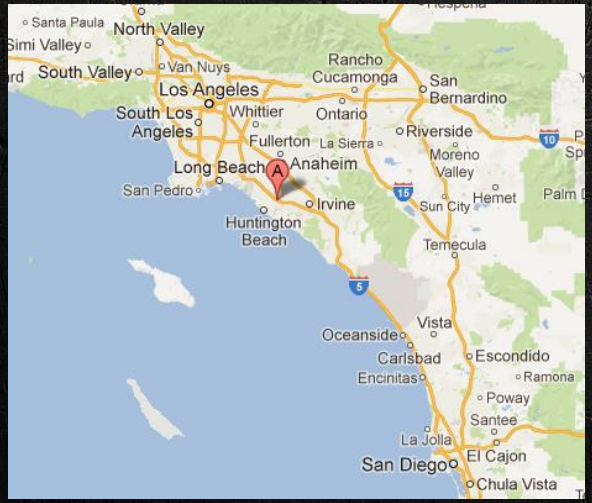
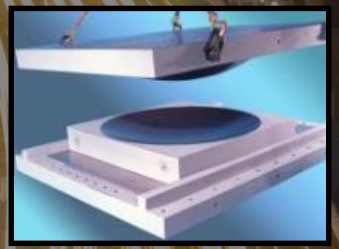
RBC LUBRON BEARING SYSTEMS

Products
Applications
Bearing design & testing



RBC Lubron Bearing Systems, Inc.
10620 Lawson River Avenue
Fountain Valley, California, USA 92708

RBC Lubron® Bearing Systems



- Fountain Valley, CA
- Self-lubricating bearings designed and manufactured for demanding applications worldwide
  - Journal, flange and thrust bearings
  - Spherical plain bearings
  - Expansion and radial bearing plates
  - Spherical bearing assemblies
- Applications
  - Architectural
  - Industrial
  - Infrastructure (highway, railroad, and pedestrian bridges)
  - Machinery and heavy equipment
  - Offshore marine
  - Power generation (hydro, nuclear, coal, gas, and solar)
  - Seismic isolation
  - Water control (dam gates, flood, and tidal barriers)

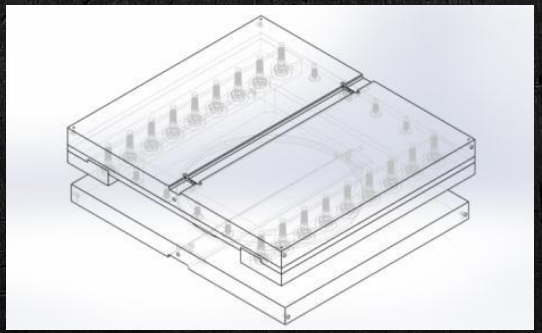
Lubron’s Niche

Design & Applications

- Self-lubricating (zero-maintenance)
- Long service life (decades)
- Heavy loads – up to 415 MPa (60 ksi)
- Large sizes – above 50 mm (2”) bore
- Slow rotation
- Custom
  - any size, any material
  - no part numbers
- Engineering
  - Complete design capabilities
  - Testing
  - Licensed PE stamp
  - Installation engineering assistance
    - Tooling design
    - Thermal expansion calculations

Markets

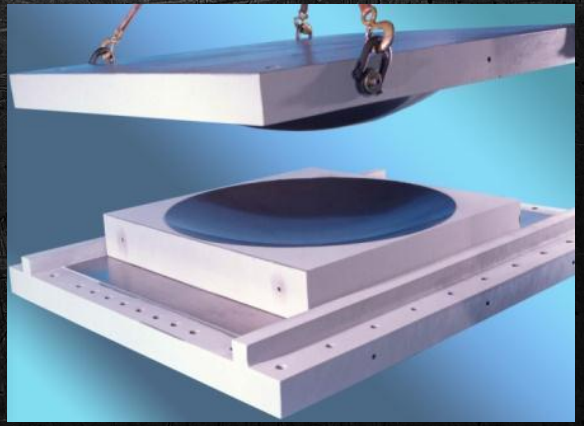
- Structural & architectural
- Bridges
- Hydroelectric dams
- Nuclear power



Types of Lubron bearings

Bushings (journal, flanged, match-split)
Plates (flat, radial, spherical)
Washers

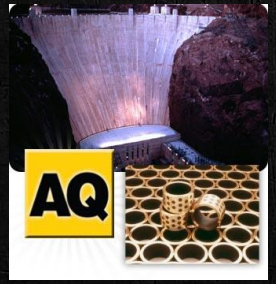
Spherical plain bearings

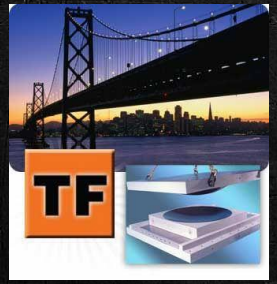


Spherical plate bearings

Lubron Self-Lubricating Liners

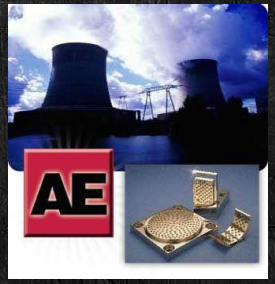
PTFE





Polytetrafluoroethylene (PTFE)
Teflon ®

Graphite



Lubron SL & AE

- Graphite-based solid lubricants
- Suitable for high-temperature applications (up to 430°C)
- Available with supplementary greasing options

