# Seismic Retrofit and Rehabilitation of the Million Dollar Bridge

**Tim Ingham**

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## Million Dollar Bridge

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# Located near Cordova, AK

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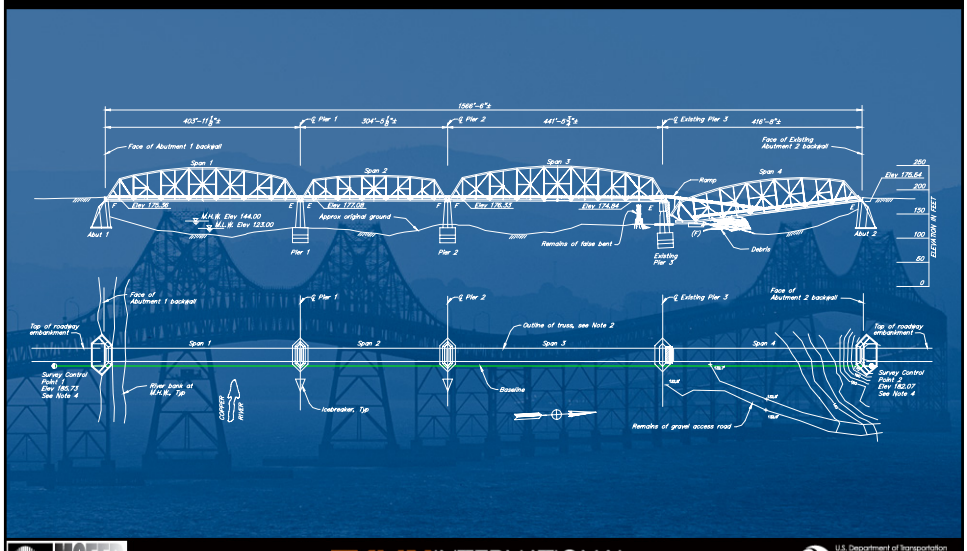
# Span Layout (Existing)

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# Million Dollar Bridge

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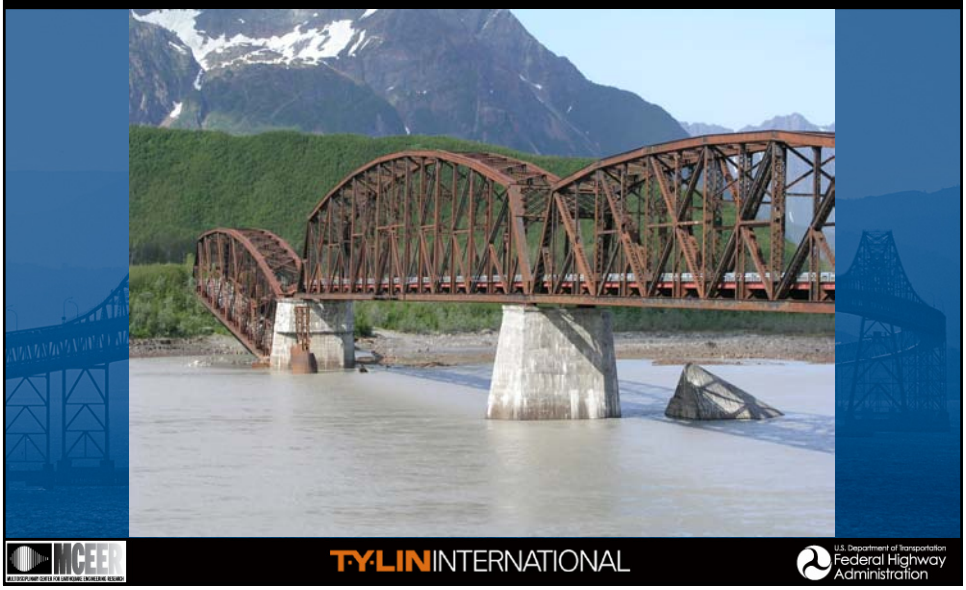
# Million Dollar Bridge



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# Bridge History

- 1909-1910: Bridge was built by the Copper River and Northwestern Railway to serve the Bonanza copper mines
  - 1570’ long Pratt truss
  - Spans are 400’, 300’, 450’, & 400’
- 1938: Railway & mine closed



# Bridge History

- 1958: Bridge was converted to a road bridge
  - New concrete deck
  - Injection of cracks in Piers 2 & 3
- 1964: Bridge was badly damaged in the Good Friday earthquake
  - Span 4 fell into the river
  - Pier 3 badly damaged

# Bridge History

- 1973: Ramp installed from Pier 3 to Span 4
- 1975: Pier 3 strengthened with internal PT and a false bent placed under Span 4
- 1995: False bent destroyed in flood
- 1996: Pilasters added to strengthen Pier 3

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# Original Construction

- Built by the Katalla Corporation
  - For the Copper River and Northwestern Railway
  - From Cordova to the Kennecott/Bonanza copper mine
- Built in the *winter* of 1909-1910
  - Caisson for Pier 1 sunk in May, 1909
  - Span 4 completed June, 1910, thirteen months later
  - Built on falsework driven through the ice
  - Wind chill temperature frequently approached -60˚F
- Cost $1,424,774

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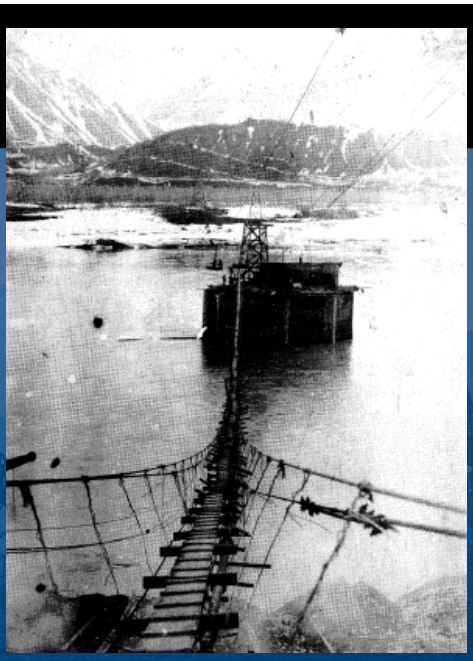
## Sinking Caisson No. 1, May, 1909



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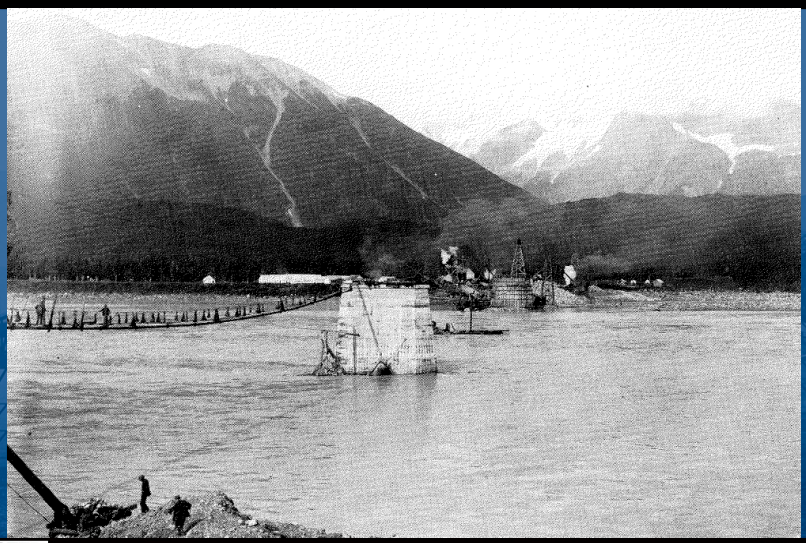
## Piers 1 and 3, August 12, 1909



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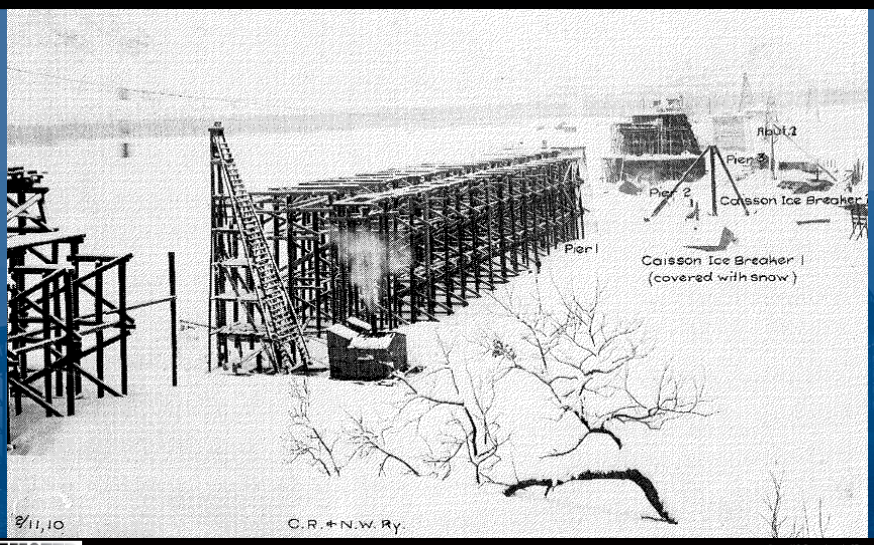
## Construction, February 11, 1910

