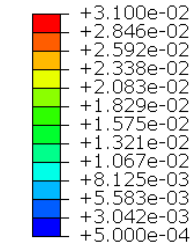
S, Mises
(Avg: 75%)



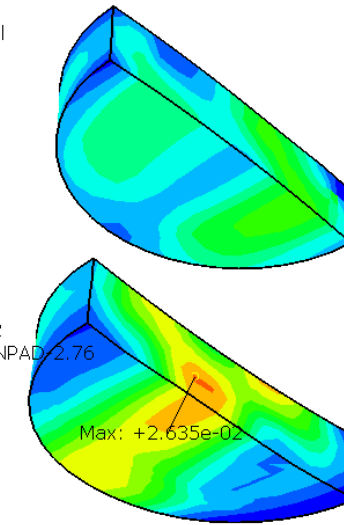
Max: +4.008e+07
Elem: FRICTIONPAD-2.76
Node: 205



LE, Max. Principal
(Avg: 75%)



Max: +2.635e-02
Elem: FRICTIONPAD-2.76
Node: 205



S3
M



4 Conclusion

1. As specimen size decreases, the discrepancy in the height depth of the variable curved surfaces becomes smaller, leading to a more confined and shallower stress and strain distribution within the friction pads. This geometric limitation causes **the adaptive stiffness behavior to diminish or disappear entirely in small-scale specimens.**
2. To recover the intended adaptive stiffness behavior in scaled VC-FPBs, it is necessary to **adopt variable curvature surfaces with more pronounced height differences.**
3. **The depth of the friction pads** plays a critical role in determining the distribution of stress and strain, and consequently the friction coefficient.
4. **The stress penetration depth and deformation mechanisms vary significantly with scale.** Larger specimens displayed deeper stress concentrations and more localized nonlinear behavior, whereas smaller specimens experienced broader, more uniform stress distributions, reducing the clarity of variable stiffness transitions.



Thanks !

