# Experimental Investigation on the Seismic Response of Bridge Bearings

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# Purpose of study

Examine the behavior of bridge bearings under seismic conditions.

- Little research has been done on their performance in seismic conditions. Bridge bearings have typically been designed for service conditions.

- An experimental program imposing a wide-range of displacements and velocities that could be experienced during an earthquake.

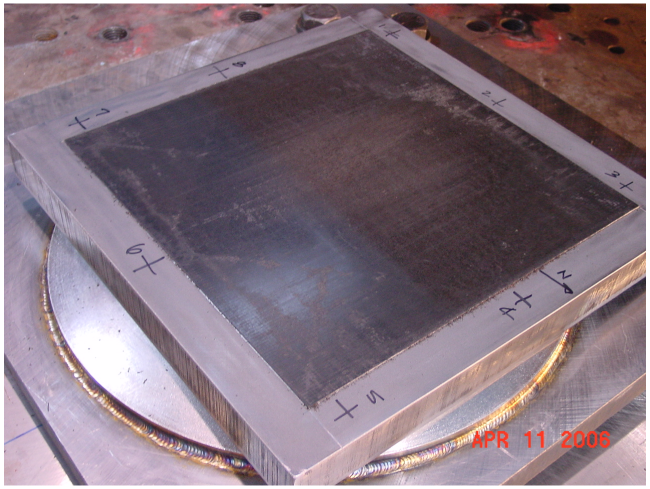
# Bridge bearing types

Study focuses on 3 types of bridge bearings:

(a) steel-reinforced elastomeric bearings

(b) steel-reinforced elastomeric bearings with PTFE (i.e. Teflon) disk sliders

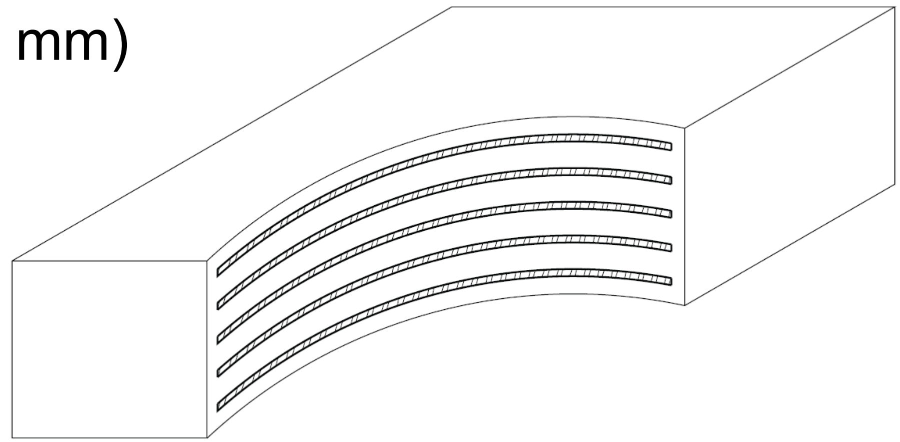
(c) spherical bearings with Woven-PTFE sliding surfaces



# Bearings in bridge design

- Allow the translation and rotation of a bridge.
- Variety of materials.
- The type of bearing.
- Elastomeric Bearings: little maintenance, no moving parts, good longevity and very economical.
- Spherical bearings: larger vertical loads, displacements and rotations but heavier and more expensive.

# (a) Steel-reinforced elastomeric bearings



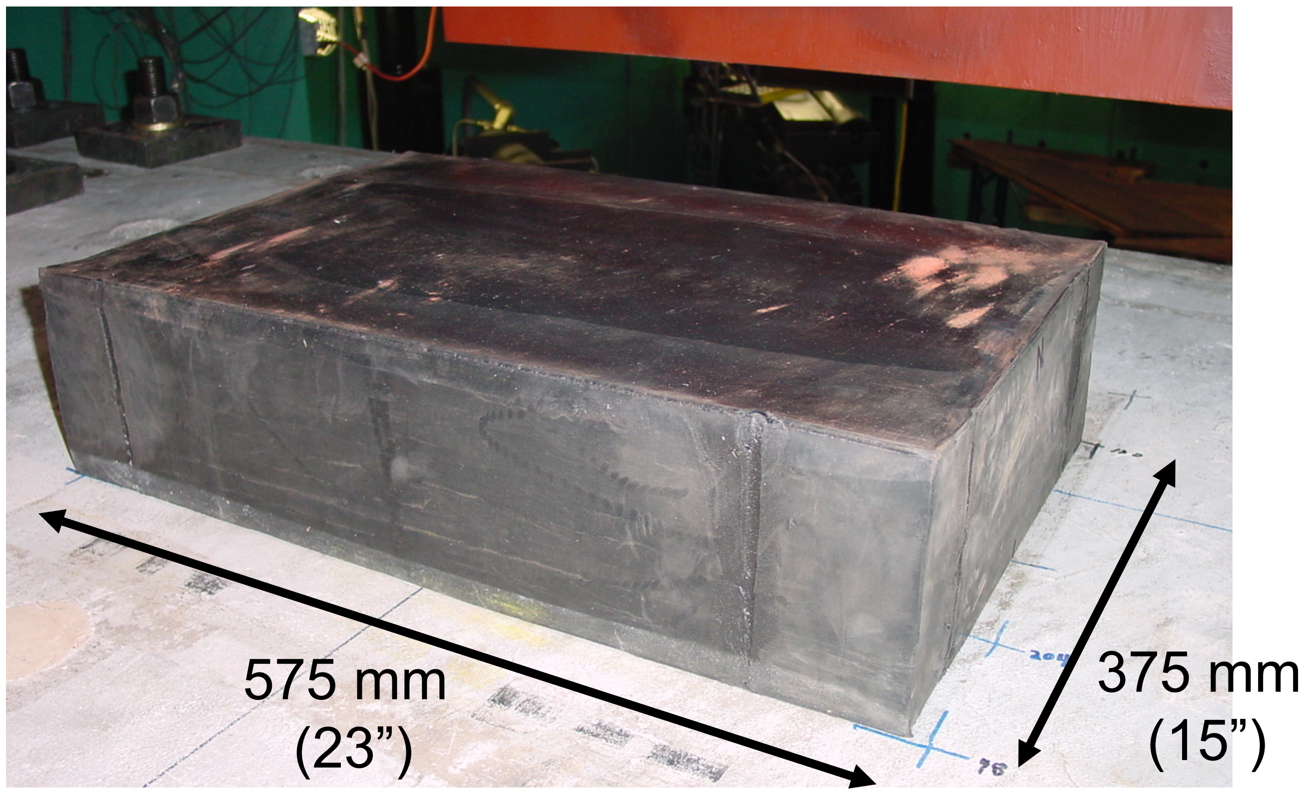
Neoprene Rubber, layer thickness: 0.47" (12 mm)
shear modulus = 0.8 MPa (117 psi)
Hardness = 55 (Shore A)

A1011 Steel Shims: 1.9 mm (14-ga)

Top/bottom layers and cover: 6 mm (0.24")

**3 sizes**

S-48: 56 mm (2.2")
S-120: 139 mm (5.5")
S-204: 236 mm (9.1")

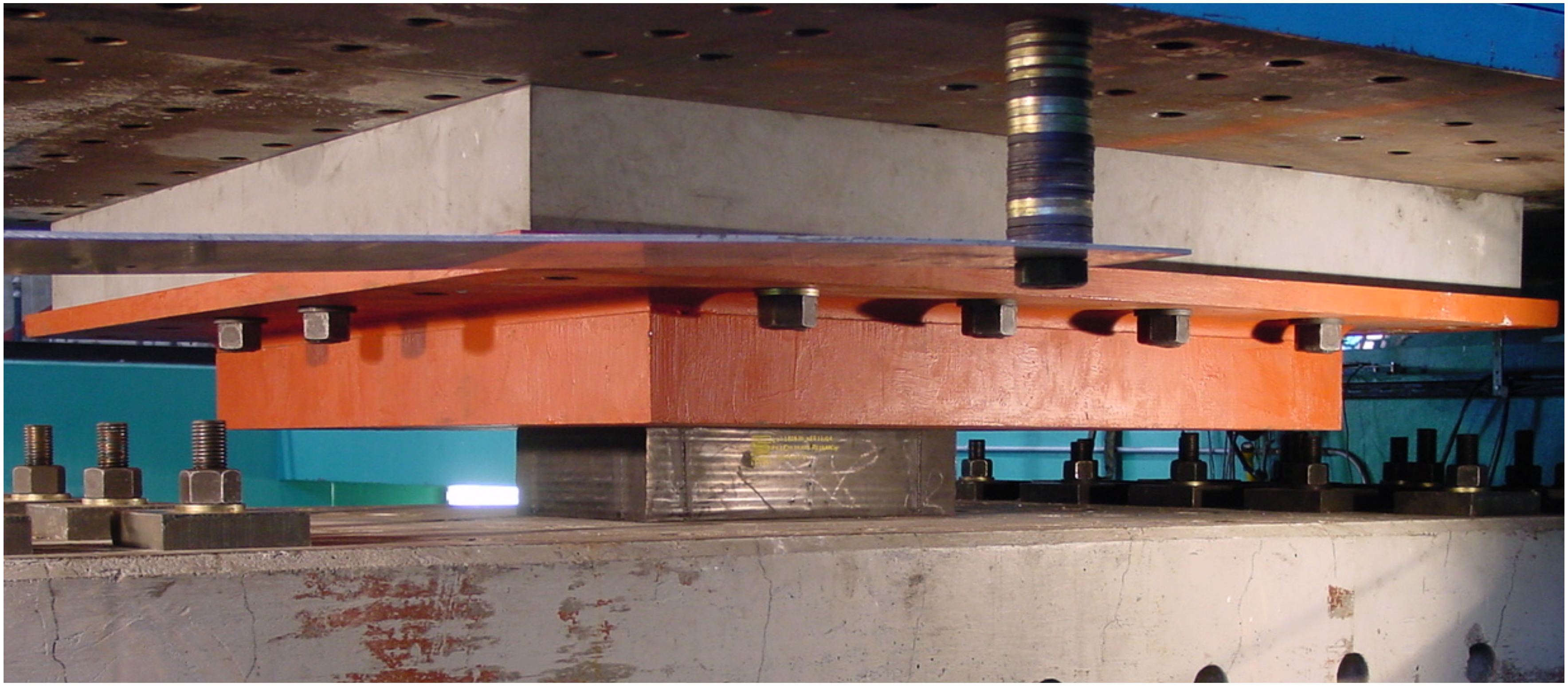


# Elastomeric bearings in bridge codes

- Under currently accepted design practice (AASHTO 1998, Caltrans 2000), the maximum shear strain developed in the elastomer due to all sources of deformation is not to exceed 50%.