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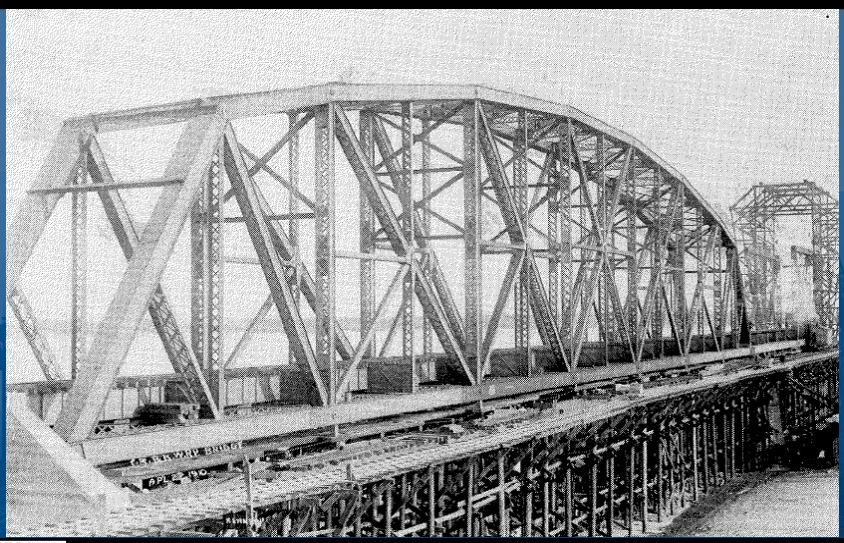
## Span 1, April 22, 1910



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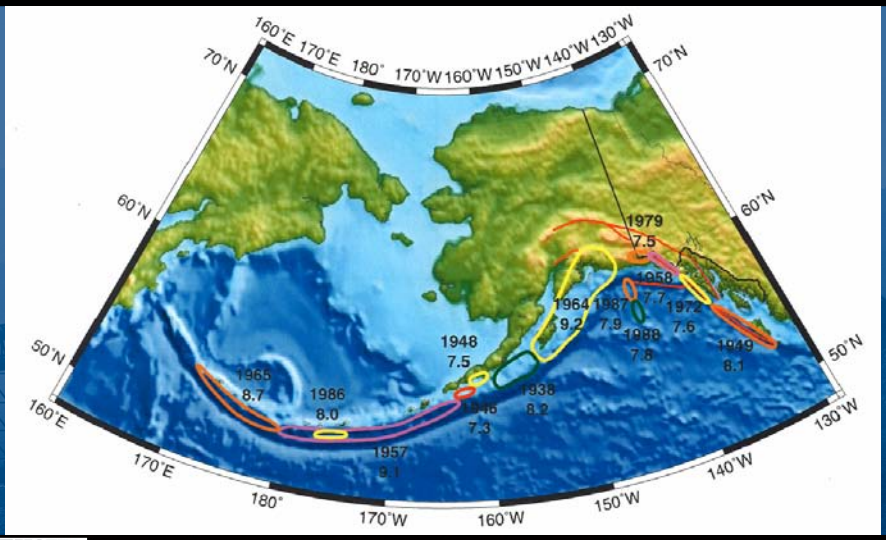
# 1964 Earthquake

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# 1964 Earthquake Damage

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## 1964 Earthquake Damage

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## 1964 Earthquake Damage (Span 4)

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## 1964 Earthquake Damage (Span 4)

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## 1964 Earthquake Damage (Pier 3)

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## 1964 Earthquake Damage (Pier 3)

## 1964 Earthquake Damage (Span 3)

## 1964 Earthquake Damage (Pier 1)

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## 1964 Earthquake Damage (Pier 1)

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# 1964 Earthquake Damage

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# Goal of Project

- **Rehabilitation**
  - To prevent further degradation of bridge
  - Restore capacity to carry full legal live loads
- **Seismic retrofit**
  - Design for earthquake comparable to 1964
  - Prevent future collapse or irreparable damage
- **Preserve historic integrity of bridge**

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# Scope of Rehabilitation

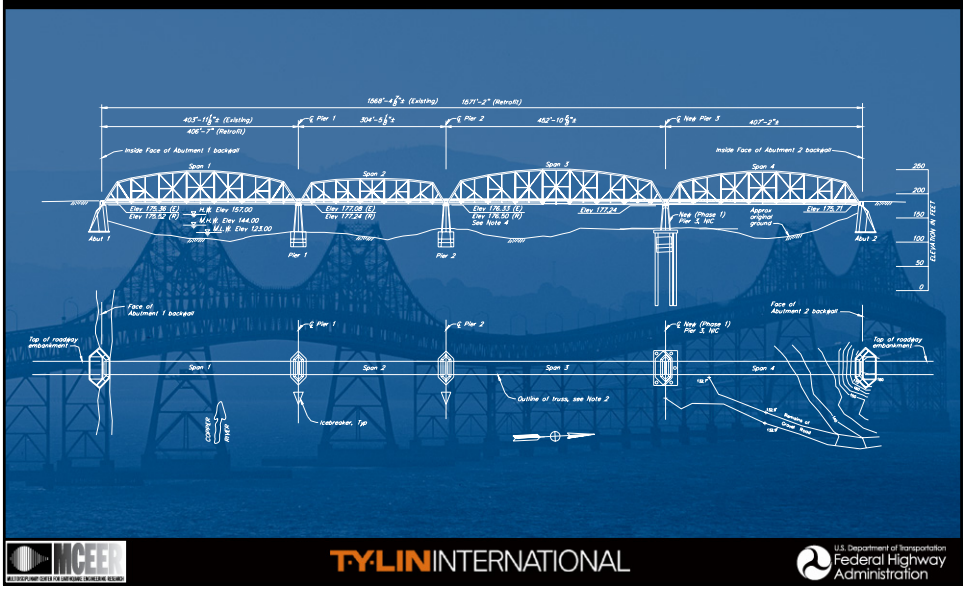
- Raise Span 4 (Phase 1)
- Replace missing or damaged members (Phase 1)
- Restore spans to original or reasonable geometry (Phase 2)
- Other general rehabilitation measures (Phase 2)
  - Deck joints
  - Concrete



# Scope of Seismic Retrofit

- Seismic Isolation of Superstructure (Phase 2)
- Strengthening of
  - Superstructure (Phase 1)
  - Piers (Phase 1 & 2)
  - Abutments (Phase 1 & 2)
  - Foundations (caissons) (Phase 2)

# Span Layout (Retrofit)






# Historic Design Criteria

- **Bridge is on the National Register of Historic Places**
  - **On the basis of its original construction**
- **"The Secretary of the Interior's Standards…"**
  - **Protect and maintain**
  - **Repair**
  - **Replace**
  - **…**

# Historic Issues

- Replacement of members in Spans 3 and 4
- Retrofit of Piers 1 & 2
  - With reinforced concrete jackets, or
  - With high-strength rods
- Replacement of Pier 3 with a new pier and foundation



# Seismic Design Criteria

- Design to 475 year hazard
- Significant damage allowed
- Collapse not allowed
- Full-ductility structure
  - Clearly defined plastic mechanism
  - Inelastic behavior restricted to properly detailed piers, piles, etc.