- Bearing capacity: 8 ksi (55 N/mm^2)
- Coefficient of friction: 0.10 – 0.30

Lubron SL & AE

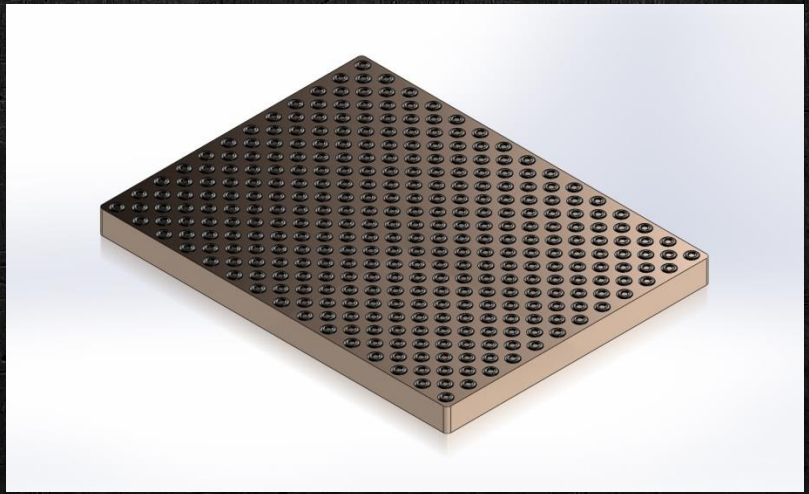
Applications

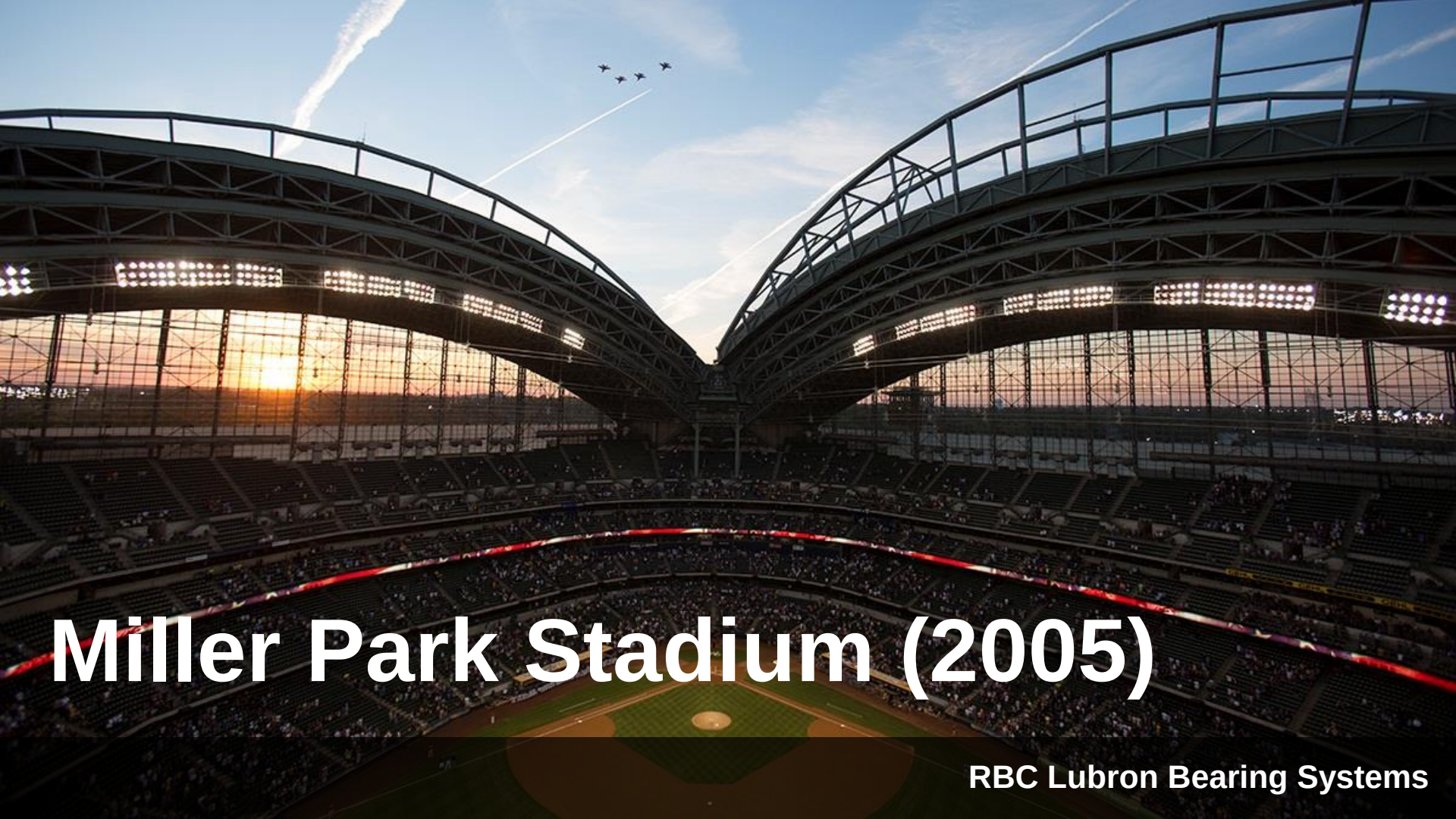
- Bridges
  - Plate supports
  - Bascule bridges
- High-temperature production
  - Mining
  - Steel mills
- Nuclear
  - Reactor supports
  - Steam generator supports
  - Core makeup tank supports
  - Pipe supports

Lubron SL & AE

Applications

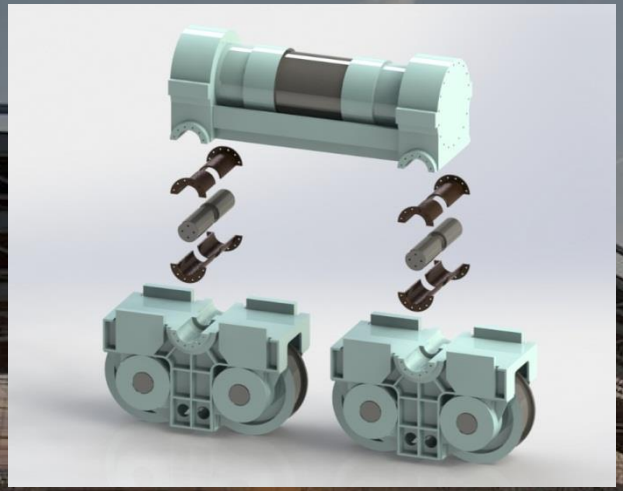
- Bridges
  - Plate supports
  - Bascule bridges
- High-temperature production
  - Mining
  - Steel mills
- Nuclear
  - Reactor supports
  - Steam generator supports
  - Core makeup tank supports
  - Pipe supports





Miller Park Stadium (2005)

RBC Lubron Bearing Systems



40 SL flanged bearings

Bogie carts

Miller Park Stadium (2005)

RBC Lubron Bearing Systems

Lubron TF

- Woven Teflon fabric liner
- Suitable for fully submerged fresh- & salt-water applications
- 100% bearing-surface coverage

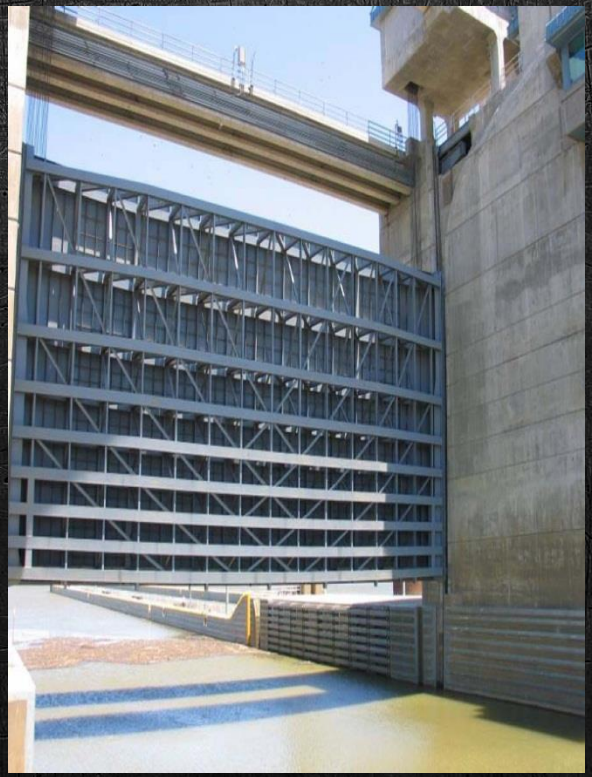
- Bearing capacity: 415 N/mm^2 (static)
  205 N/mm^2 (dynamic)
- Coefficient of friction: 0.01 – 0.07