- On the other hand, seismic isolation bearings for bridges and buildings are designed for much larger shear strains, and it is known that under shear loading the shear strain at failure can exceed 400%.

# Caltrans-SRMD testing facility (UC San Diego)

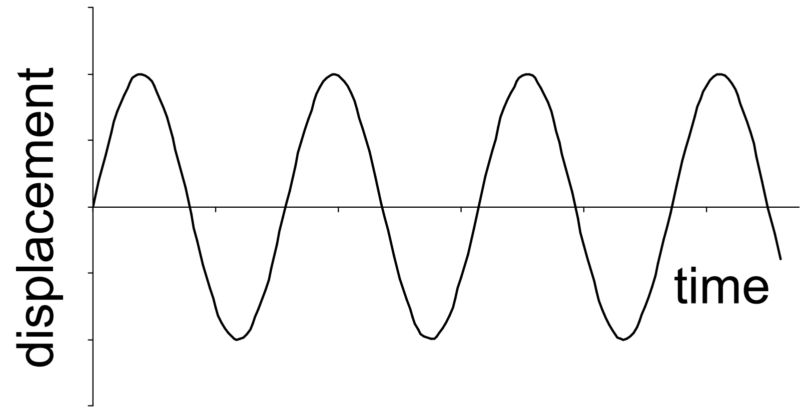


**S-120 bearing on the Caltrans-SRMD testing facility**


**S-204**

# Test program

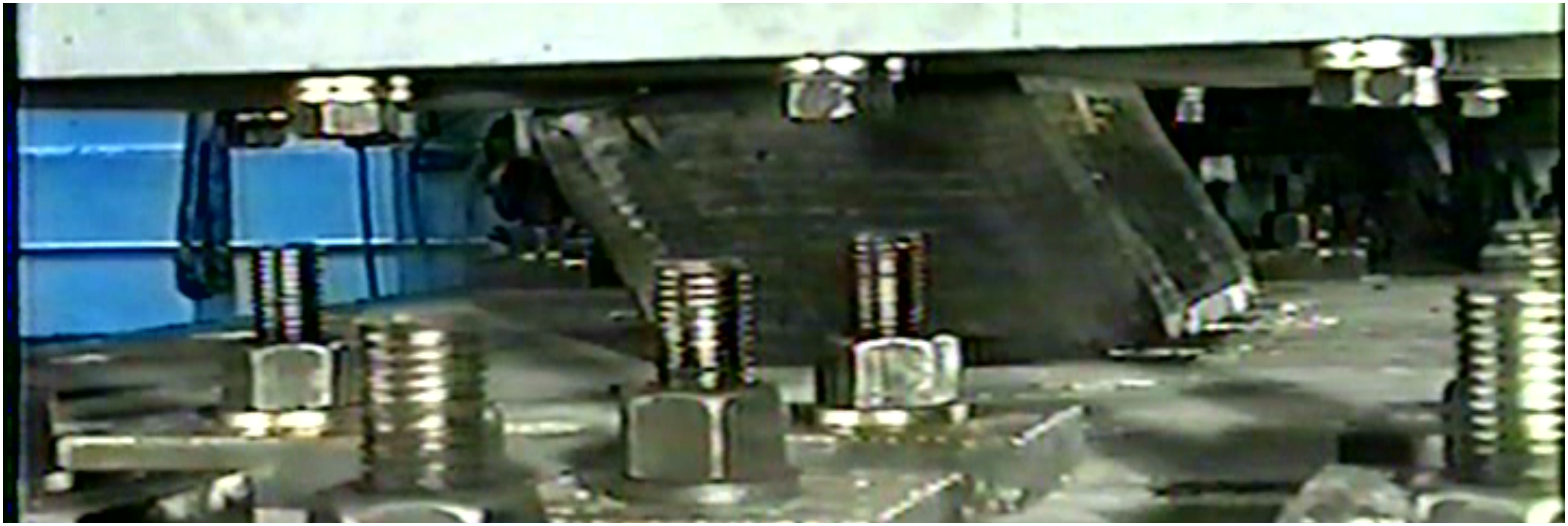
- Sinusoidal input signals with varying
  - shear strain amplitude
    (up to 300% for short bearing)
  - frequency (velocities up to 32 in/sec)




- Vertical load
  - 400 kips (1,200psi average pressure)
  - 65 kips (200psi average pressure)
- Rotation
  - 0 degrees, and
  - 1.5 degrees

about axis transverse to the loading axis

# S-204 bearing



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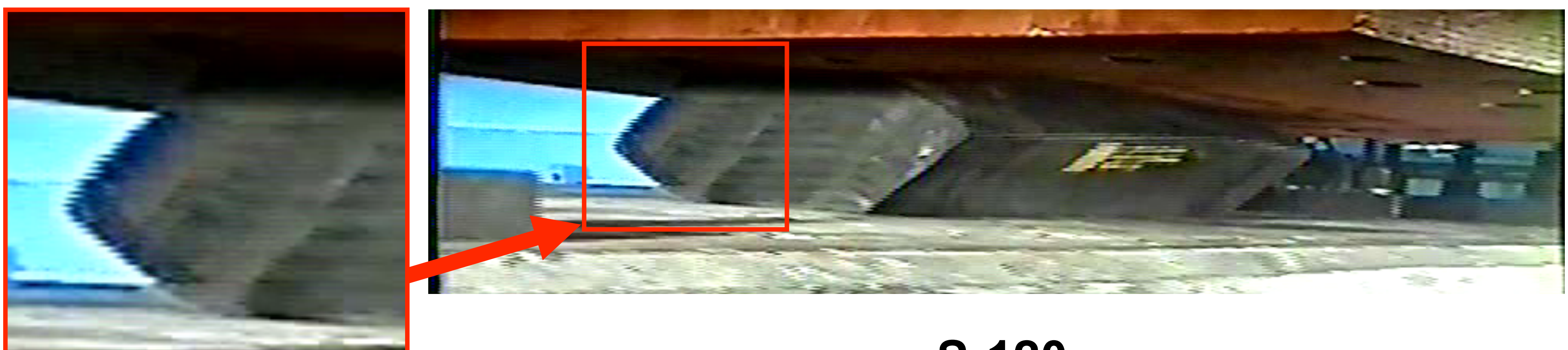
# Findings on the seismic response of elastomeric bearings (1)

- Elastomeric bridge bearings perform exceptionally even under seismic loading conditions, withstanding very large shear strains without any damage.

- The unbonded bearing's corners roll off the top and bottom, thus relieving the tensile stresses that would otherwise be produced if the top and bottom surfaces of the bearing were bonded to the supports.



S-120

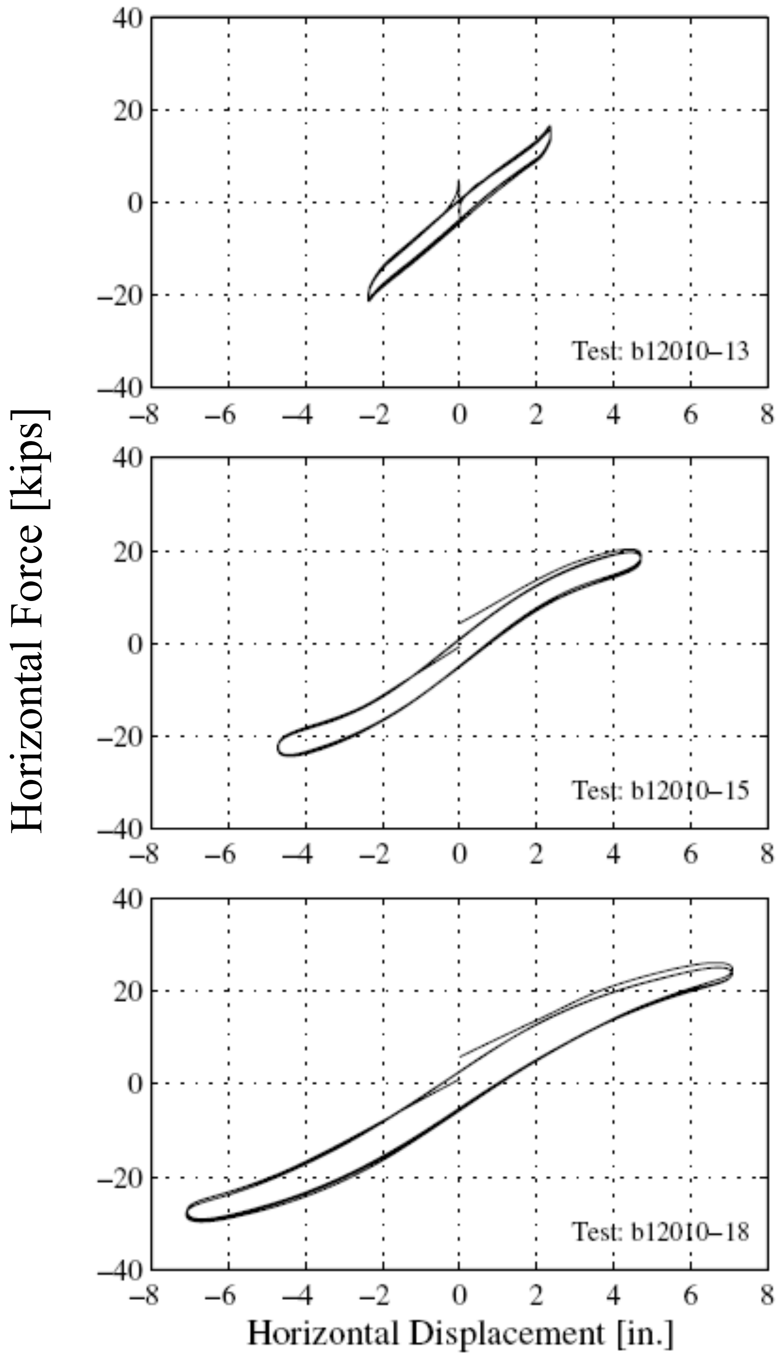
# Findings on the seismic response of elastomeric bearings (2)

- **Roll-over**: The free edges of the bearing rotate from the vertical towards the horizontal and eventually come in contact with the horizontal supports at top and bottom.