# Environmental Issues

- ADF&G Permit
- Temporary access roads & work pads
  - Provided an opening in the access road, to minimize blockage of the river
  - Remove each summer



# Construction Site Factors

- Remoteness of the bridge from Cordova
- Remoteness of Cordova from major metropolitan centers
- High water in summer
- Cold weather and high winds in winter
- Access to north shore difficult for heavy equipment

# Hydrologic Conditions

- **Copper River**
  - Currents reach 12 mph
  - Average discharge is 57,400 cubic feet / second
  - Transports a great deal of sediment
    - 1 gram / liter
    - 1,000,000 tons per day during peak flows
- **Water surface elevation varies greatly during summer**
- **River freezes in winter**
  - Ice is 2-3 feet thick on average
- **Icebergs are commonplace when the river is flowing**

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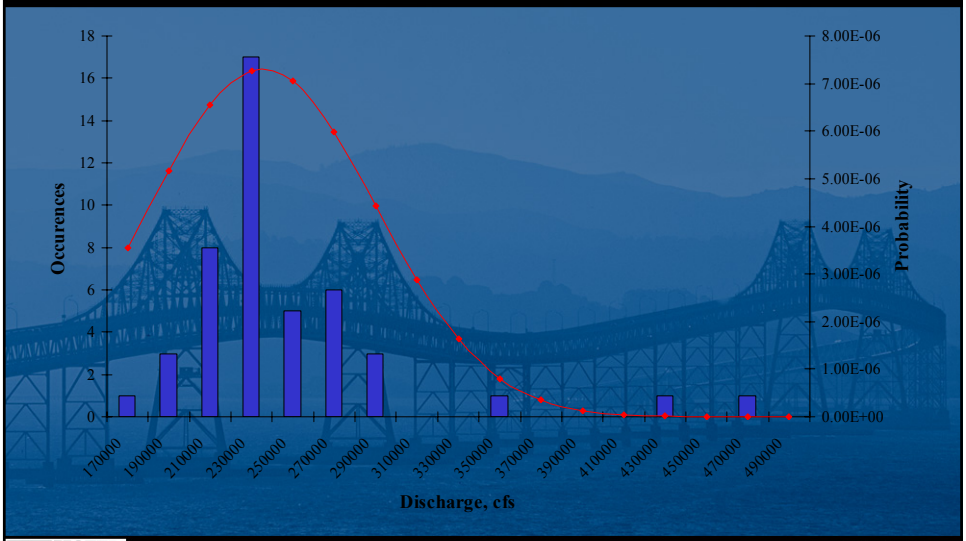
# Peak Yearly Discharge, 1950-1995

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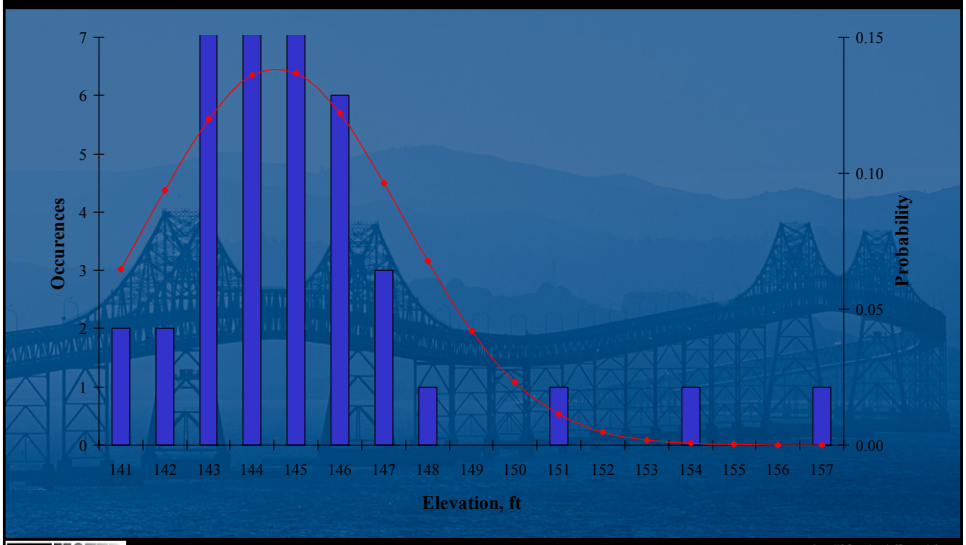
# Water Surface Elevation

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# Winter Conditions

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## Winter Conditions

## Contractor Camp

# Contractor Yard

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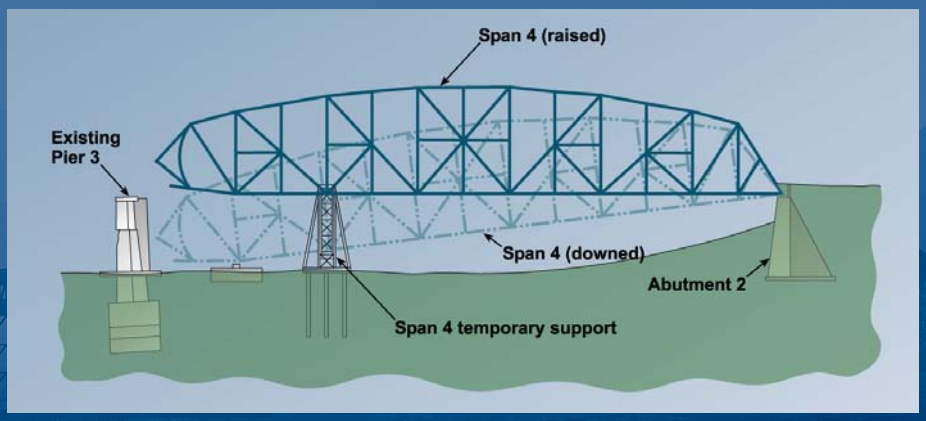
# Span 4 Lift and Temporary Support

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## Span 4 Lift

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## Span 4 Lift

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## Temporary Strengthening

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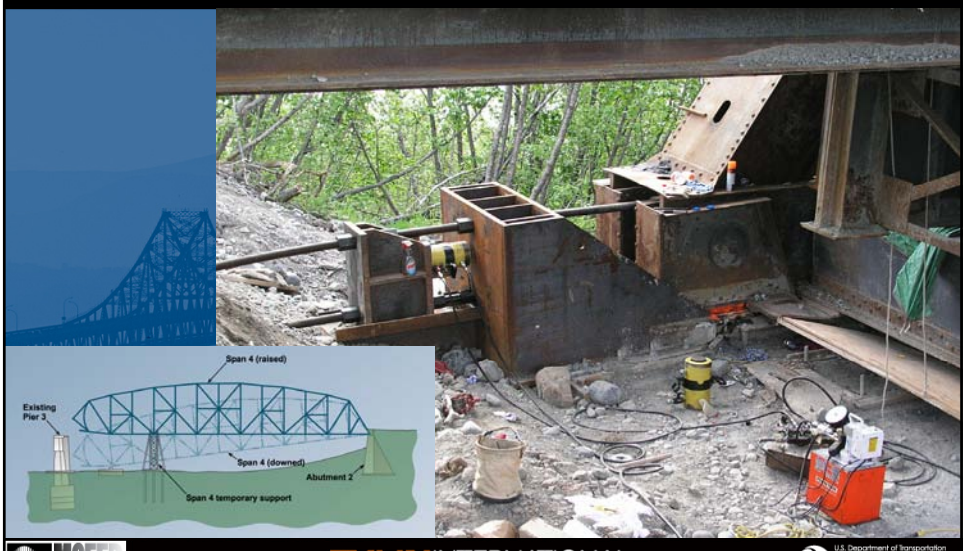
## Span 4 Lift

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## Span 4 Temporary Support

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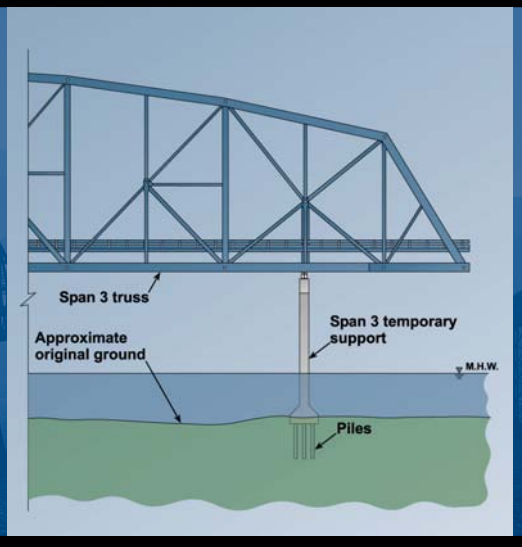
## Span 3 Lift and Temporary Support

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## Span 3 Temporary Support

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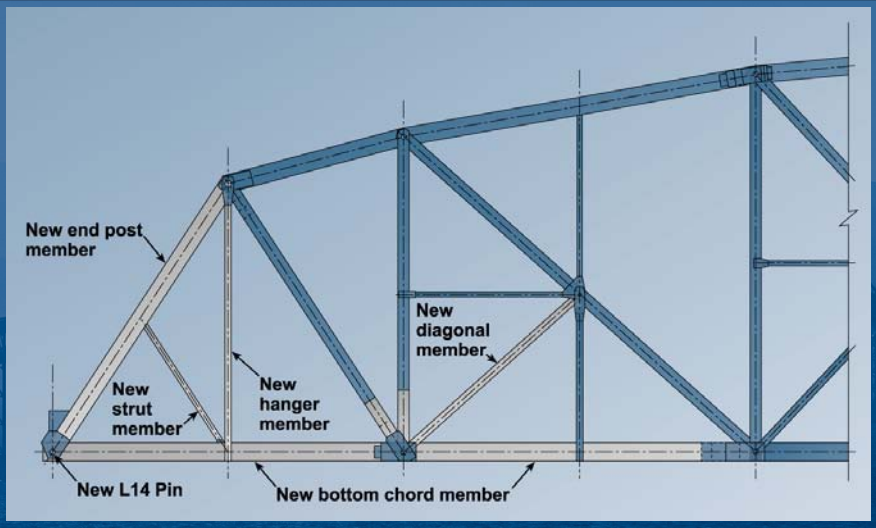
## Span 4 Rehabilitation