Lubron TF

Applications

- Hydroelectric and water control
  - Lock and dam gates
  - Turbine gates
- Structural & Bridges
  - Spherical plate supports

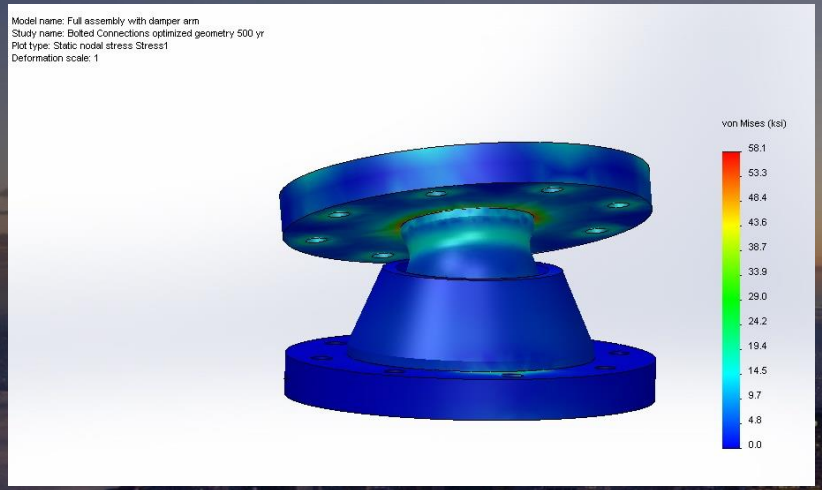
Oakland Bay Bridge – Touchdown Structure