- Horizontal displacement beyond roll-over causes slippage which results in damage to the bearing.

S-48

# Findings on the seismic response of elastomeric bearings (3)




The effect of the roll-off increases with increasing displacement.

For a bonded bearing:

$$F_s = GA\gamma$$

For an unbonded bearing, the *effective* area, *A*, is a function of displacement and can be approximated by:

$$A_{eff} = A(1-\lambda\gamma) \quad \text{where} \quad \lambda = t_r/(2b)$$

So,

$$\boxed{F_s = GA_{eff}\gamma = GA\gamma(1-\lambda\gamma)}$$

# Findings on the seismic response of elastomeric bearings (4)

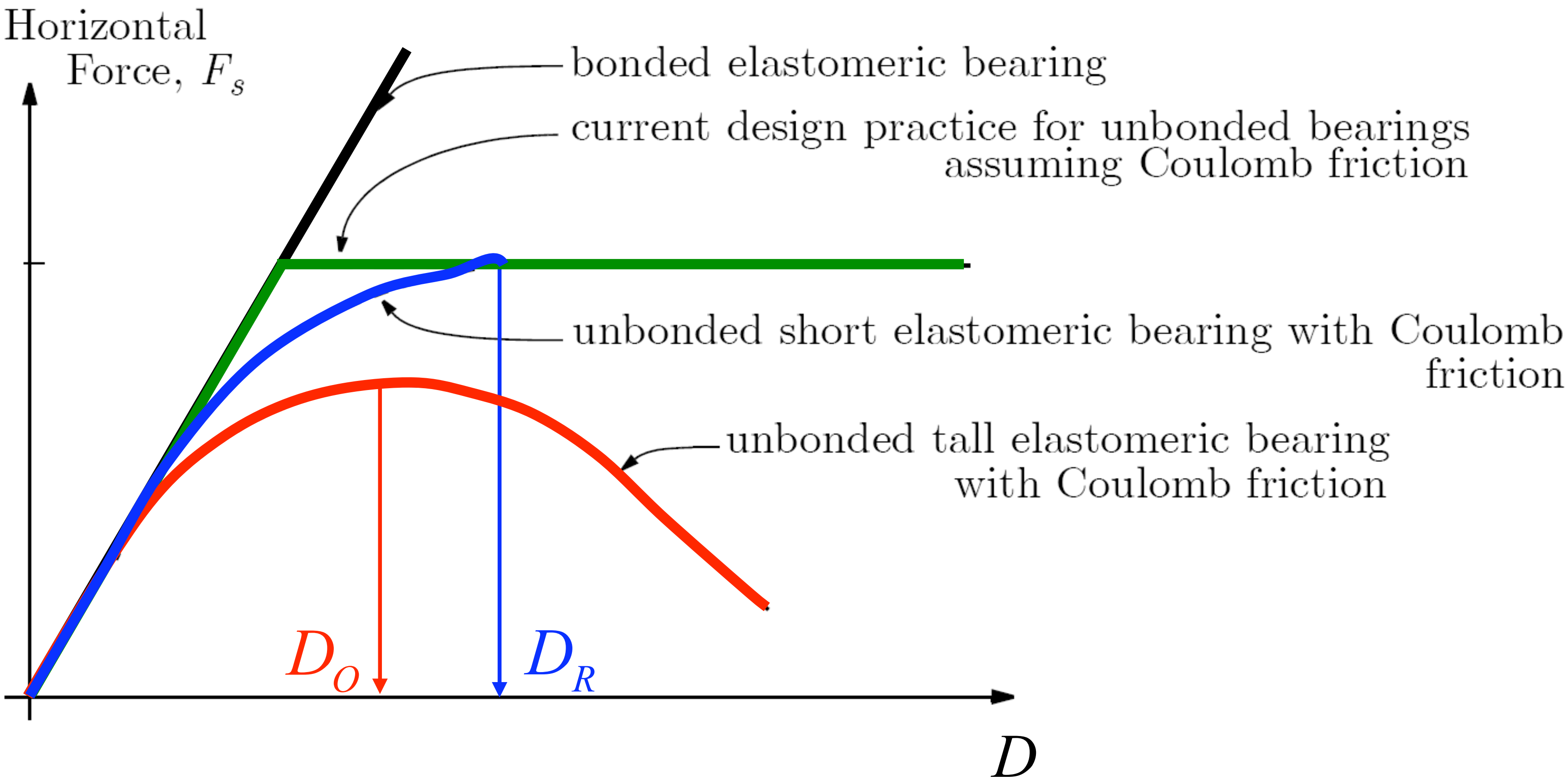
The tangent stiffness is

$$K_H = \frac{dF_s}{dD} = \frac{dF_s}{d\gamma}\frac{1}{t_r} = \frac{GA}{t_r}\left(1 - 2\lambda\gamma\right)$$

and becomes zero when

$$\gamma_O = \frac{1}{2\lambda} = \frac{b}{t_r} = \begin{cases} 3.92 \text{ for S-48} \\ 1.56 \text{ for S-120} \\ 0.92 \text{ for S-204} \end{cases}$$

# Findings on the seismic response of elastomeric bearings (5)




- For stocky bearings, the design displacement must not exceed the roll-over displacement, $D<D_R$
- For slender bearings, the design displacement must not exceed the displacement where the load-displacement curve begins to descend, $D<D_O$

$$\boxed{D < \min\left\{D_O, D_R\right\}}$$

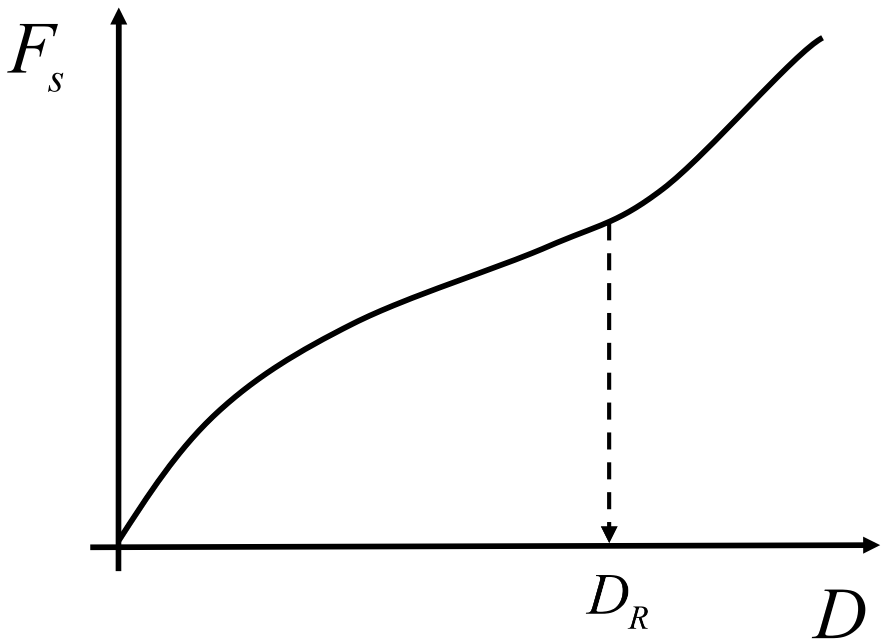
# Findings on the seismic response of elastomeric bearings (6)

**Rate Effects**

- Energy Dissipated per Cycle is unaffected by loading rate, i.e., damping is predominantly hysteretic, not viscous.

- There is generally an increase in the EDC with increasing vertical load for all bearings tested.

# Findings on the seismic response of elastomeric bearings (7)




**Post roll-over behavior**

No further shear deformation was possible, and the increased displacement resulted in slippage. The force continued to increase

The slip process is **not** simple Coulomb friction (i.e., no constant force during slipping).

# Findings on the seismic response of elastomeric bearings (8)

**Friction coefficient**

Caltrans recommends:

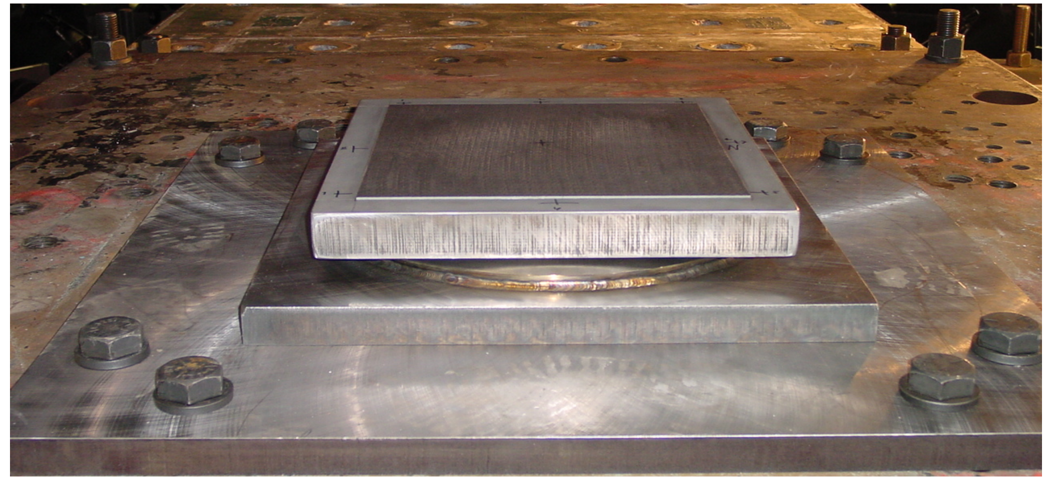
- 0.40 for concrete-rubber interfaces
- 0.35 for steel-rubber interfaces

Tests showed:

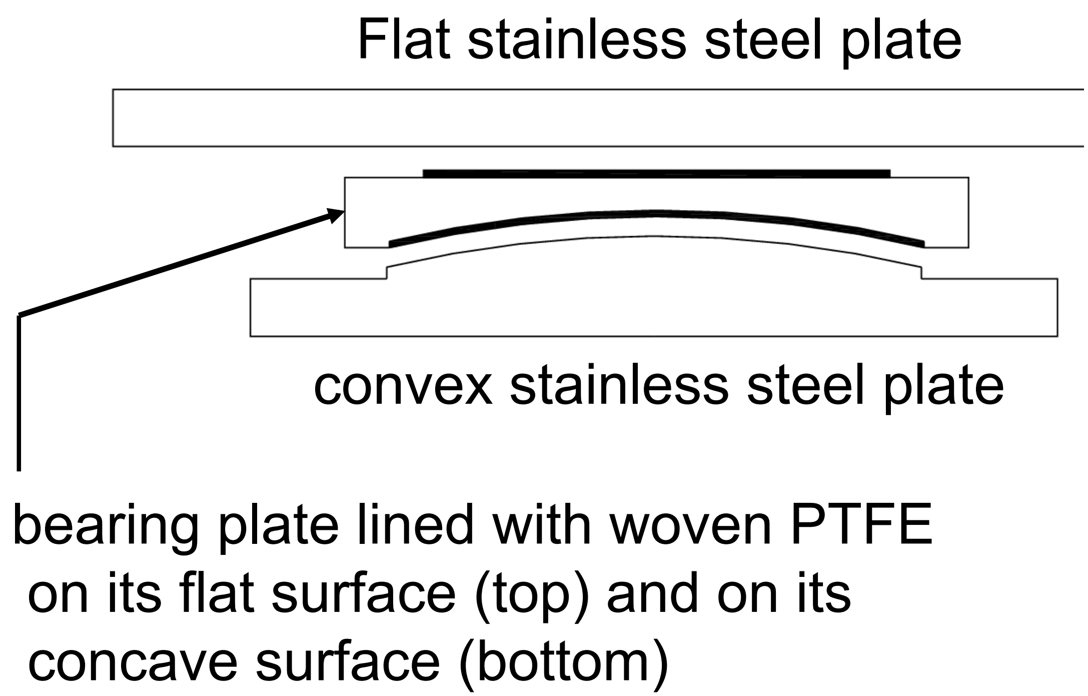
- The ratio of $F_s/P$ sometimes exceeds the above recommended values even if sliding does not occur.

# (c) PTFE spherical bearings

Lubron TF Spherical Bearing

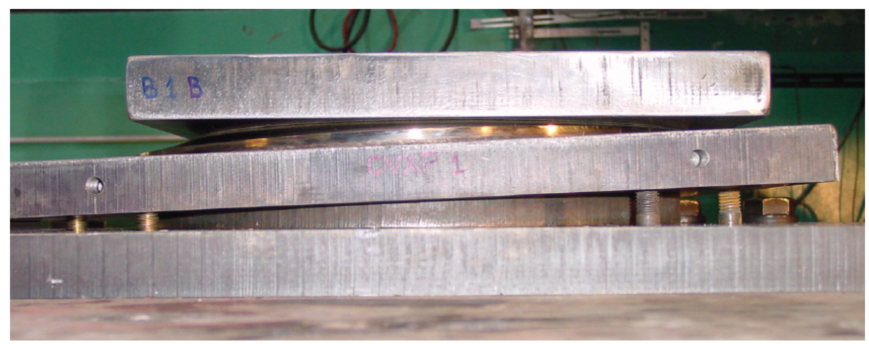


- Flat sliding surface allows horizontal displacement
- Concave sliding surface allows rotation
- Woven PTFE fabric is held together and bonded to the carbon steel substrate using a ***general-purpose epoxy*** (**GPE**) adhesive (rated at 250ºF)
- Two identical bearings were manufactured. Each bearing was resurfaced with new woven-PTFE fabric on the horizontal surface several times



# Test program

- Sinusoidal input signals with varying
  - displacement amplitude (2.5 in., 5 in., few 8 in.)
  - velocity (0.2, 1, 5, 10, 15, 20, and 30 in/sec)
- Pressure
  - 2.0,  3.5,  5.5,  7.5, and 10.0 ksi
- Rotation about axis transverse to the loading axis
  - 0 degrees
  - 2 degrees (using wedge plate)



# Findings on the seismic response of spherical bearings (1)

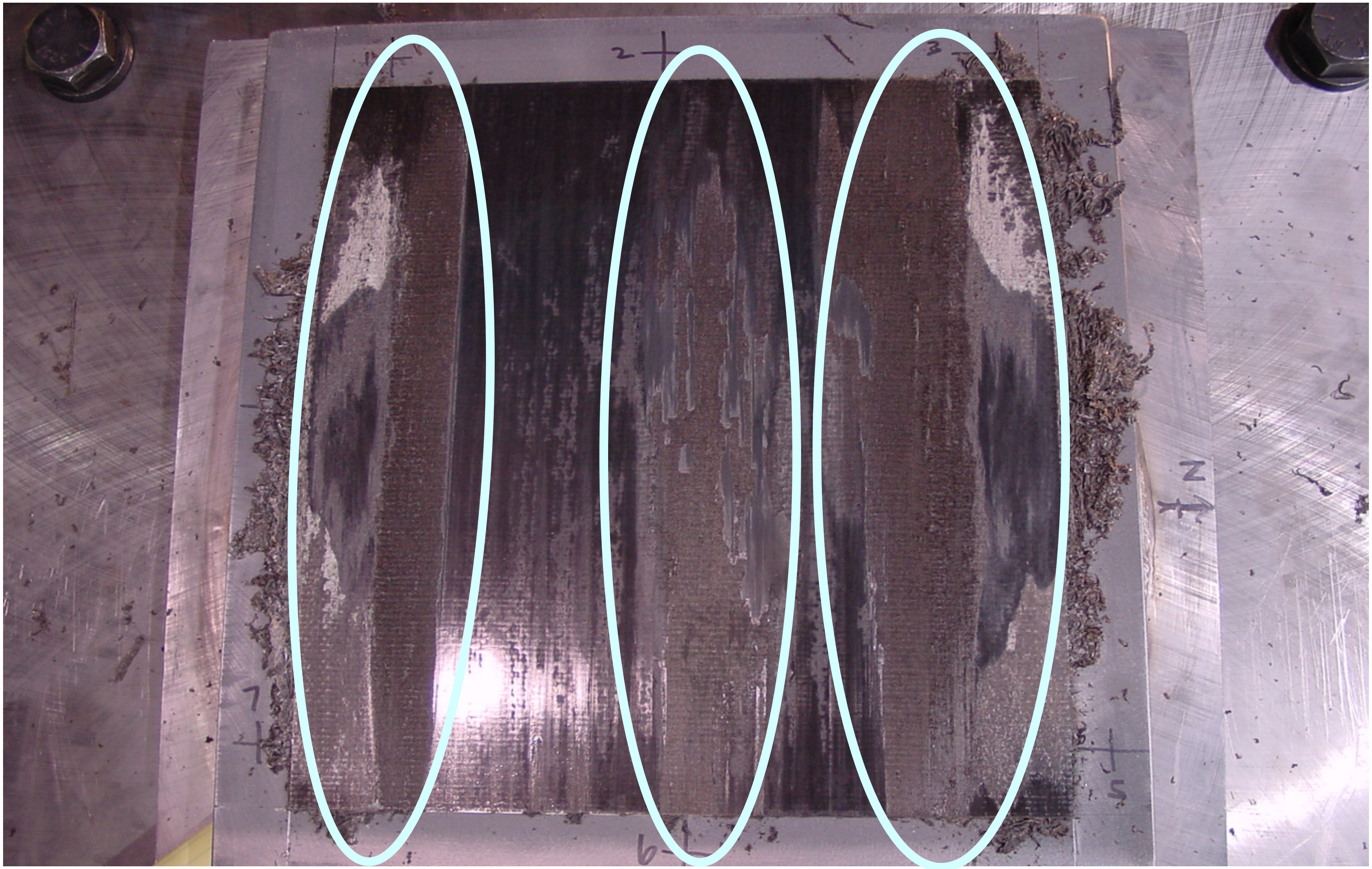
- Only two of the six specimens were able to survive the entire test protocol.

- One specimen experienced moderate damage, while three others experience significant damage after repeated testing; testing on them was eventually suspended.

- **Serious Degradation Problem**: the heat generated under high pressures and velocities resulted in the *general-purpose epoxy* (**GPE**) adhesive to melt, which resulted in the rapid degradation of the PTFE sliding surface.

# Findings on the seismic response of spherical bearings (2)

# Findings on the seismic response of spherical bearings (3)



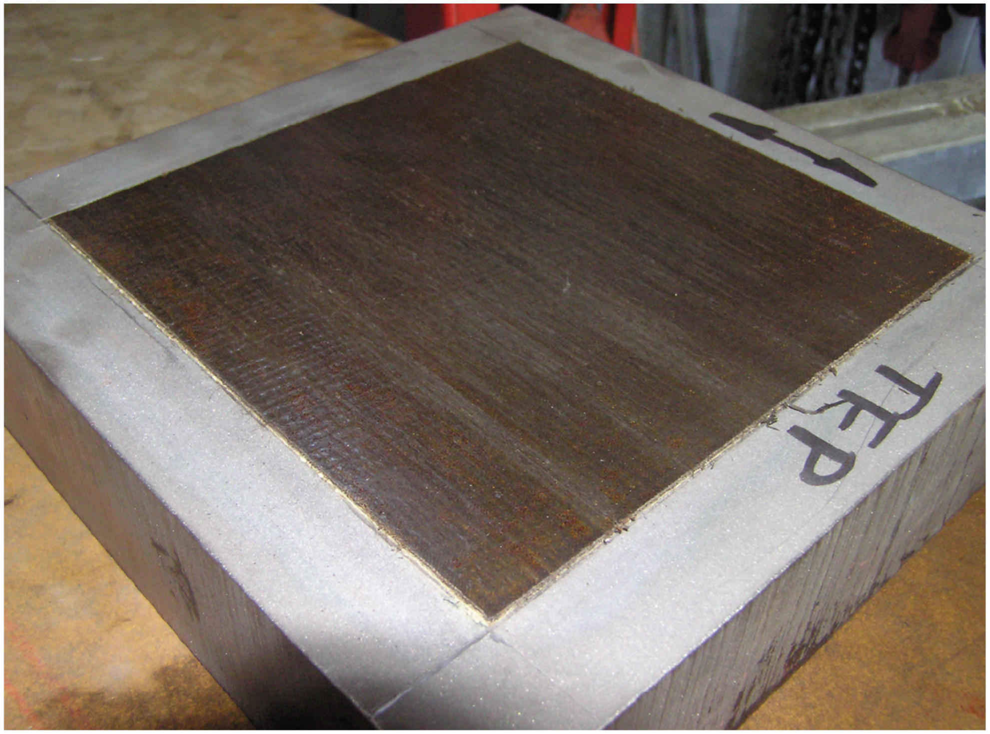
# Findings on the seismic response of spherical bearings (4)

# Solution to problem with GPE: High-Temperature Adhesives?

The underperformance of bearings with GPE adhesives motivated an experimental investigation at UC Berkeley's PEER Center test facilities into the performance of PTFE liners which use **High-Temperature** adhesives.