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# Structural Steel Fabrication

- Fabricate members per original shop drawings
- But
  - Use single, rather than multiple plates
  - Use modern shapes
  - Use bolts, rather than rivets
- Maintain external dimensions & appearance
- Bolt heads to outside

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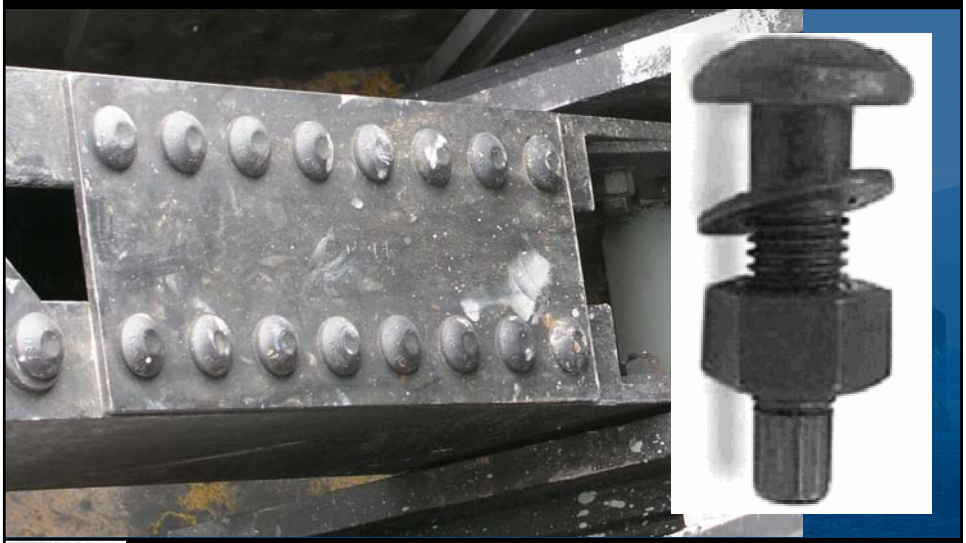
# Tension Control Bolt



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## Span 4 Rehabilitation

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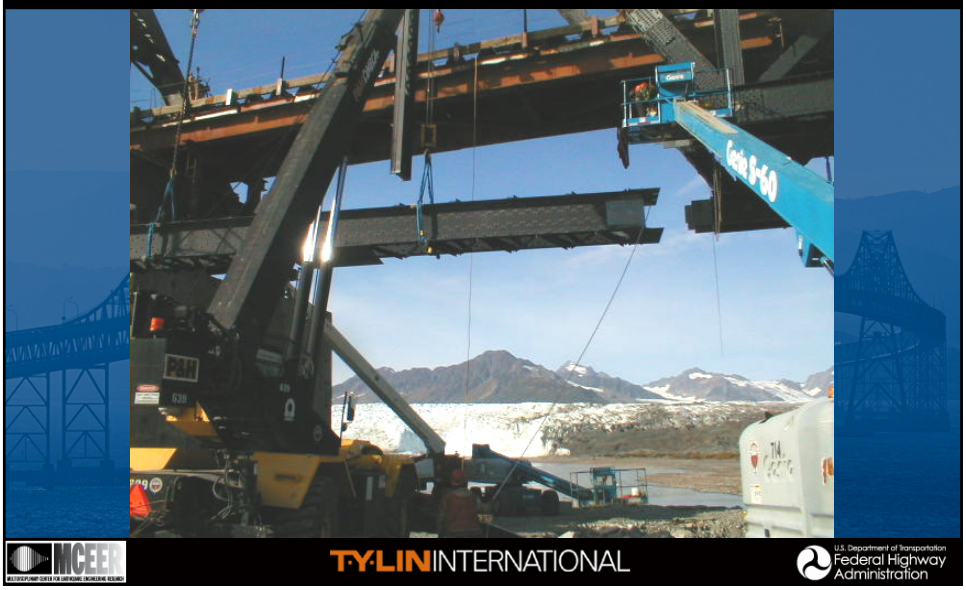

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## Completed Span 4

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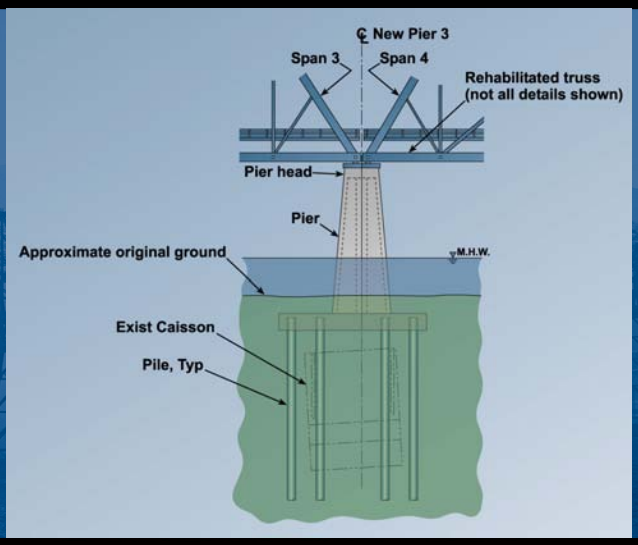
# Pier 3 Demolition and Replacement

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# Pier 3 Shafts

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## Pier 3 Shafts

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## Pier 3 Demolition

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# Pier 3 Demolition

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# Pier 3 Footing

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## Pier 3 Footing

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## New Pier 3

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# Conclusion of Phase 1

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# Phase 2

- Strengthen Piers 1 & 2
- Reposition spans
- Replace bearings with friction pendulum bearings

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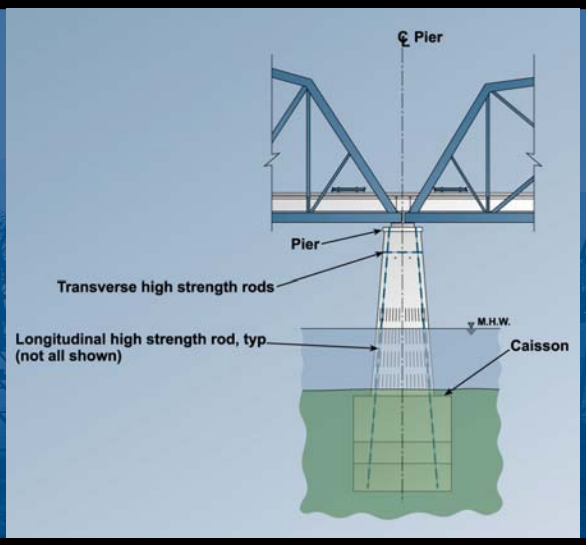
# Pier 1 and 2 Retrofit

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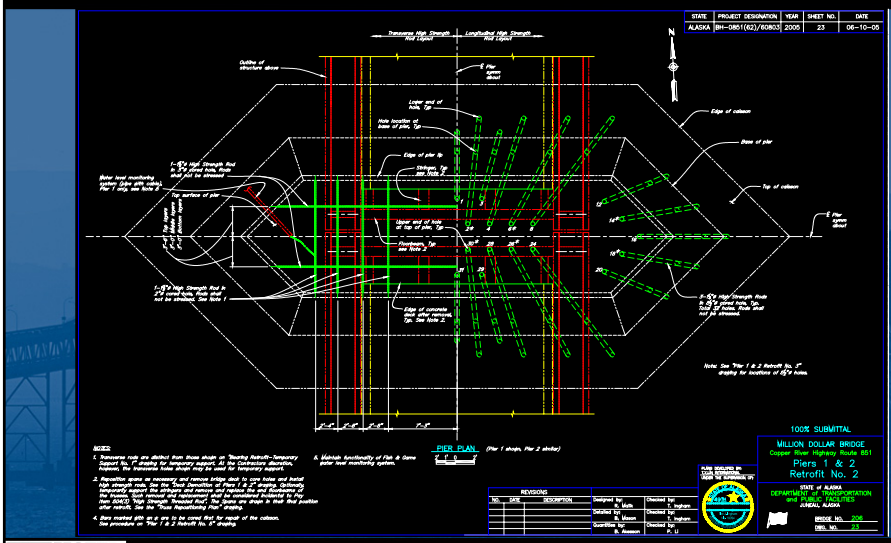
# Pier 1 and 2 Retrofit

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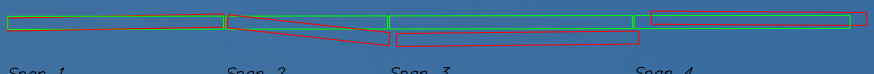
# Truss Repositioning Plan




