Seismic Retrofit of the Dumbarton Toll Bridge

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Presentation Outline

• Bridge Description
• Schedules and Retrofit Criteria
• Site Specific Ground Motions
• Modeling and Analysis
• Seismic Vulnerability Assessment
• Retrofit Alternatives
• Contractor Outreach
• Retrofit Construction and Cost
• Conclusions
Dumbarton Bridge Description

Location

- Southern most toll bridge on Route 84 connecting the cities of Newark and East Palo Alto
- “Important Bridge,” (not a lifeline route) connects Silicon Valley – Hub of world high tech. industry
- Average Daily Traffic of ~80,000
- 8600’ long, 6- lanes
- Designed in 1978 and constructed in 1982
- Consistent with the Seismic Advisory Board’s recommendation, Caltrans completed seismic retrofit design in 2010 and construction completed in 2013
Description of Bridge

- East Approach Structure *
- East Trestle Structure
- West Approach Structure *
- West Trestle Structure
- Main Channel Crossing Steel Box Girder Pier 16 thru P31
Bridge Structure Type

Trestles and West /East Approaches:
- 600’ long slab bridge - 20 spans @ 30’ - 5 frames
- 20” square pile extensions – tot. 7 per bent
- 2100’ long concrete bath tub superstructure: 14 spans @150’ – 4 frames each side
- Supported on 2 V-shape hollow column bent
- Substructure - Pile cap with 20” pipe pile group

Main Channel:
- 3150’ long - Steel Box composite concrete deck - 14 spans supported on 2 V-shape hollow column bent
- 3 frame with 2 in spans hinges with 340’ center span
- Substructure consists of
  - Pile cap with 20” dia. pipe pile group
  - Pile cap with 54” dia. Hollow P/S concrete pile
Seismic Retrofit of the Dumbarton Bridge

Schedule

• Extremely Aggressive Schedule

• Lots of Unknown ???
  • Hollow Columns, Hollow P/S concrete piles
  • Joint Shear Behavior
  • Column Main Rebar - Staggered couplers at the bottom
  • Soil Structure Interaction

• Complicated structure type and details
• Helps designers to plan construction details and sequencing
• Hinge hangers pins vulnerable
Retrofit Schedule

Project Delivery Completed at Risk - Top Priority Expedite Seismic Safety
Aggressive Schedule – **Missing deadline was not an OPTION**

- Retrofit Design start - end of 2007
- Env Document
- Permitting
- PS&E – Aug 2009
- OE - Dec 2009
- Contractors Outreach Apr 2010
- Awarded June 2010
- Approaches Retrofit removed July 2010
- Construction start 8/2010
- Safety - Dec 2013
- Retrofit Complete May 15, 2013

Environmental/Design Process

Bid

Construction

Bearing Prototype Program – Manf/Testing

UCSD Bent Testing Program
Site Specific Geotechnical Investigation

Phase 1 - Extensive Geotechnical Investigation - Earth Mechanics Inc.

- 14 soil borings,
- 6 down-hole seismic suspension loggings,
- 7 vane shear tests, and 33 cone penetration tests (CPT).
- Boreholes and CPT soundings penetrated to depths of from 67 to 270 feet

**Subsurface Condition**

- Fill – Silty clay and silty sand present from elevation +10 ft to -10 ft
- Young Bay Mud (YBM) – Marine clay underlies the fills, generally - elevation 0 to -40 ft;
- Posey Sand – River sand can be found throughout the bridge alignment from elevation -40 ft to -80 ft;
- San Antonio Formation (SAF) – Stiff to very stiff clay can be found from elevation -70 ft to -140 ft;
- Old Bay Mud (OBM) – Very stiff to hard marine clay, found from elevation -120 ft to -190 ft;
- Alameda Formation – Very dense sand and gravel, and very hard clay can be found below elevation -190 ft;
- Franciscan Formation – Sedimentary bedrock, expected at elevation -600 feet.
• Located between the San Andreas and Hayward.
• Depth varying non-linear p-y, t-z, q-z curves
• Foundation Springs 6x6 matrix
• ARS Curves, Spectral Displ. Curves
• 7 set of pier-specific kinematic time histories were developed for 7 earthquake with each pier having three-component kinematic motions
Seismic Retrofit Criteria

Various Range of Seismic Retrofit Performance Criteria Alternatives were considered.