Woven PTFE surfaces with 2 types of adhesives were investigated:

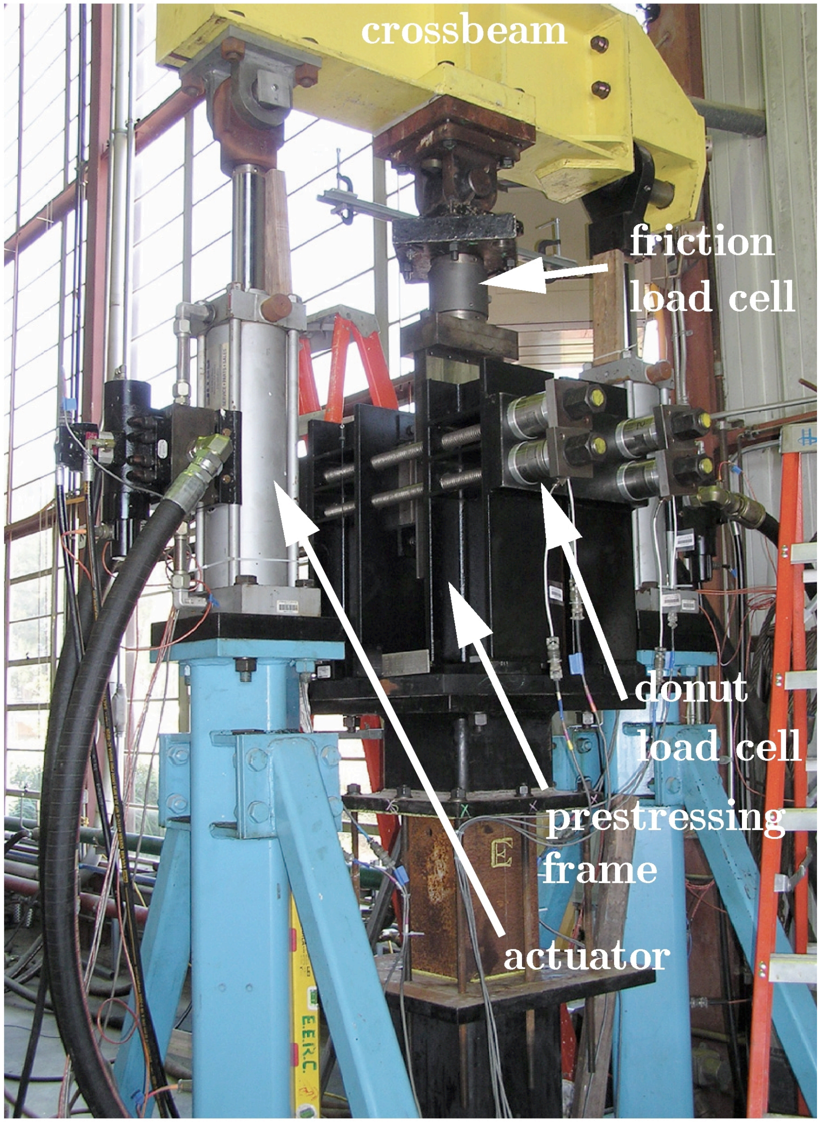
- A High-Temperature Epoxy (**HTE**) adhesive suitable for temperatures up to 400ºF (204ºC).
- A High-Temperature Phenolic (**HTP**) adhesive suitable for temperatures up to 500ºF (260ºC).




6 in. square woven PTFE liner bonded with HTE adhesive to 8 in. square bearing plate