TRUSS POSITION AND MOVEMENT

| | | | Existing | | | | Retrofit | | | | Movement | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Local | | Global | | Local | | Global | | Local | |
| Span | Pier | Corner | x | y | X | Y | x | y | X | Y | x | y |
| Span 1 | Abutment 1 | East | -3.53 | -12.87 | 107.99 | 7.30 | -3.53 | -12.57 | 107.99 | 7.60 | 0.00 | 0.30 |
| | | West | -3.83 | 11.13 | 107.88 | 31.30 | -3.75 | 11.43 | 107.95 | 31.60 | 0.07 | 0.30 |
| | Pier 1 | East | -1.51 | -12.12 | 508.04 | 8.50 | -1.56 | -12.51 | 507.98 | 8.10 | -0.05 | -0.39 |
| | | West | -1.53 | 11.88 | 507.96 | 32.50 | -1.54 | 11.49 | 507.95 | 32.10 | -0.01 | -0.39 |
| Span 2 | Pier 1 | East | 2.53 | -12.26 | 512.07 | 8.37 | 2.35 | -12.51 | 511.90 | 8.11 | -0.17 | -0.26 |
| | | West | 2.87 | 11.74 | 512.37 | 32.36 | 2.38 | 11.49 | 511.87 | 32.11 | -0.50 | -0.25 |
| | Pier 2 | East | -1.83 | -13.42 | 812.03 | 5.41 | -1.98 | -10.34 | 811.90 | 8.49 | -0.15 | 3.08 |
| | | West | -1.73 | 10.58 | 812.29 | 29.40 | -2.18 | 13.66 | 811.87 | 32.49 | -0.44 | 3.08 |
| Span 3 | Pier 2 | East | 2.78 | -13.53 | 816.64 | 5.26 | 1.51 | -10.31 | 815.40 | 8.49 | -1.26 | 3.22 |
| | | West | 2.59 | 10.47 | 816.62 | 29.26 | 1.32 | 13.69 | 815.37 | 32.49 | -1.27 | 3.22 |
| | New Pier 3 | East | -0.22 | -14.80 | 1266.68 | 6.32 | -1.49 | -12.07 | 1265.40 | 9.06 | -1.27 | 2.74 |
| | | West | -0.28 | 9.20 | 1266.59 | 30.32 | -1.49 | 11.93 | 1265.37 | 33.06 | -1.21 | 2.74 |
| Span 4 | New Pier 3 | East | *4.82* | *-11.73* | *1271.71* | *9.41* | 2.01 | -12.07 | 1268.90 | 9.06 | *-2.81* | *-0.34* |
| | | West | *4.80* | *12.27* | *1271.66* | *33.41* | 2.01 | 11.93 | 1268.87 | 33.06 | *-2.79* | *-0.34* |
| | Abutment 2 | East | 6.53 | -11.99 | 1671.71 | 10.18 | 3.72 | -12.61 | 1668.90 | 9.57 | -2.81 | -0.62 |
| | | West | 6.40 | 12.01 | 1671.66 | 34.18 | 3.61 | 11.39 | 1668.87 | 33.57 | -2.79 | -0.62 |

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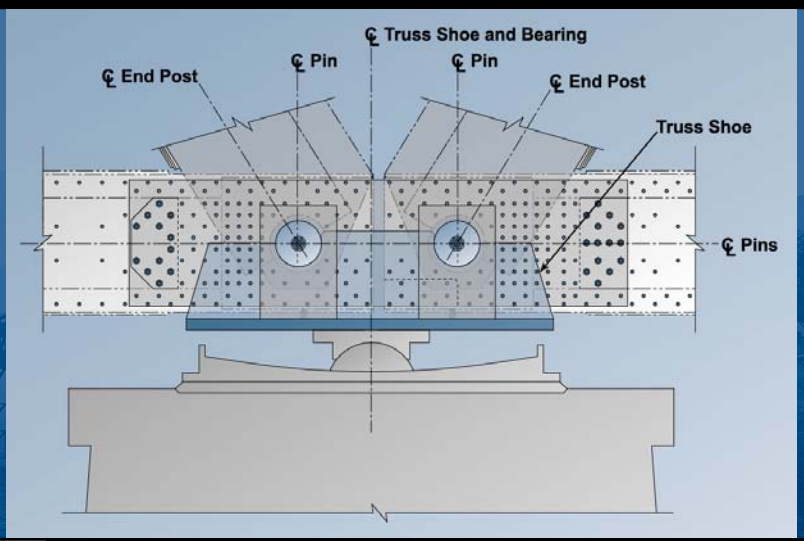
# Friction Pendulum Bearing Retrofit

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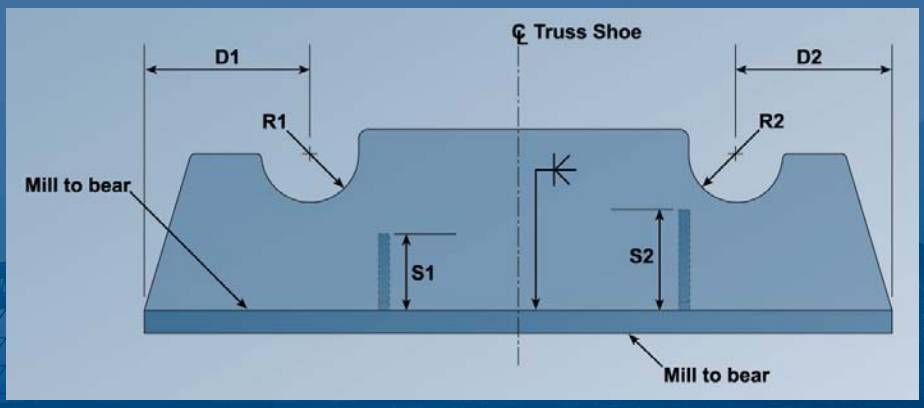
# Bearing Retrofit

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# Friction Pendulum Bearings

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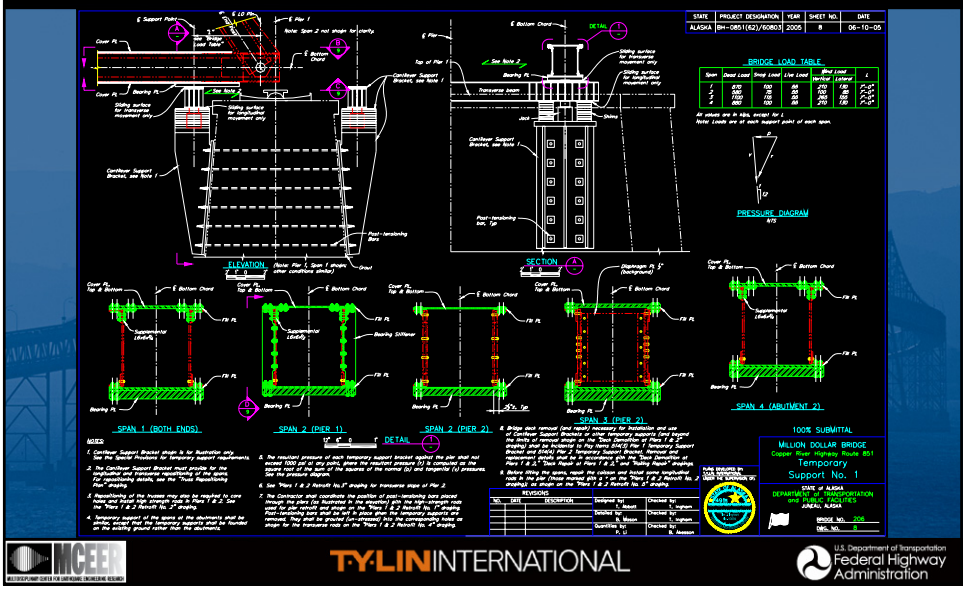
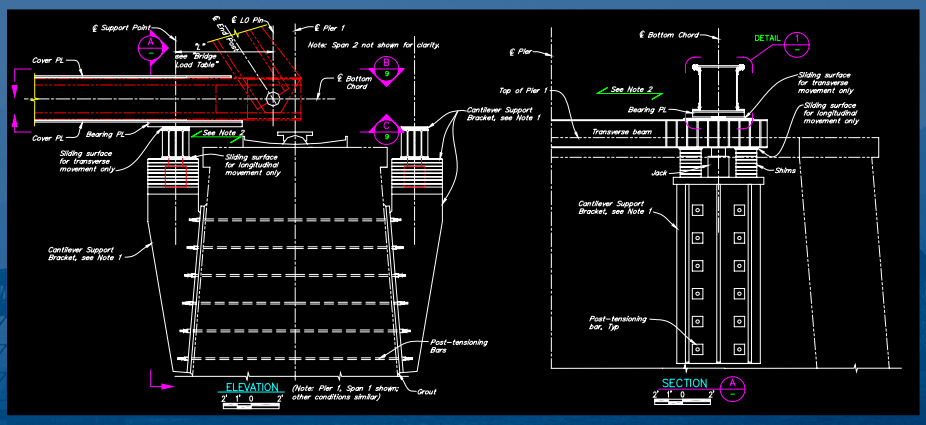
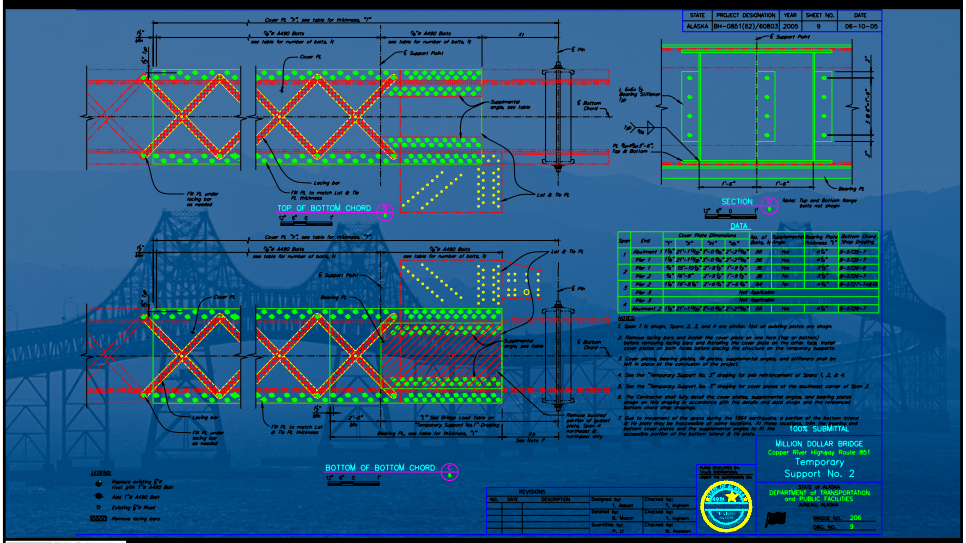
# Temporary Support