- Bay Area Transportation Authority (BATA) wanted
  - Same Performance Level as San Mateo Bridge
  - Design Criteria – Open
  - Start with “no collapse” and then investigate upward, while monitoring costs and benefits
Seismic Performance Criteria was developed in consultation with Bay Area Transportation Authority (BATA), Caltrans and Peer Review Panel.

SEE: Seismic safety specified for the 1000 year return period Safety Evaluation Earthquake with acceptable damage at predetermined locations *

- Immediate service to emergency traffic
- Full traffic within 6 months after a design seismic event.

*Damage was identified as: concrete spalling at superstructure diaphragm - pier cap connection, cracking at the column and pedestal base, yielding of steel pipe piles and damage to Seismic Isolation Joint

FEE: Essentially Elastic Response

- Minor damage at Seismic Isolation Joint - Transflex 650 Assembly

Repairs to acceptable damage could be done using epoxy injection post-design earthquake
Modeling and Analysis

- **Global Models – Demand Calculation**
  - The global model included East and West Approaches and the Main Channel Crossing

- **Finite element – Demand Calculation**
  - Shell Elements model developed for steel box girder main channel crossing

- **Local Models - Capacity (Pushover Models)**
  - Local models of representative piers were selected to conduct soil structure interaction analysis in transverse and longitudinal direction
  - Piers 2, 9, 15, 16 of West Approach - 20-inch diameter steel pipe piles
  - Piers 30 and 43 within East Approach - 20-inch diameter steel pipe piles
  - Piers 17 and 23 within Main Channel Crossing - 54-inch diameter concrete hollow piles with a long cantilever pile length above mud-line
• Acceleration Response Spectra (ARS) and Non-Linear Time Histories (NTHA) of the entire structure (global model) were performed to capture the overall dynamic response of the bridge using SAP2000 and ADINA – Displacement Demands

• Multi - support excitation

• Avg. of 7 NTHA demand used for design
Models developed by separate teams

West Approach Model

Main Channel Model

East Approach Model
Separate finite element models of East and West Approaches, and Main Channel Crossing combine to develop the “Global Model”
Local Model - Pier 15

**TABLE II: PILE EXTREME FIBER STRAIN (%) AT IN-GROUND HINGE**

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<th>Pier No.</th>
<th>Transverse Direction</th>
<th>Longitudinal Direction</th>
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<tr>
<td></td>
<td>ARS</td>
<td>Avg. TH</td>
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<tr>
<td></td>
<td>Tension $\varepsilon_t$</td>
<td>Compression $\varepsilon_c$</td>
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<td>15</td>
<td>0.14</td>
<td>-0.30</td>
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<tr>
<td>Main Channel</td>
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<td></td>
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<tr>
<td>30</td>
<td>1.36</td>
<td>-1.59</td>
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<tr>
<td>East Approach</td>
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<tr>
<td>43</td>
<td>0.12</td>
<td>-0.23</td>
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</table>

*Extreme fiber strain greater than yield but pipe piles have a reliable ductility of 3 with ultimate strains up to 2.5%*
Seismic Vulnerability Assessment

Seismic Vulnerability and Retrofit Evaluation - Approaches

The presence of couplers at the bottom of the columns was investigated:
- Seismic displacement demands computed assuming half of the column couplers are ineffective
- Column ductility demands were compared with the displacement capacities for half of the column main bars

Displ. Capacity > Displ. Demand

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<th>Pier</th>
<th>31</th>
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<th>33</th>
<th>34</th>
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Transverse