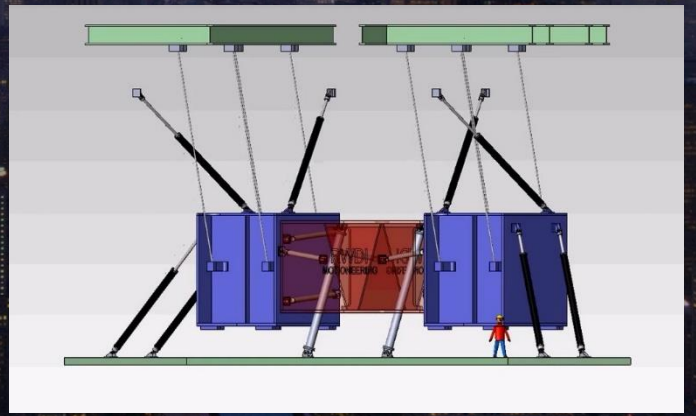


4 Lubron TF slot-loader track roller bearings
Olmsted Bulkhead Maintenance Gate
Ohio River, Illinois (2006)

432 Park Avenue
Tuned Mass Damper

RBC Lubron Bearing Systems





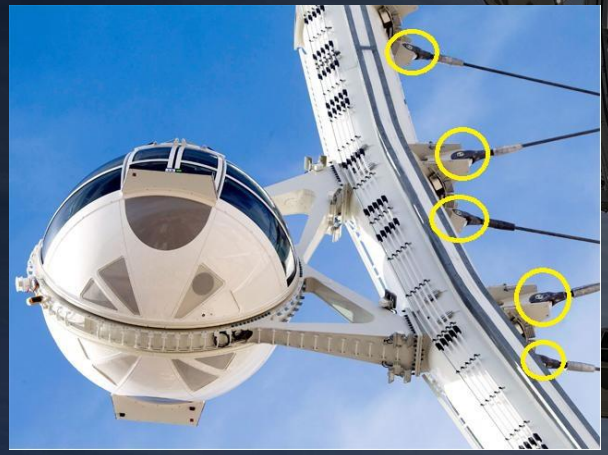
432 Park Avenue
Tuned Mass Damper

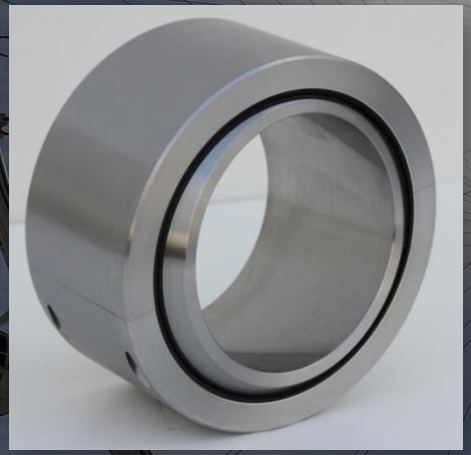
RBC Lubron Bearing Systems

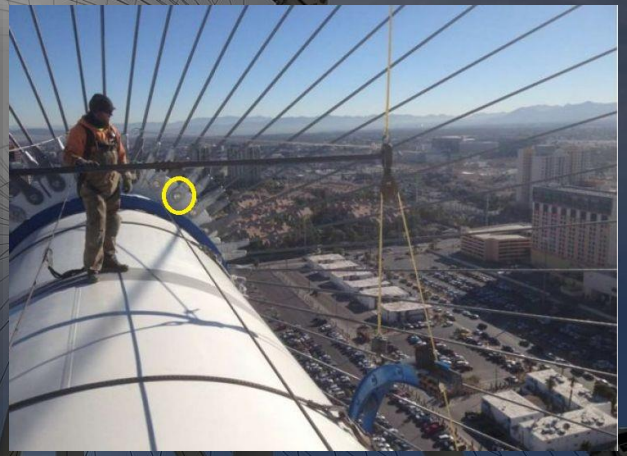
Las Vegas High Roller Observation Wheel

RBC Lubron Bearing Systems

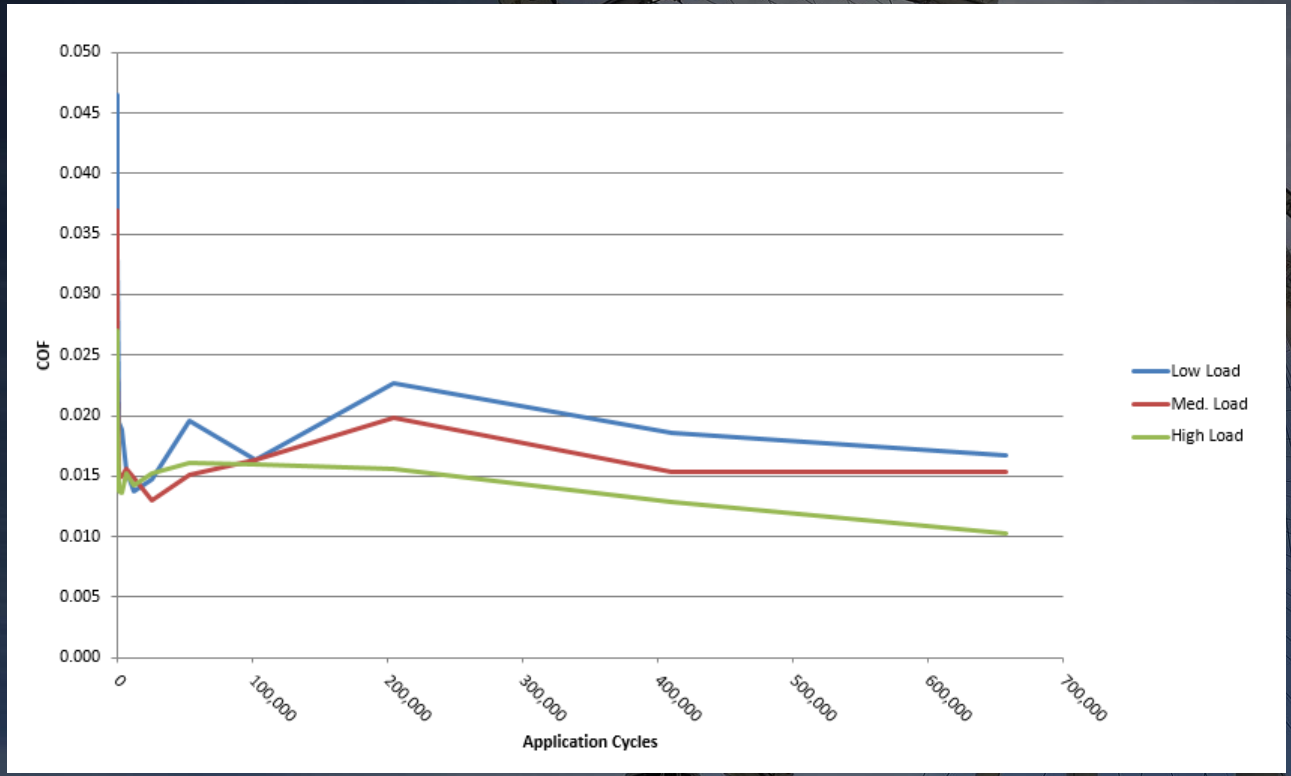
230 RBC Lubron TF spherical plain bearings (5.5” bore)







Las Vegas High Roller Observation Wheel



- **Low load** **= 37.2 N/mm^2**
- **Medium load** **= 69.6 N/mm^2**
- **High load** **= 113.8 N/mm^2**

- Travel = 3.2 km
- Full-scale fatigue testing performed by Freyssinet for Arup

Lubron AQ

- PTFE-based-epoxy solid lubricant
- Suitable for fully submerged fresh- & salt-water applications
- Available with 100% or partial bearing-surface coverage
- Available with supplementary greasing options

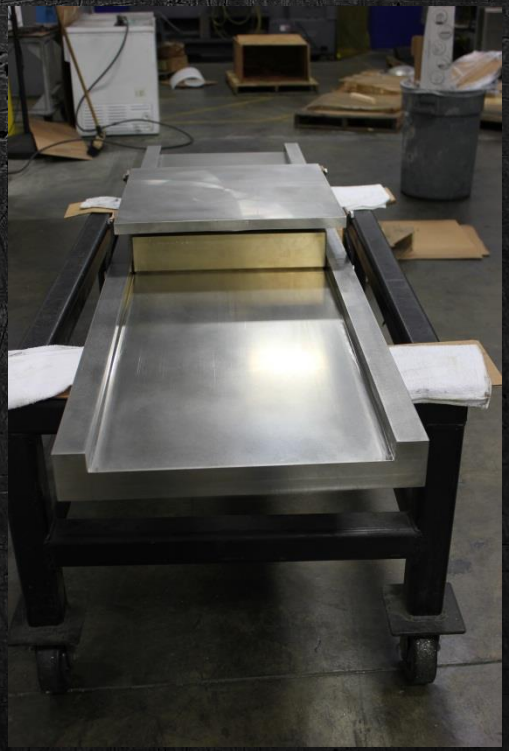
- Bearing capacity: 55 N/mm^2
- Coefficient of friction: 0.10 – 0.25

Lubron AQ

Applications

- Hydroelectric and water control
  - Lock and dam gates
  - Turbine gates
- Offshore
  - Oil rig & ship fairleads & cranes
  - Oil rig bridges

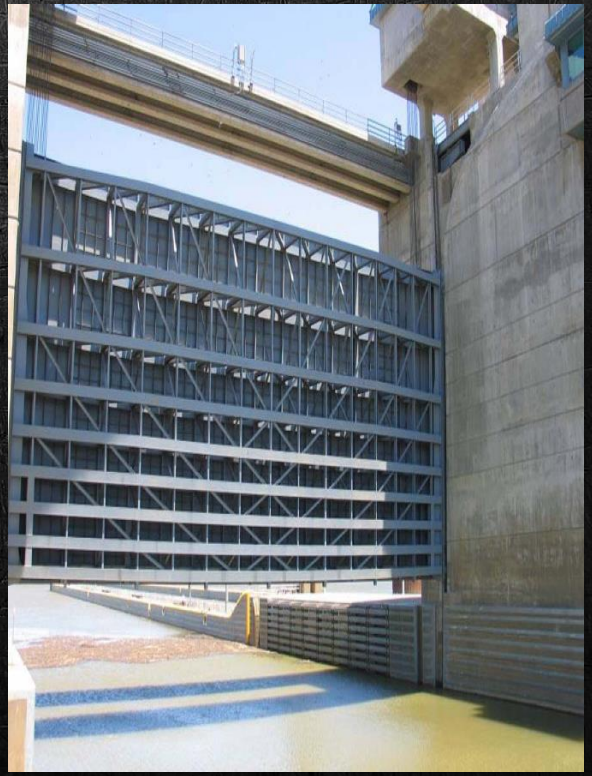
Offshore Bridge Platform Spherical Bearings