# Temporary Support



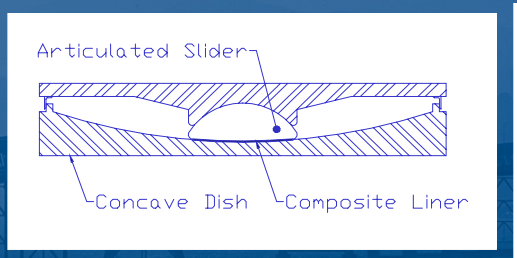
# Temporary Strengthening

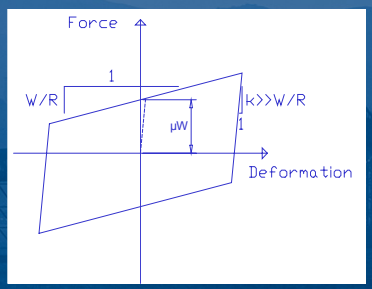





# Friction Pendulum Bearings

- Mechanically simple
- Mathematically complex



# Force-Deformation Relationship

- **One-dimensional behavior**

$$F = \frac{N}{R} D + \mu N (\operatorname{sgn} \dot{D}) \quad \text{where} \quad N = \text{vertical force}$$

- **Common simplification**

$$F = \frac{W}{R} D + \mu W (\operatorname{sgn} \dot{D}) \quad \text{where} \quad W = \text{dead weight}$$

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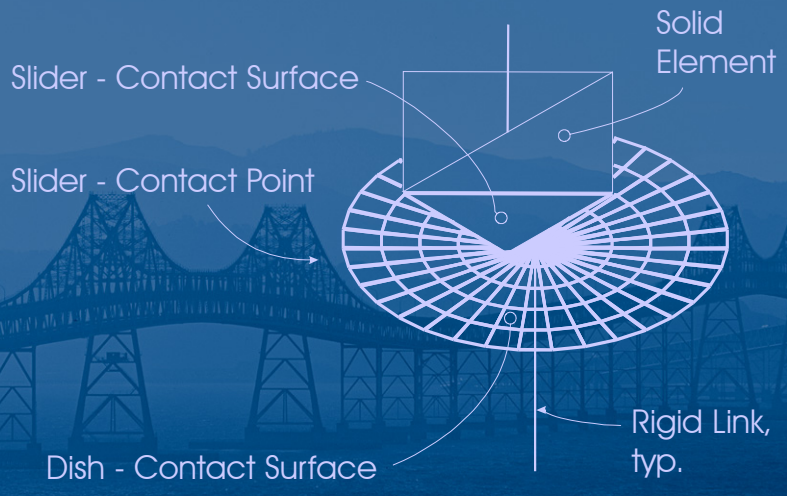
# Contact Surface Model

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# Period of Vibration Test

- **Give the slider an initial velocity**
  - Radius = 20 feet
  - Coefficient of friction = 1%

Video Clip

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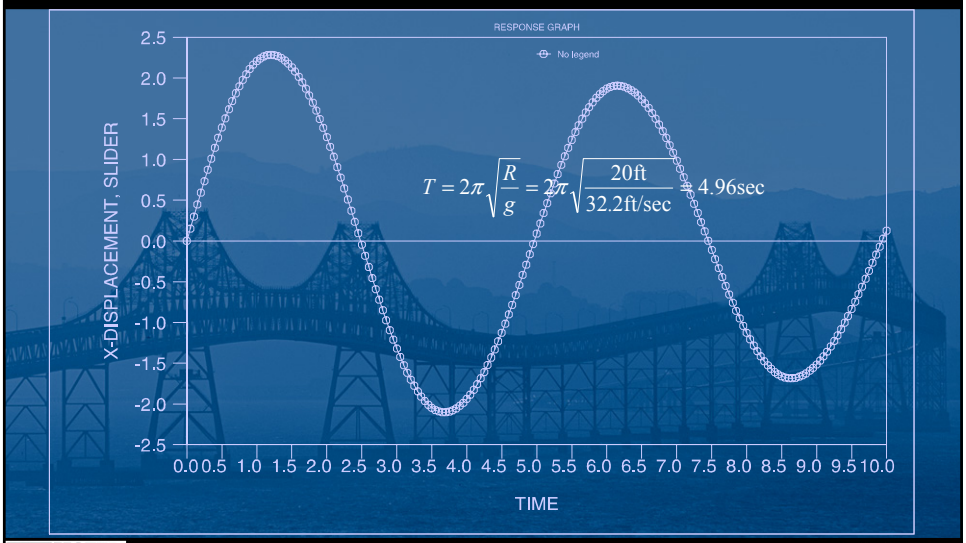
# Period of Vibration Result

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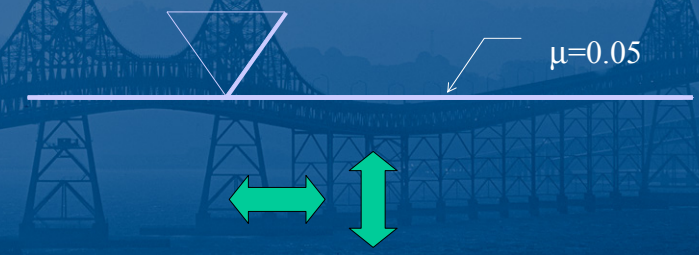
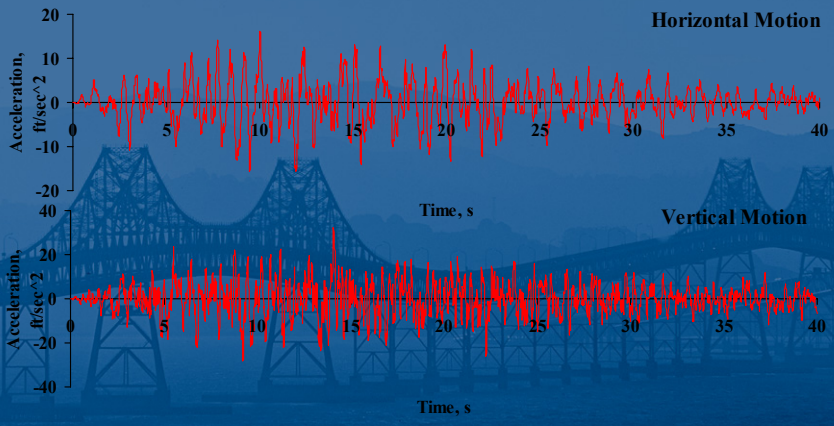
# Friction Test

- Analyze slider on a *flat*, frictional surface
- Apply both horizontal and vertical motions