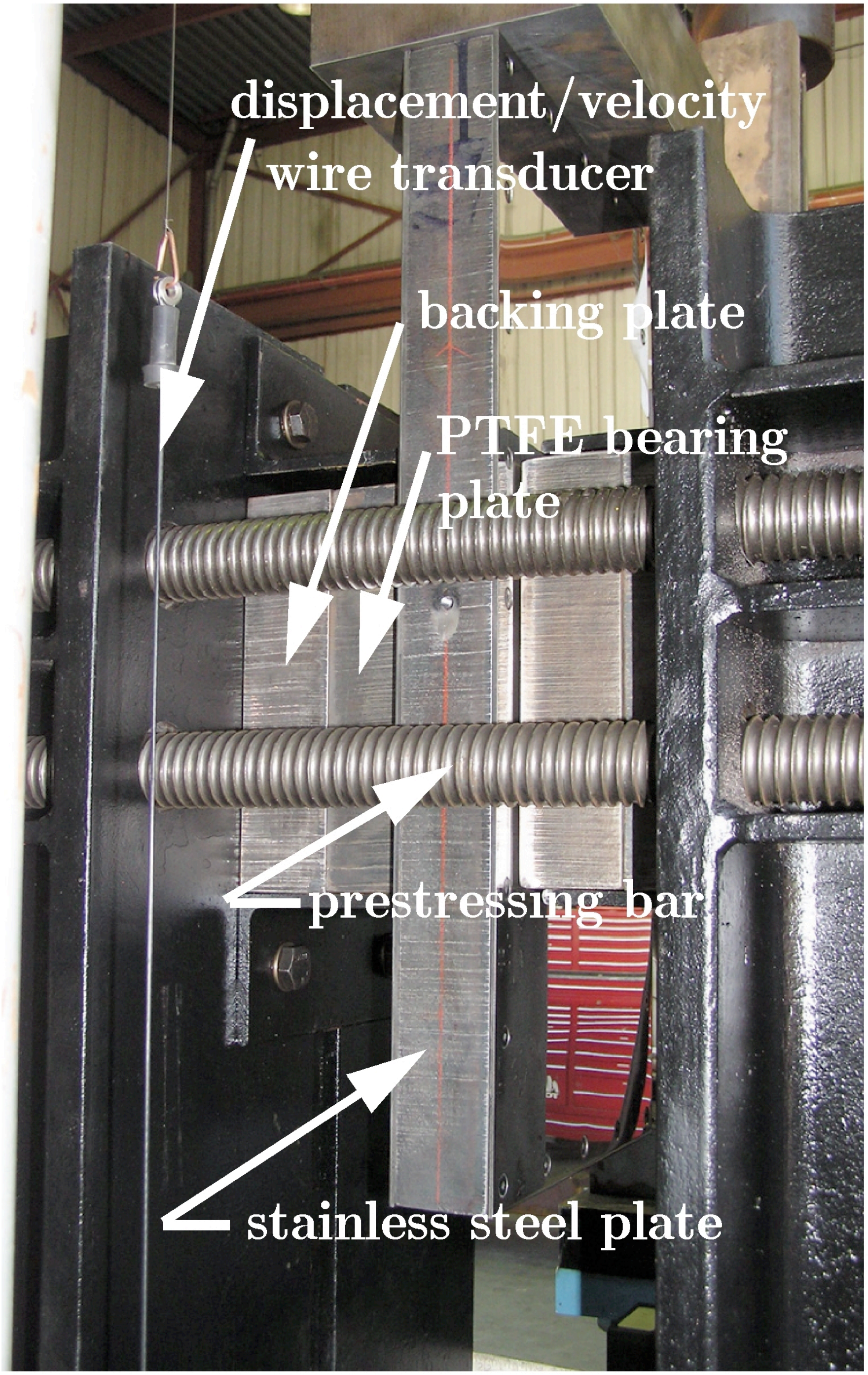
# Test program

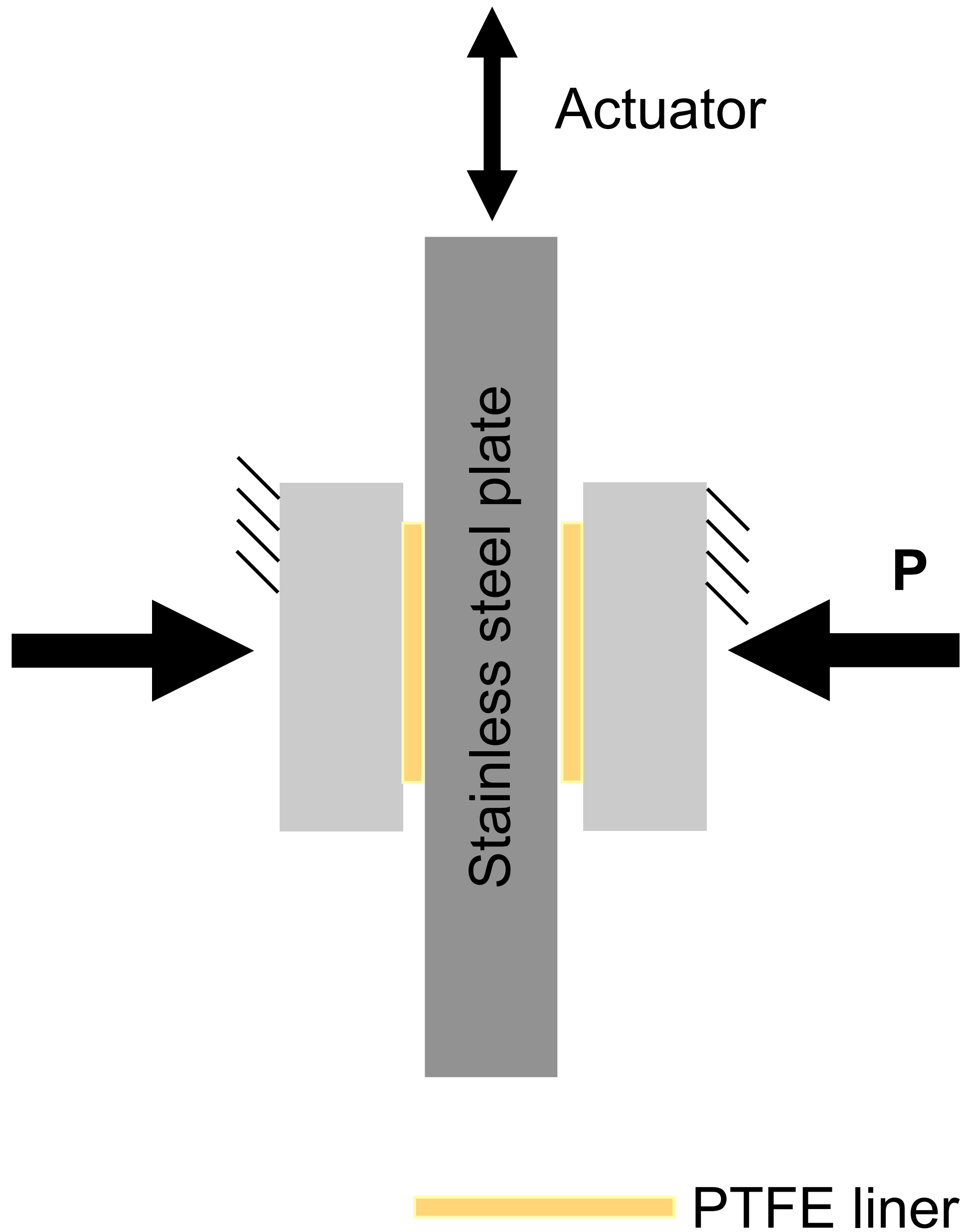
- 1 set with GPE
- 3 sets with HTE
- 3 sets with HTP
- Sinusoidal signals with 5 in. displacement amplitudes and with velocity amplitudes of 0.2, 1, 2, 5, 8, 11, 14, 17, 20, and 30 in/sec.
- Pressures of 2000, 3500, 5500, 7500 and 10000 psi.




A 100-kip small-viscous-damper testing machine was modified to accommodate the PTFE bearing plates.

# Test setup

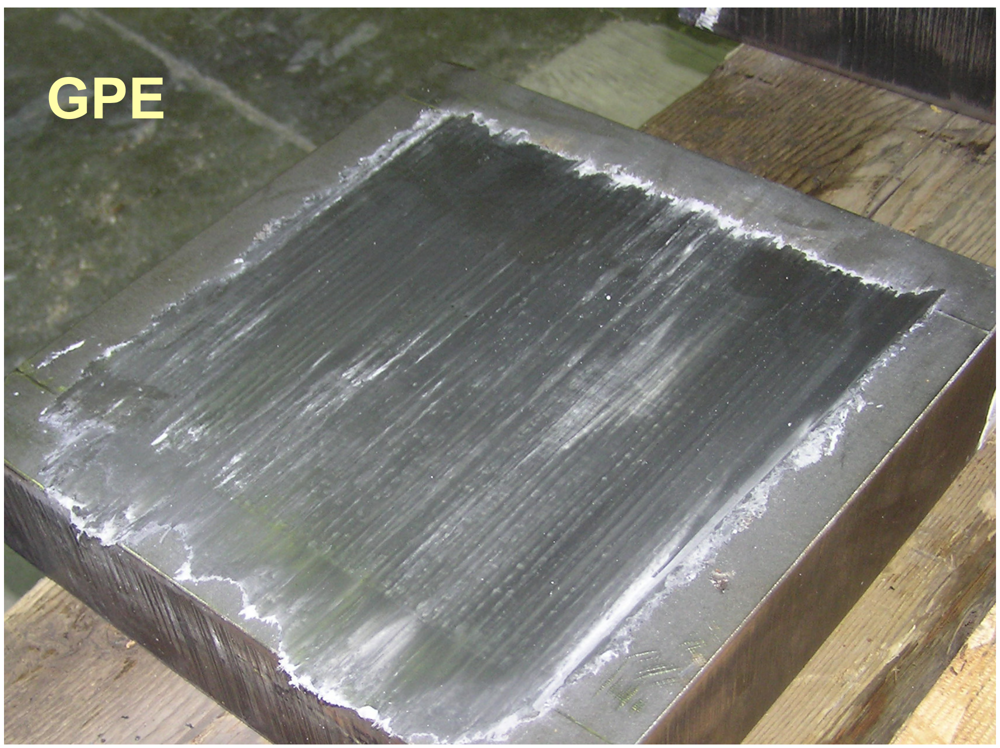

displacement/velocity wire transducer
backing plate
PTFE bearing plate
prestressing bar
stainless steel plate

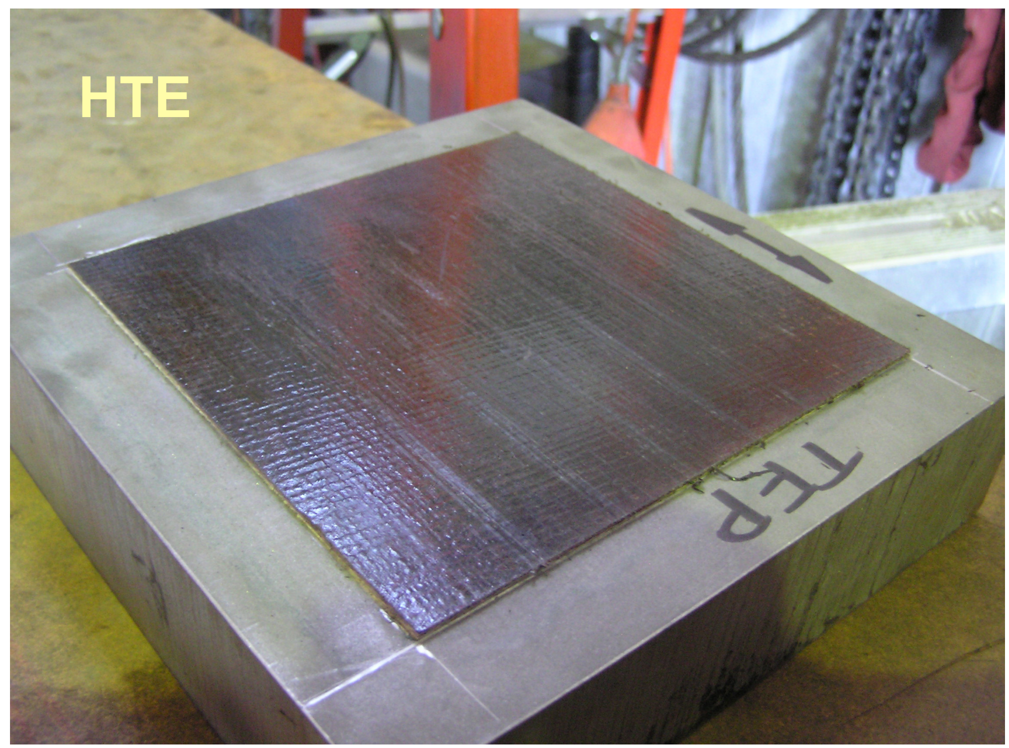

Actuator
Stainless steel plate
P
PTFE liner

# Findings on the seismic response of spherical bearings (5)

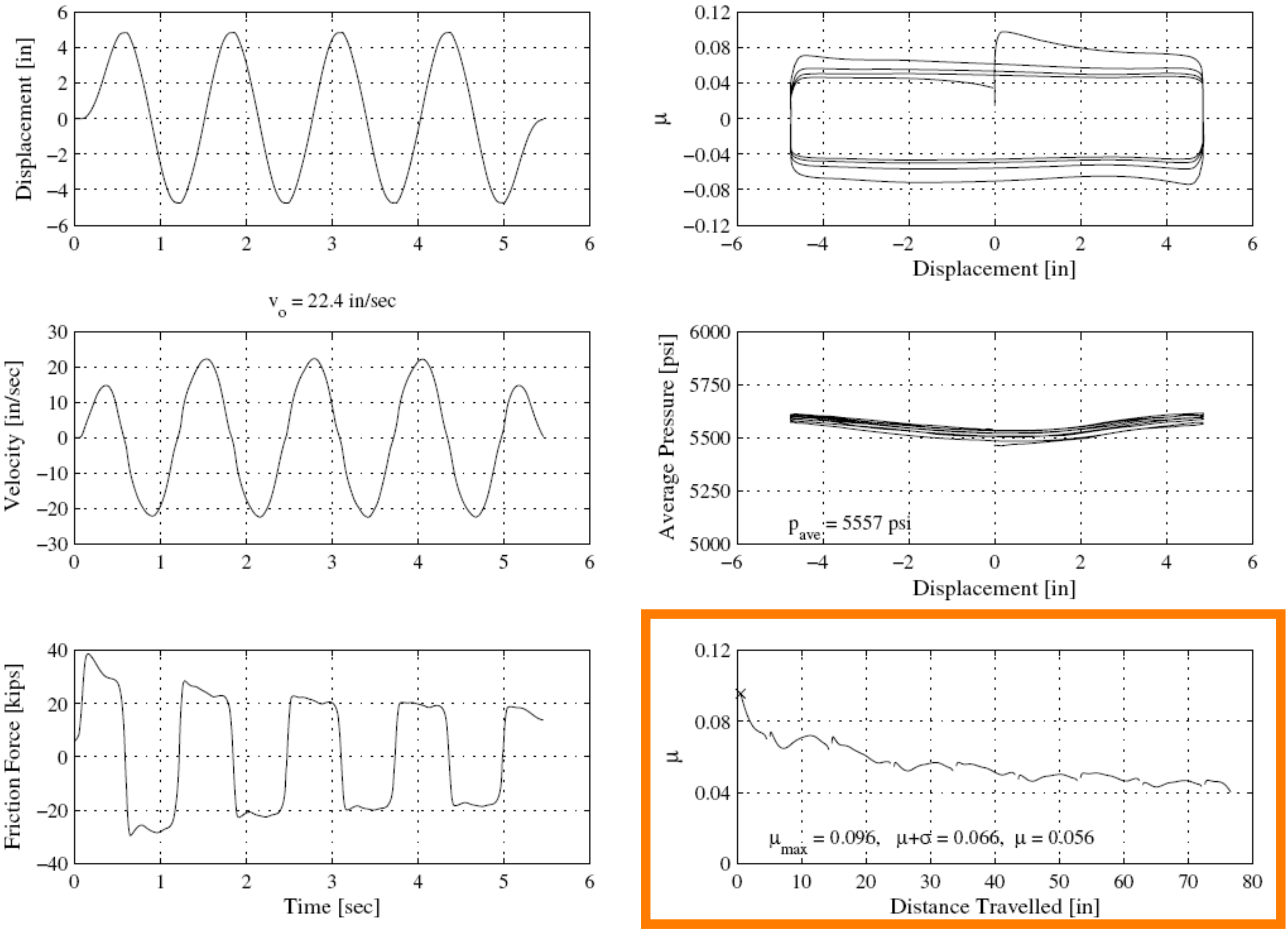
- Both the HTE and the HTP Adhesive PTFE bearings exhibited superior performance during the tests.
- Minimal shedding was noticed, the adhesive did not melt and bake onto the stainless steel.