RBC Lubron Bearing Systems

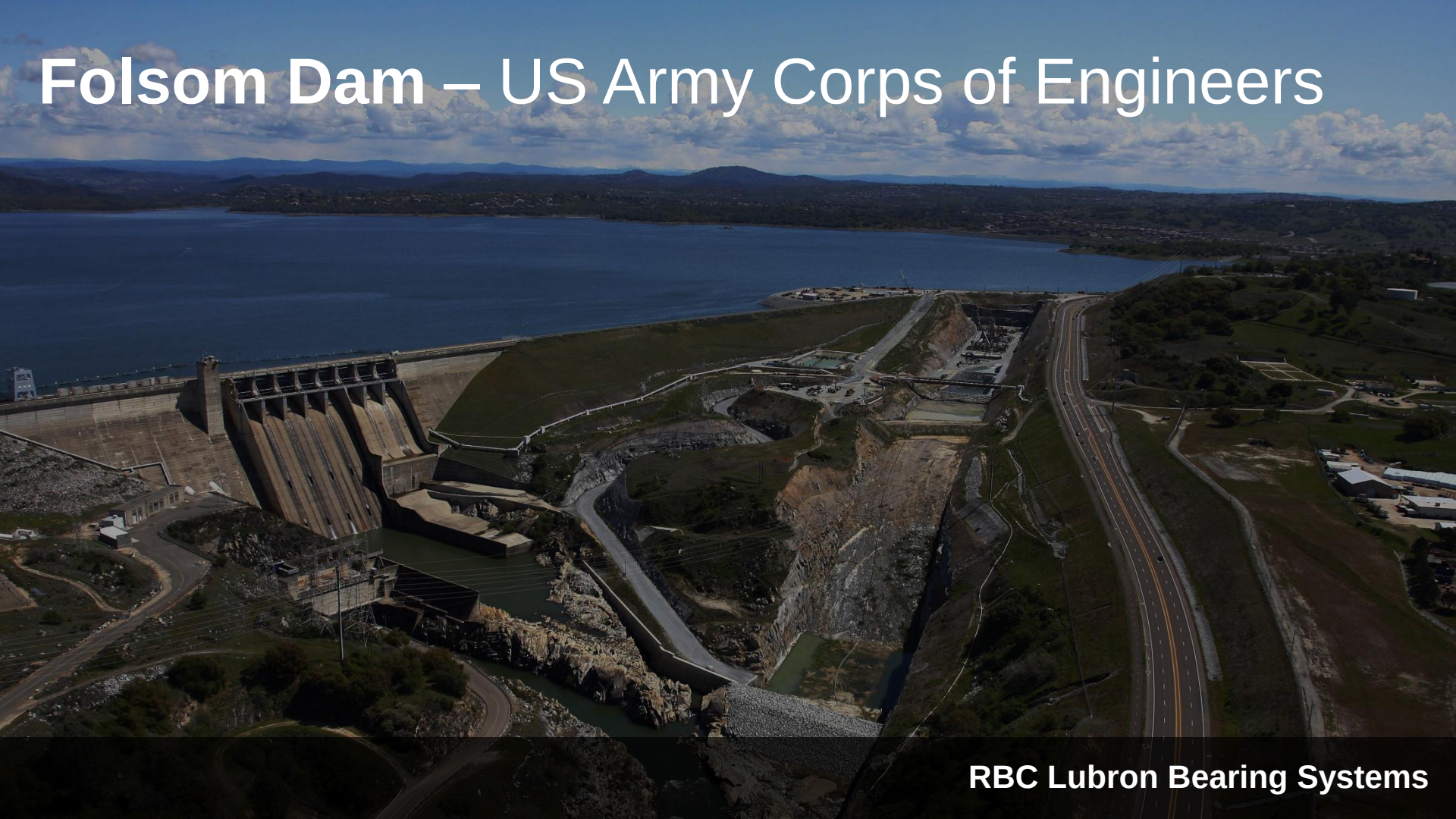
Hydro applications

- Vertical lift gates
- Radial gates
- Tainter gates
- Bulkhead gates
- Sector gates
- Slide gates
- Intake gates
- Roller gates
- Crest gates
- Sluice gates
- Miter gates
- Flap gates
- Draft tub gates
- Jet flow gates
- Navigation locks
- Roller & hoisting chains
- Sheaves



4 Lubron TF slot-loader track roller bearings
Olmsted Bulkhead Maintenance Gate
Ohio River, Illinois (2006)

Folsom Dam – US Army Corps of Engineers



RBC Lubron Bearing Systems

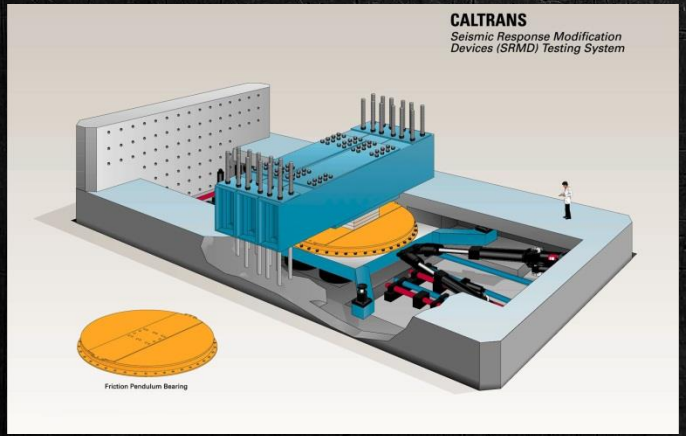
Folsom Dam – US Army Corps of Engineers

- Auxiliary spillway bulkhead gates
  - 96 RBC Lubron TF SPB track rollers (27” OD)
- Main spillway radial gates
  - 16 RBC Lubron AQ100 bushings (36” OD)
- Bypass bridge
  - 6 RBC Lubron TF spherical plate bearings

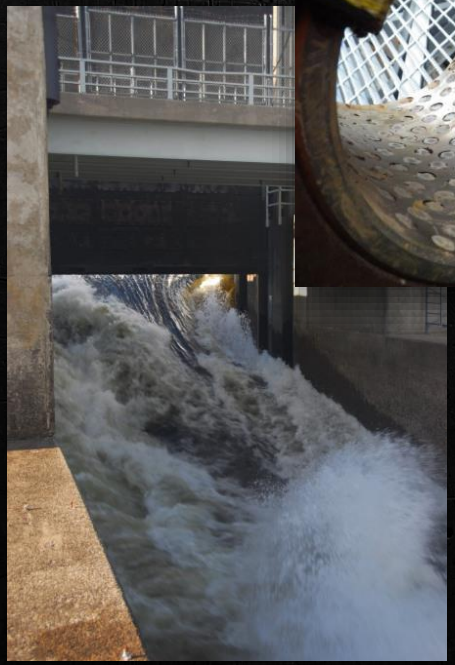
Folsom Dam Testing

University of California, San Diego

- Testing for the Folsom Dam track rollers at the Seismic Response Modification Device facility
  - Test for rolling resistance at maximum expected operating load (3336 kN)
  - Loaded to theoretical extreme load and statically held (8896 kN for ten minutes)
  - Then released and re-tested rolling resistance
  - CoF was less than 0.05
  - Visual inspection revealed no damage to the bearing