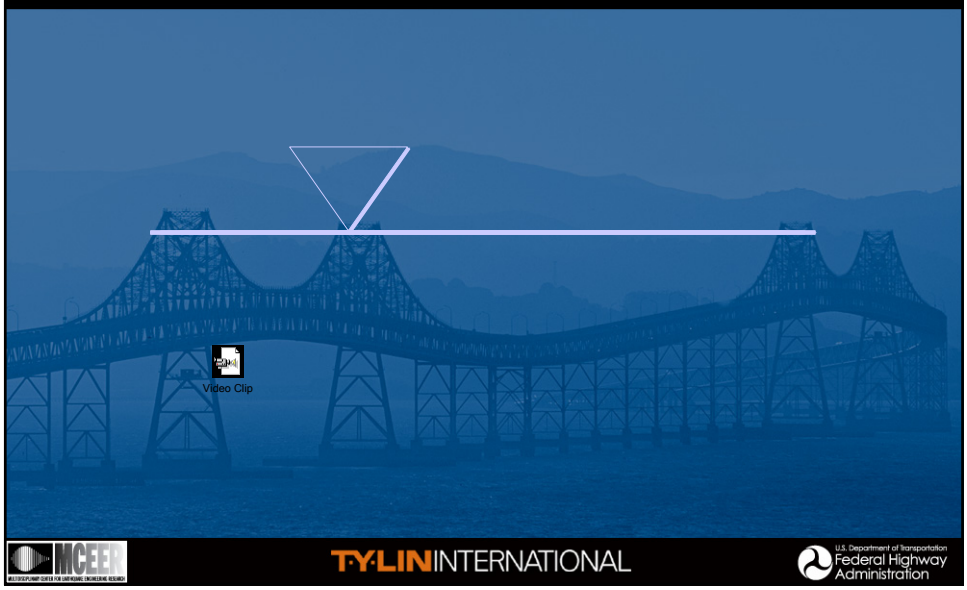





# Motions

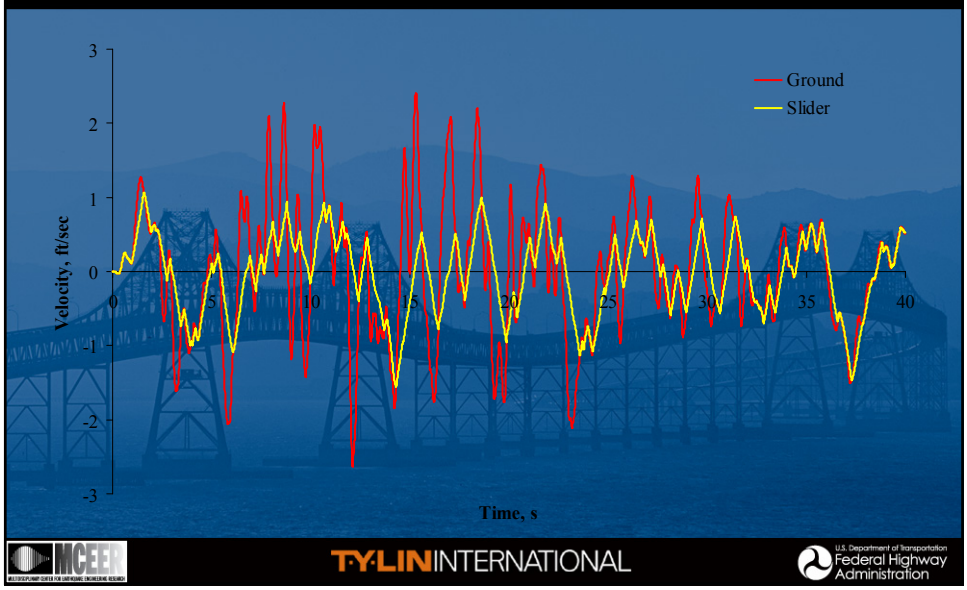


# ADINA Solution

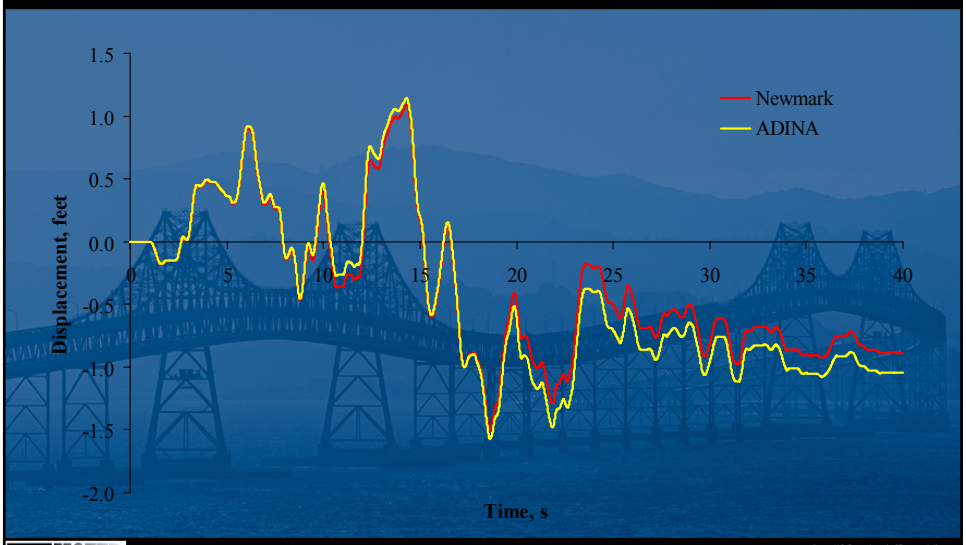





# Solution using Newmark Method

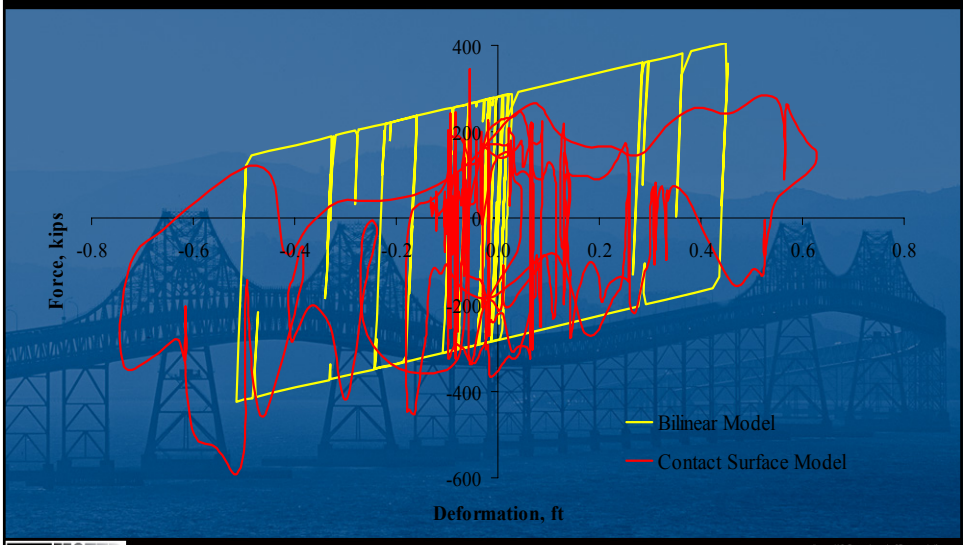


# Comparison






# Model Comparison



# ADINA Model

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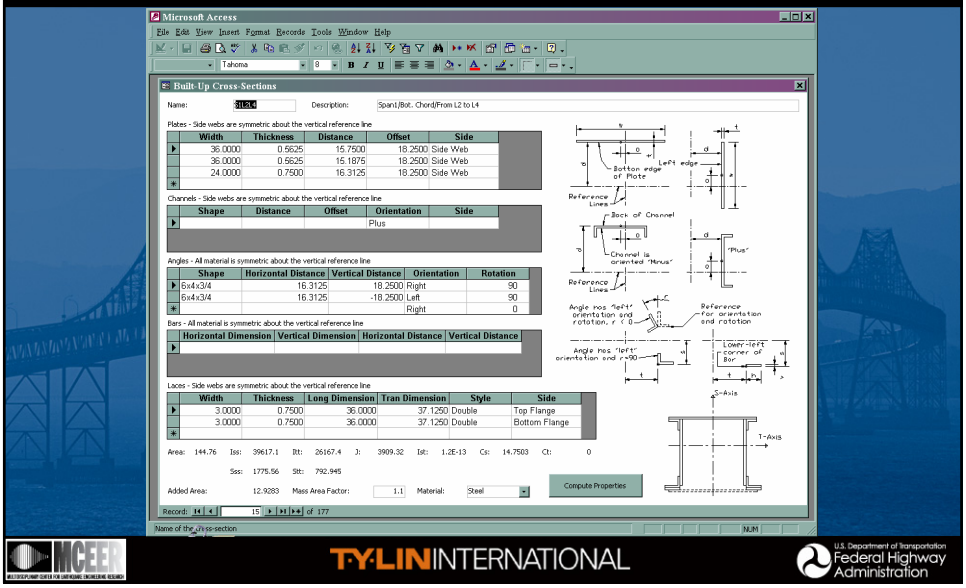
# Truss Database