Condition after test protocol completed:

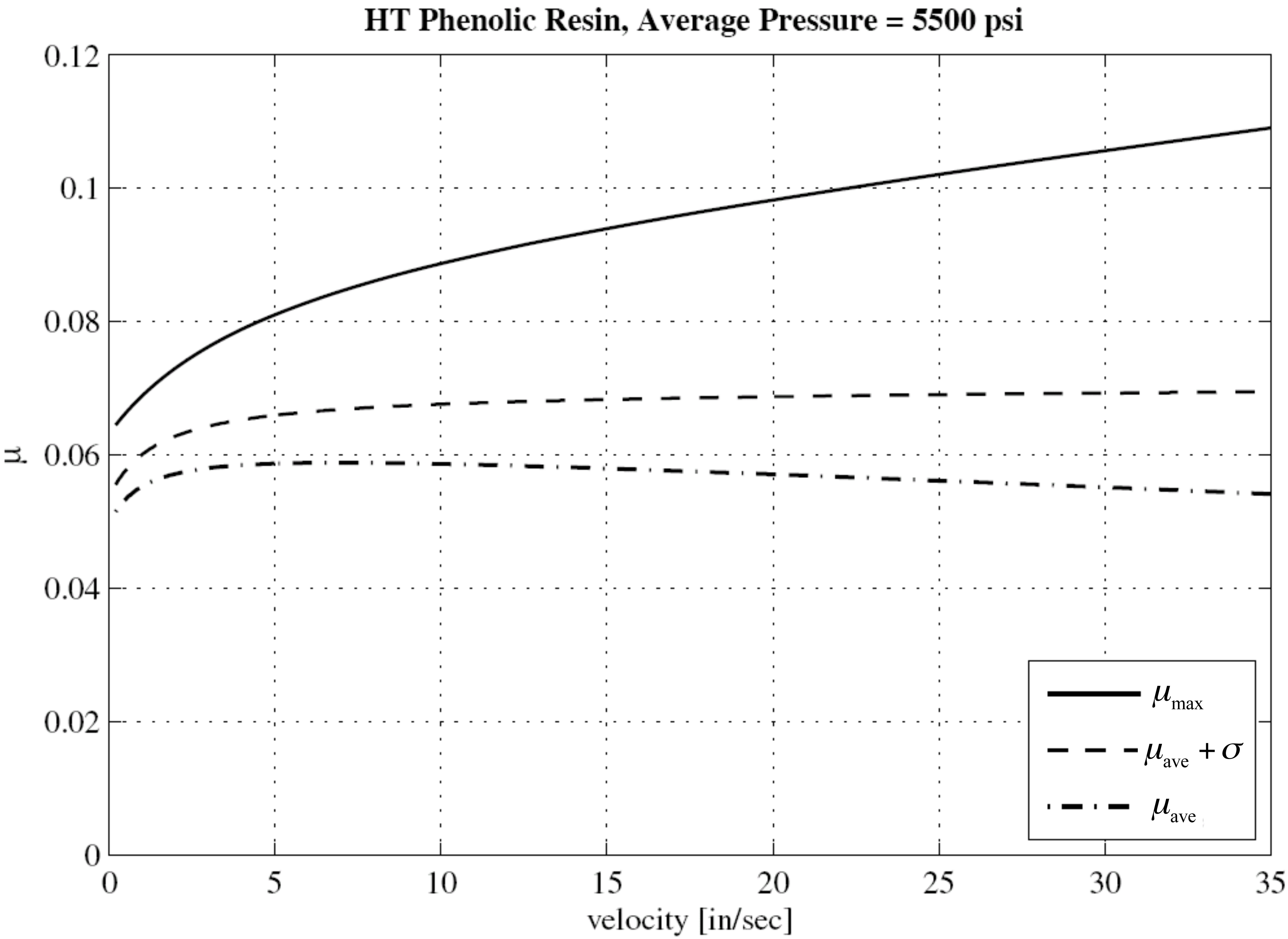


# Findings on the seismic response of spherical bearings (6)



# Findings on the seismic response of spherical bearings (7)



# GENERAL CONCLUSIONS

## ELASTOMERIC BEARINGS

- They roll off the supports and can undergo very large displacements without damage.
- Design displacement is limited by the smaller of roll-over displacement and displacement at which stiffness becomes zero.
- Damping is predominantly hysteretic, not viscous.
- Force during sliding does not follow Coulomb's Law
- Need to modify the Caltrans-recommended values for apparent "friction coefficient" (i.e. horizontal-to-normal force ratio)

# GENERAL CONCLUSIONS

## PTFE SPHERICAL BEARINGS

- PTFE liners bonded with GPE adhesives degrade very rapidly under seismic loading conditions.
- PTFE liners bonded with HT adhesives experience minimal shedding.
- They can accommodate very large displacements and rotations.
- Friction coefficient of woven-PTFE is pressure- and velocity -dependent and decreases with increasing temperature.

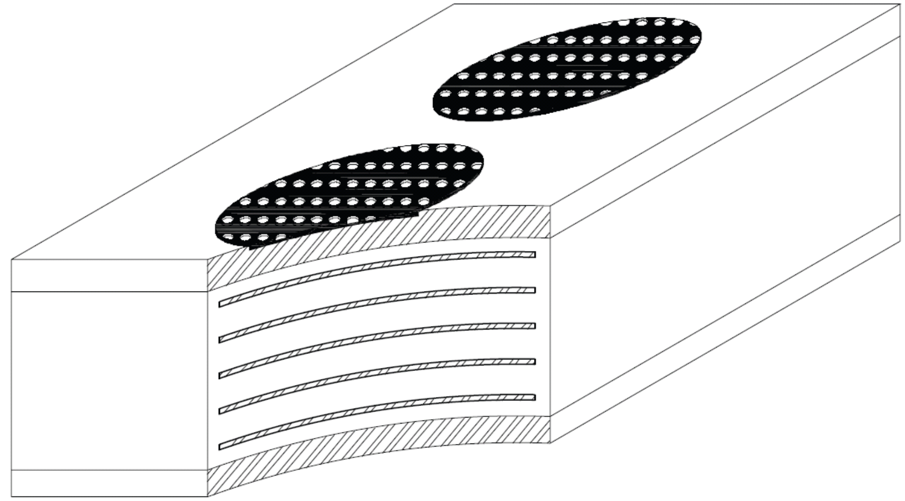
THANK YOU

# How are they different from isolation rubber bearings?

| | Thermal-expansion elastomeric bearings | Typical seismic-isolation elastomeric bearings |
|---|---|---|
| Steel end-plates | none | 1 in [24 mm] |
| Steel shims | 0.075 in [1.9mm] | 0.12 in [3 mm] |
| Weight | light | heavy |
| Cost in dollars | hundreds | thousands or tens of thousands |

# (b) Steel-reinforced elastomeric bearings with PTFE disks

Identical to elastomeric pads described previously but bonded to thick steel plates on either end: *intermediate* plate and *masonry* plate.



The intermediate plate features two PTFE (Teflon) disks. These disks are in contact with a stainless steel sole plate.

2 sizes:

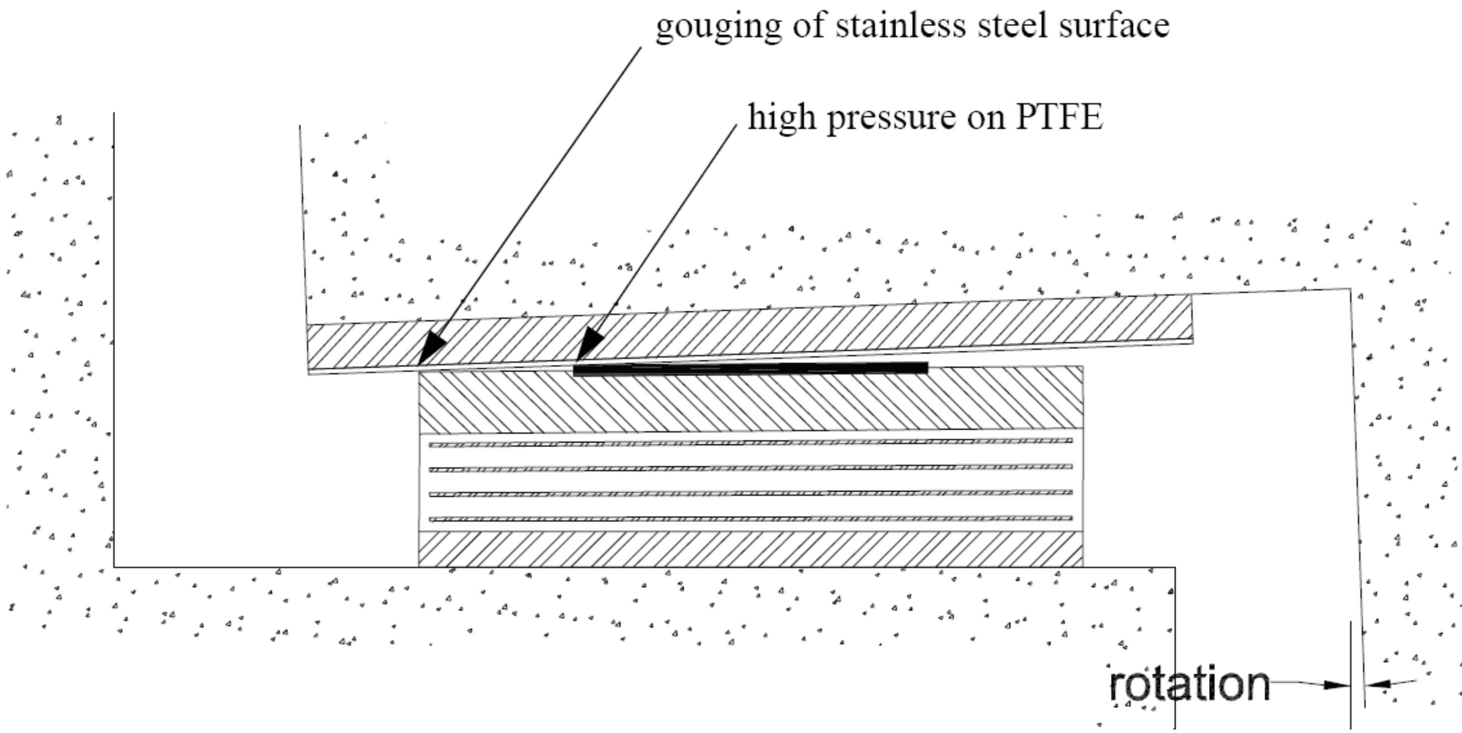
- T-48
- T-120

# Test program

- Sinusoidal input signals with varying
  - displacement amplitude (2 in. to 8 in. for T-48, 6 in. to 12 in. for T-120)
  - velocity (up to 32 in/sec)
- Vertical load
  - 400 kips (1200 psi on rubber, 4100 psi on PTFE)
  - 195 kips (580 psi on rubber, 2000 psi on PTFE)
- Rotation about axis transverse to the loading axis
  - 0 degrees (T-48 and T-120), and
  - 0.5 degrees (T-120)

# Findings on the response of PTFE-elastomeric bearings (1)

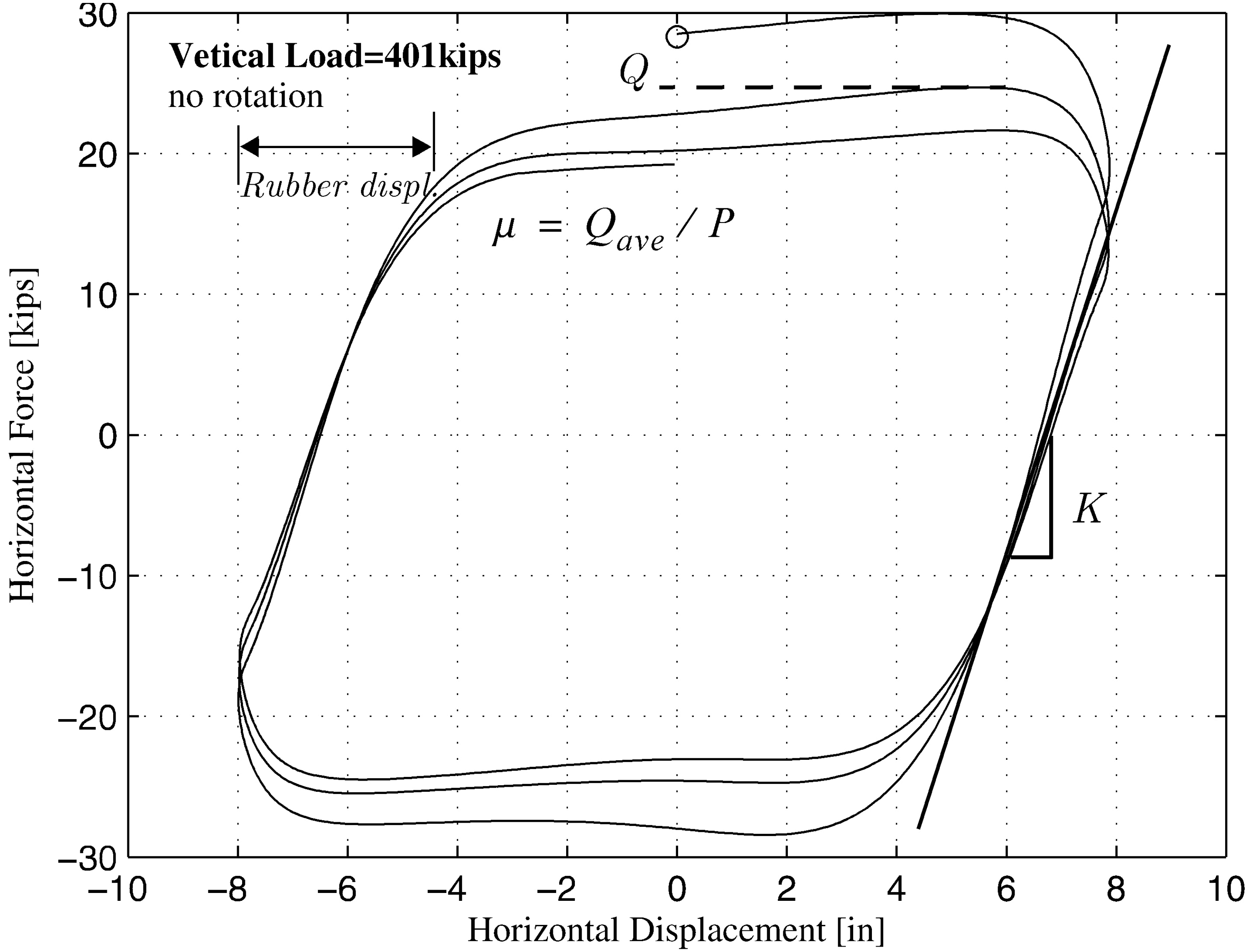
Bearing unable to handle imposed rotation



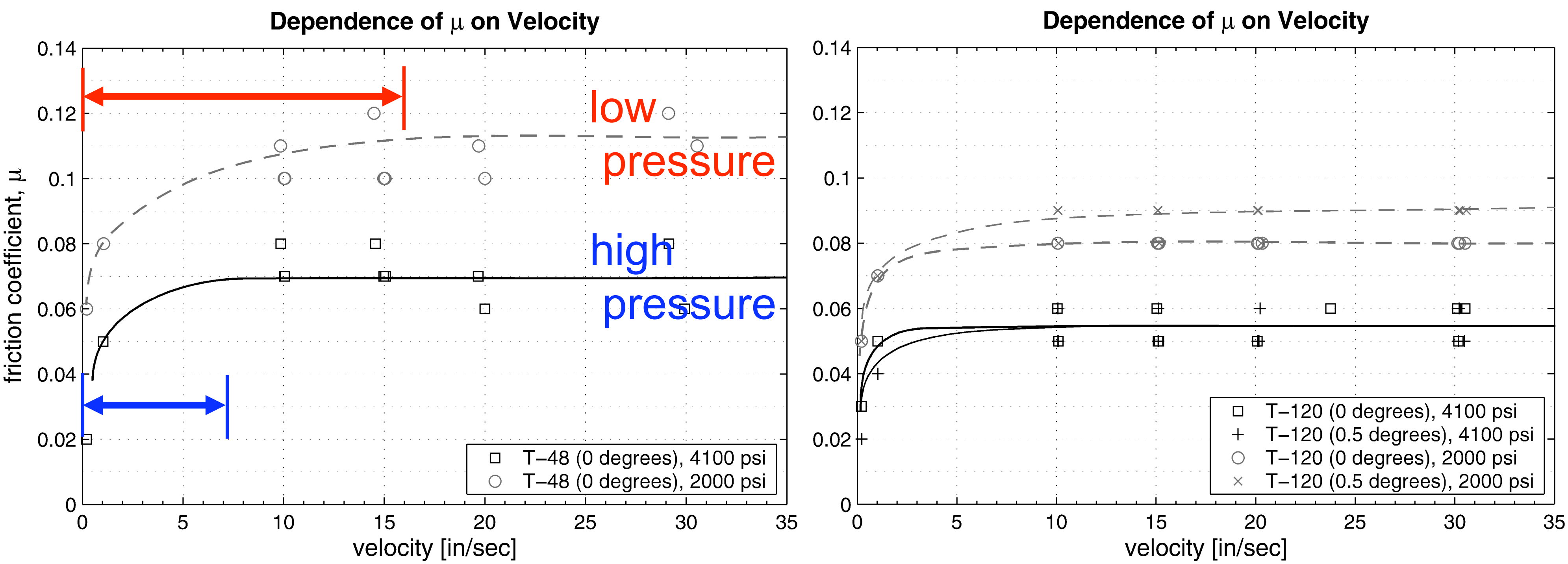

- The original test protocol included tests at 1.5-degree rotation.
- The T-120 bearing could barely accommodate 0.5 degree rotation, and the T-48 bearing could only accommodate a fraction of this.
- To prevent gouging of the stainless steel plate, the 48-mm bearing was tested only **unrotated**.

# Findings on the response of PTFE-elastomeric bearings (2)

Bearing: T-48, Displacement amplitude = 8 in., velocity amplitude = 30 in/sec



# Findings on the response of PTFE-elastomeric bearings (3)




- behavior similar to previous studies (e.g., Mokha et al. 1988).
- $\mu$ depends on velocity. Ranges from 3% to 11%.
- lower $\mu$ at higher pressures (Bowden and Tabor 2001).
- wider range of variability of $\mu$ as function of velocity amplitude.

# Findings on the response of PTFE-elastomeric bearings (4)

Excessive shedding of PTFE was observed.