Notable hydro projects



Replacement of Lubrite bearings for the Churchill Falls Dam Whitefish Control Structure (Nalcor Energy) - Canada

Thames Barrier sector gate latch bearings
UK Environment Agency

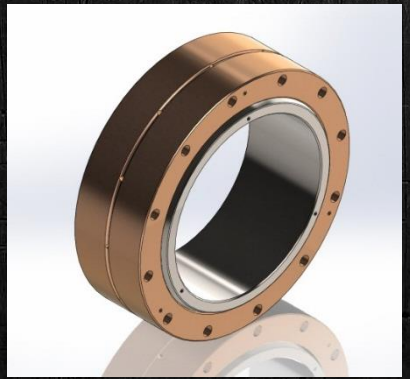
Notable related hydro projects

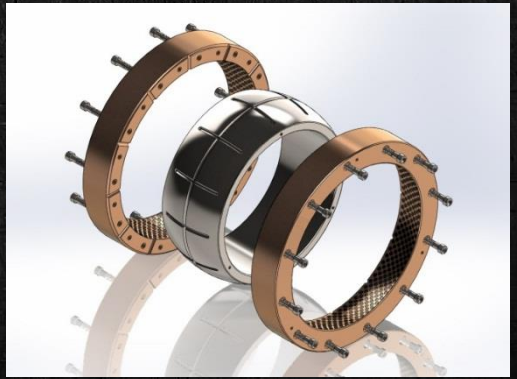
- **Robert Moses Dam**
  - New York Power Authority
  - Wicket gates (upper, middle, lower)
  - Flanged and straight bushings
- **Pinopolis Dam**
  - Oregon Iron Works for the SCPSA
  - Navigational lock tainter valve
  - Matched-split flanged bushings
- **Folsom Dam**
  - Oregon Iron Works for the USACE
  - Main spillway radial gate
- **Lake Fork Dam**
  - Johnson Machine Works for the USACE
  - Radial gate main trunnion bearing
  - Large spherical plain bearings

Ipswich Barrier (previous design)

Bushing and spherical designs

- Spherical design allowed for approximately 6° of misalignment
- UNS C95500 nickel aluminum bronze selected for the bushing and spherical bearing outer race (housing)
- UNS S31600 (316) stainless steel selected for the spherical bearing inner race (ball)
- AQ30 selected as the solid lubricant
- Grease grooves utilized fro supplementary greasing options
- 2 bearings utilized per single gate
- Approximate dimensions:
  - Bushing:
    - ID: 500 mm
    - OD: 550 mm
    - Width: 350 mm
    - Lead time: 10 weeks
  - Spherical bearing:
    - ID: 500 mm
    - OD: 710 mm
    - Width: 330 mm
    - Lead time: 12 weeks



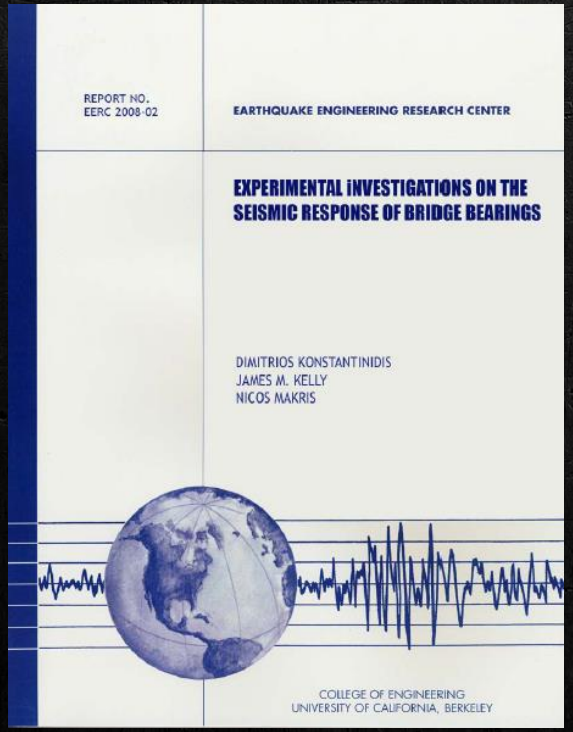


In-House Testing Capabilities

4,000 kip Friction Test Frame

Caltrans EERC 2008

to more stringent requirements, and they are considerably heavier. The steel-reinforced elastomeric bearings and the PTFE-elastomeric bearings described in Parts I and II of this report are much more commonly used as thermal expansion bridge bearings. These types of bearings however are not capable of accommodating large rotations. In applications where large rotations (even up to 3 degrees) need to be accommodated, spherical bearings are used.



9.1 SPHERICAL BEARING DESIGN

Lubron manufactures three types of spherical bearing: unguided, guided and fixed. This study investigated only the unguided bearing—that is one that is free to slide in any direction along the horizontal sliding interface.

The type of bearing tested is labeled by Lubron a *TF structural spherical* bearing. It consists of a woven PTFE fabric liner bonded to the carbon steel substrate. The PTFE fibers are interwoven with secondary glass fibers so that the PTFE is predominant near the sliding surface for minimum coefficient of friction, while the glass fibers are predominant near the bonded surface for maximum adhesion to the carbon steel. The construction of these bearings provides support of the individual PTFE fibers and ensures a rigid bond of the fabric to the substrate by using a general-purpose epoxy adhesive with high peel strength and high toughness. The adhesive is rated for temperatures up to 250°F (120°C). The design of these bearings allows rotations about any horizontal axis by sliding along a spherically shaped interface on one side of the bearing (Figure 9-1). Large horizontal displacements of the superstructure can be accommodated by sliding along a flat woven PTFE sliding interface on the other side of the bearing. Figures 9-2, 9-3 and 9-4 provide full details of the Lubron TF spherical bearing that was used for the tests. The design was based on a previous Caltrans project titled "Indian Hill Flume." Figures 9-5 and 9-6 show photographs of the com-

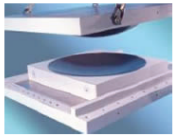


Figure 9-1 The concave-convex sliding interface of a guided Lubron TF bearing [Lubron 2006].

Figure 9-5 Convex and masonry plates.

ponents of the spherical bearings on the testing machine.

Two identical bearings were manufactured for the purpose of this study. Each bearing was resurfaced with new woven-PTFE fabric on the horizontal surface several times during the course of the test program so as to provide a virgin surface to the extend practically possible. Figure 9-7 shows a photograph of the woven PTFE fabric liner.