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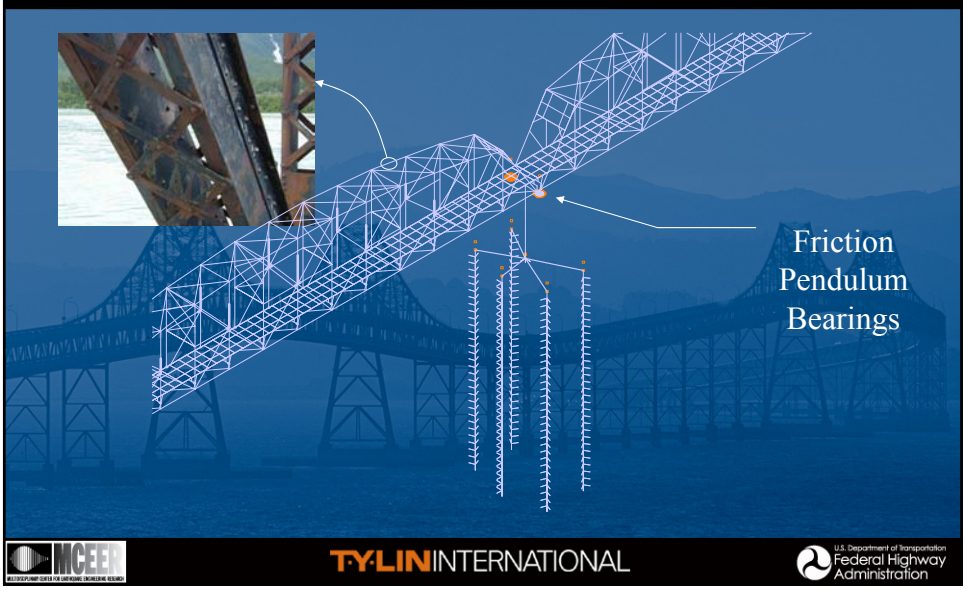
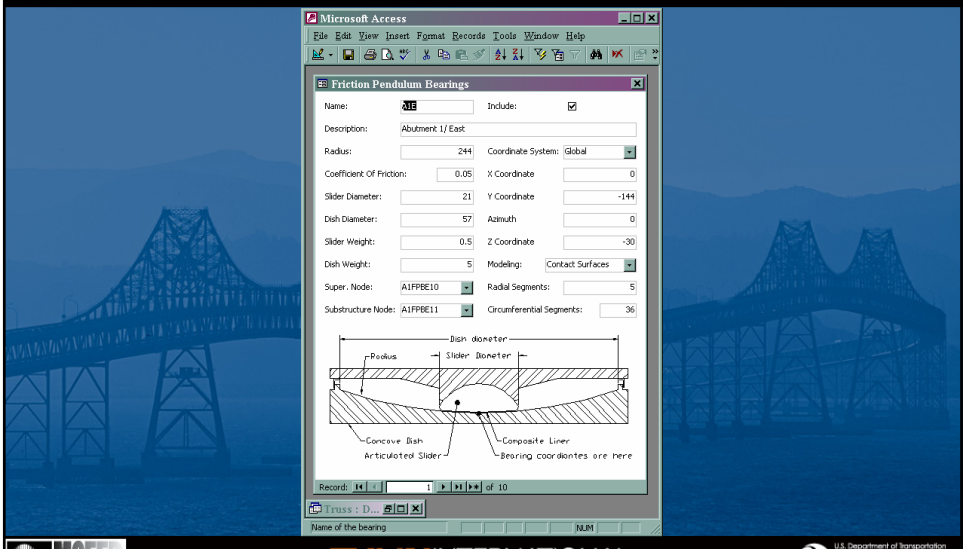
# New Pier 3

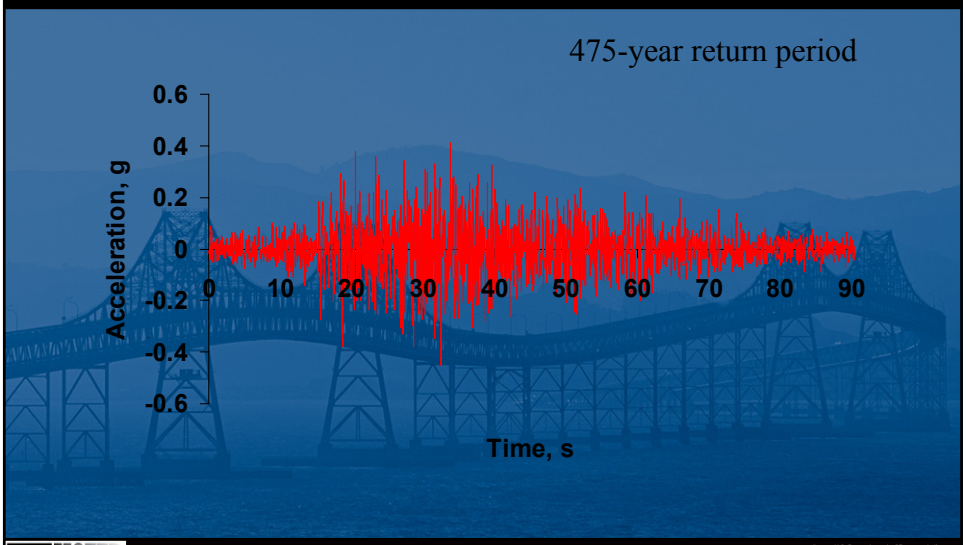





# Friction Pendulum Bearing Form



# Ground Motion

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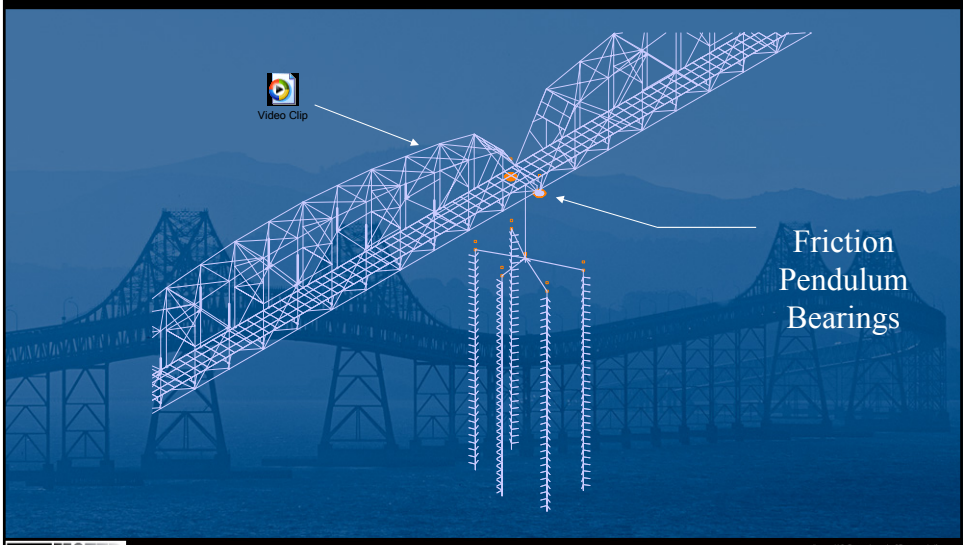
# Bearing Response

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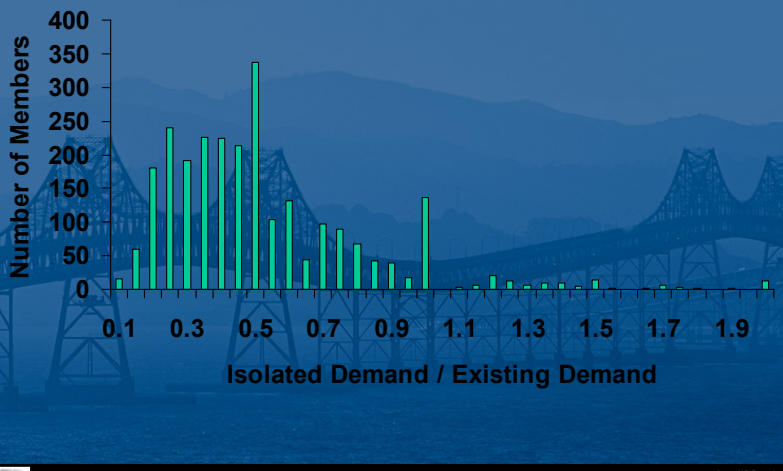
# Reduction of Superstructure Forces

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# Current Status

- **Phase 1**
  - Drive piles
  - Lift Spans 3 & 4
  - Replace structural steel
  - Build new Pier 3 & footing
  - Done!
- **Phase 2**
  - Reposition spans
  - Replace bearings with friction pendulum bearings
  - Strengthen Piers 1 & 2

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