Unlike elastomeric and PTFE-elastomeric bearings, spherical bearings do not have any rubber components and can therefore accommodate much larger compressive loads. By virtue of their geometry that features a concave-convex sliding interface, they can accommodate large rotations about any horizontal axis. Until now, there had not been sufficient testing done on these types of bearings at higher velocity

RBC Lubron Bearing Systems

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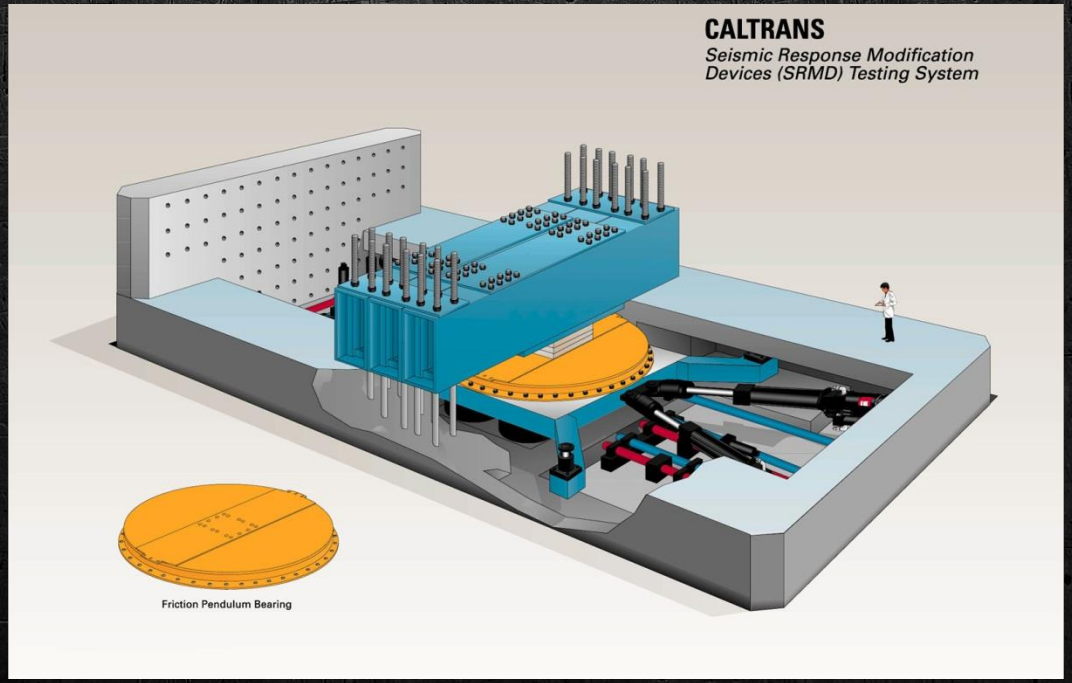
Loads Tested (ksi)

- 2.0
- 3.5
- 5.5
- 7.5
- 10.0

Speeds Tested (in/sec)

- 0.2
- 1.0
- 10.0
- 15.0
- 20.0
- 30.0



SRMD 12,000 kip rig

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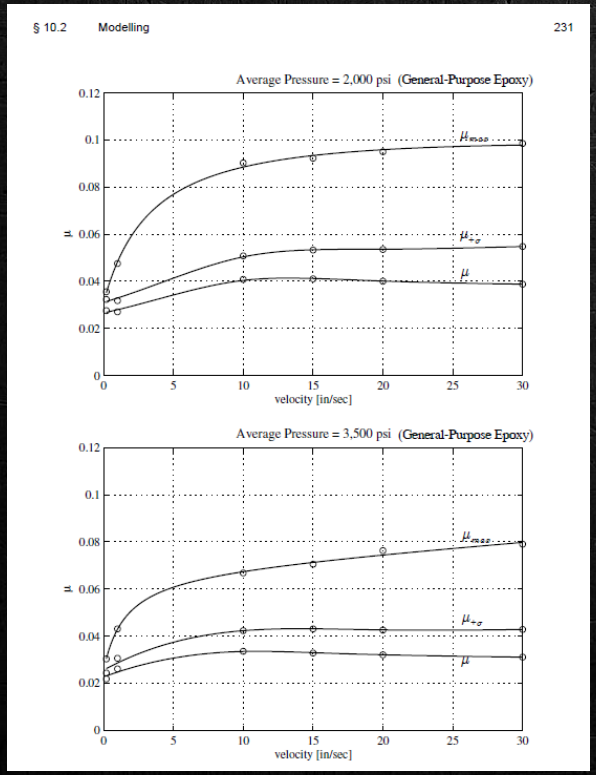


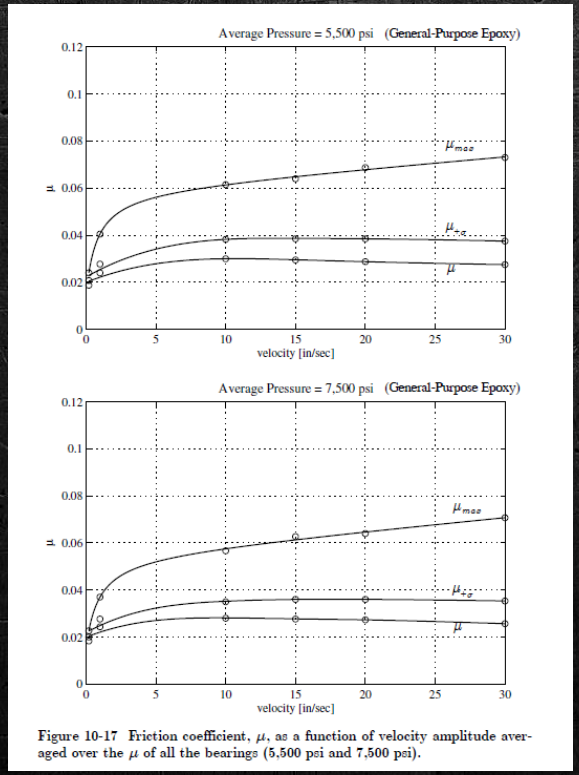
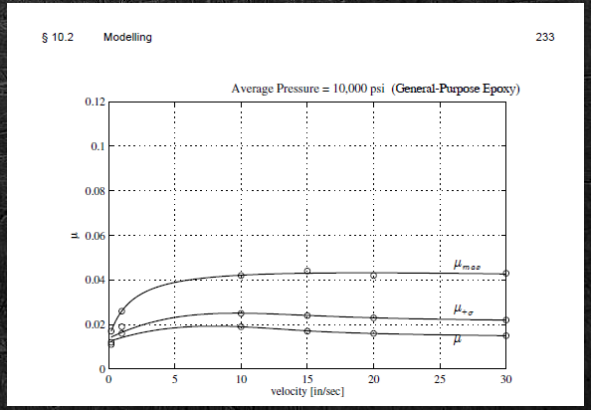


Figure 10-17 Friction coefficient, μ, as a function of velocity amplitude averaged over the μ of all the bearings (5,500 psi and 7,500 psi).



RBC Lubron Bearing Systems

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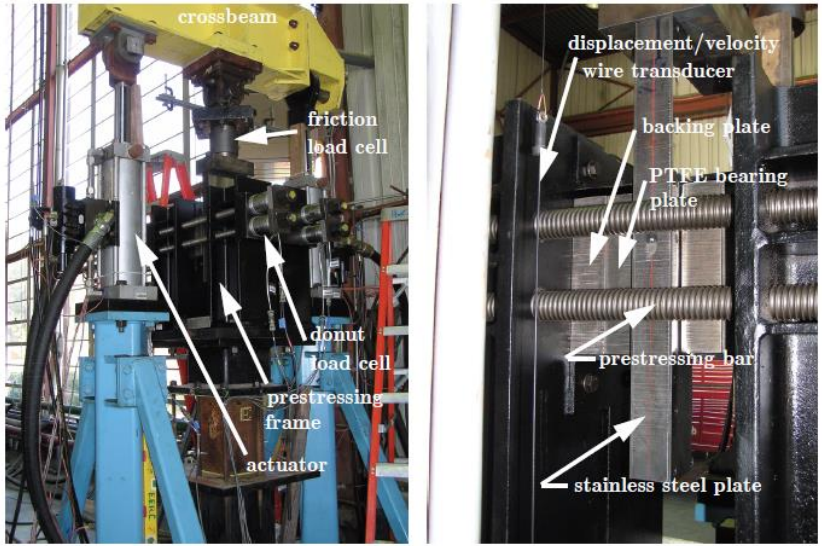

Figure 11-4 *Left*: Fluid damper testing machine at EERC, UC Berkeley, modified to accommodate the PTFE bearing plates. *Right*: Close-up of the PTFE bearing plates sandwiching the stainless steel plate.

Re-test at UC Berkeley
Speeds (in/sec): 0.2, 1, 2, 5, 8, 11, 14, 17, 20, 25, 30, 40
Pressures (ksi): 2.0, 3.5, 5.5, 7.5, 10.0

High-Temp Epoxy
High-Temp Phenolic

Caltrans EERC 2008

Table 11-3 Friction Coefficients for HT-Epoxy PTFE Surface.

μ_{max}

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.037	0.069	0.061	0.052	0.046
1	0.059	0.075	0.063	0.054	0.048
2	0.070	0.079	0.064	0.055	0.050
3	0.076	0.081	0.066	0.057	0.052
5	0.082	0.084	0.068	0.060	0.055
10	0.090	0.089	0.075	0.067	0.062
15	0.095	0.094	0.082	0.073	0.069
20	0.099	0.098	0.088	0.079	0.074
30	0.106	0.107	0.100	0.089	0.083

$\mu_{ave}+\sigma$

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.039	0.061	0.054	0.046	0.039
1	0.065	0.069	0.055	0.046	0.039
2	0.073	0.073	0.057	0.047	0.040
3	0.076	0.074	0.058	0.047	0.041
5	0.079	0.076	0.059	0.049	0.042
10	0.083	0.077	0.061	0.051	0.045
15	0.085	0.077	0.062	0.053	0.047
20	0.086	0.077	0.063	0.054	0.049
30	0.089	0.077	0.066	0.056	0.051

μ_{ave}

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.036	0.057	0.049	0.042	0.034
1	0.062	0.065	0.052	0.042	0.035
2	0.068	0.068	0.053	0.042	0.035
3	0.071	0.069	0.053	0.043	0.036
5	0.073	0.069	0.054	0.043	0.037
10	0.075	0.069	0.054	0.044	0.038
15	0.076	0.068	0.054	0.045	0.039
20	0.076	0.067	0.054	0.045	0.040
30	0.076	0.065	0.054	0.046	0.041

Table 11-4 Friction Coefficients for HT-Phenolic PTFE Surface.

μ_{max}

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.056	0.085	0.064	0.065	0.059
1	0.083	0.087	0.069	0.067	0.061
2	0.087	0.089	0.073	0.069	0.063
3	0.089	0.091	0.076	0.071	0.066
5	0.092	0.095	0.081	0.075	0.070
10	0.100	0.101	0.089	0.082	0.076
15	0.106	0.105	0.094	0.088	0.079
20	0.113	0.108	0.098	0.091	0.081
30	0.126	0.112	0.106	0.094	0.082

$\mu_{ave}+\sigma$

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.063	0.081	0.056	0.054	0.045
1	0.081	0.082	0.060	0.057	0.050
2	0.086	0.082	0.063	0.058	0.052
3	0.089	0.082	0.064	0.059	0.052
5	0.091	0.082	0.066	0.060	0.053
10	0.095	0.082	0.068	0.060	0.053
15	0.097	0.082	0.068	0.060	0.052
20	0.099	0.083	0.069	0.060	0.051
30	0.103	0.083	0.069	0.059	0.050

μ_{ave}

velocity [in/s]	pressure [psi] 2,000	3,500	5,500	7,500	10,000
0.2	0.053	0.076	0.051	0.049	0.041
1	0.077	0.075	0.055	0.051	0.044
2	0.081	0.075	0.057	0.052	0.045
3	0.083	0.075	0.058	0.052	0.046
5	0.085	0.074	0.059	0.052	0.046
10	0.086	0.073	0.059	0.051	0.045
15	0.087	0.072	0.058	0.050	0.043
20	0.088	0.071	0.057	0.049	0.042
30	0.089	0.068	0.055	0.047	0.039

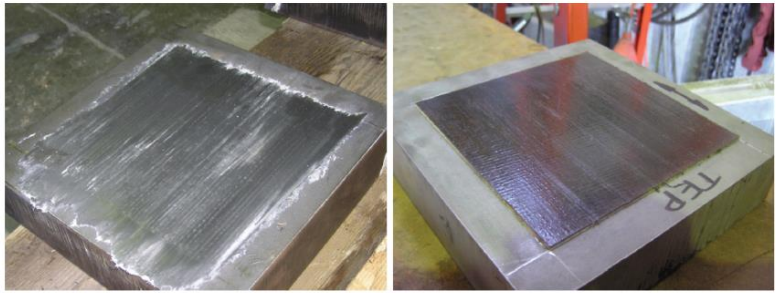

Figure 11-5 *Left*: General-Purpose Epoxy adhesive PTFE liner after 10 tests. *Right*: High-Temperature Phenolic adhesive PTFE liner after completing the entire test protocol (60 tests).

Re-test at UC Berkeley

High-Temp Epoxy CoF: 0.034 – 0.106
High-Temp Phenolic CoF: 0.041 – 0.126

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