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<tbody>
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<td>$\mu_D$</td>
<td>1.71</td>
<td>1.91</td>
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<td>1.54</td>
<td>1.81</td>
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<td>1.40</td>
<td>1.61</td>
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<td>1.67*</td>
<td>1.97*</td>
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<tr>
<td>$\mu_C$</td>
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<td>3.05</td>
<td>2.51</td>
<td>3.22</td>
<td>3.50</td>
<td>2.74</td>
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<td>2.59</td>
<td>3.29*</td>
<td>4.15*</td>
<td>6.88*</td>
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</table>
As-Built Testing at UCSD and Independent Design Review

- Flexural capacity of hollow columns, and joint shear capacity of column-pier cap joint and column-pedestal joint verified by
- 1/3 scale Pier 23 and Pier 37 tested at UCSD
- Test showed reliable ductile behavior of hollow columns with a ductility of 5
- Bent cap-column and column to pedestal joints remained essentially elastic

Results of testing at UCSD, Caltrans further rigorous analyses and independent analyses by Dr. Nigel Priestly confirmed that retrofit for column and pier cap joint was not needed.
1/3 Scale Testing – UCSD
Pier 37 and Pier 23

Test Specimen and Cracks $\mu = 2$

Post Test, West Side, Broken #3
Tie North Column Base @
$\pm 18''$ Displacement $\pm \mu 6$

South Column to Cap Beam Joint (@ -15'' Disp $\mu 5$)

Office of Structure Design
Seismic Vulnerability Assessment
Main Channel Crossing

- Pushover curves Pier 23 - tallest pier supporting the longest 340 ft span
- This curve shows typical foundation behavior for most of the Main Channel piers

Pier 23- Transverse and Longitudinal Pushover Curve

- Plastic hinging of the 54” dia. concrete filled P/S hollow concrete pile
- Plastic hinging of columns at the bottom. These columns have couplers at the base
- Retrofit reduced the foundation/pile cap demands significantly
Seismic Vulnerability Assessment
Main Channel Crossing

Results analyses of Main Channel showed following deficiencies:

- Plastic hinging of the 54” dia. concrete filled P/S hollow concrete pile
- Elastic buckling of the thin web panels at sections close to pier support
- Buckling of the compression and subsequent failure of tension braces in steel box cross frames at pier
- Plastic hinging of columns at the bottom. These columns have couplers at the base.
- Pier cap torsion capacities exceeded
- Pile cap negative moment capacity exceeded
- Hinge hangers pins vulnerable for large seismic longitudinal displacement demands
Main Channel Crossing

Retrofit Alternatives

Two Retrofit Alternatives:

• Alt. 1- Retrofit with adding new piles and
• Alt. 2- Retrofit with isolation bearings
  • At the superstructure to pier cap connection.
  • Friction pendulum isolators 10.5 inch in height, 112 inch wide
  • Period of 5 second
  • Displacement capacity of 42 inches
  • Period of the main channel crossing increased from 3.3 seconds in longitudinal and 2.3 second in transverse direction, to over 5 seconds.
  • The displacement capacity of isolators was about 20% more than the maximum displacement demand at all piers, except Pier 16 was about 8%
Main Channel Crossing
Preferred Retrofit with Isolation Bearing

Retrofit Alternative 2 with isolator bearings was selected as preferred alternative based on:

a) Significant reduction in foundation demands
b) No plastic hinging of columns at the bottom, except at Pier16 and Pier 31, where moment demands were slightly greater than column nominal moment capacity
c) Elimination of steel box girder superstructure retrofit
d) Early completion of seismic safety of important toll bridge channel crossing,
e) Reduction in environmental impacts
f) Reduction in time requirement to obtain permits for constructing new piles in the bay
g) Reduction in retrofit construction cost and time
Displacement Demand for 20 ft and 30 ft Radius Isolator

- 20 ft radius friction pendulum isolator bearing with a displacement capacity of 42 inches and height of 10.5 inches selected
Main Channel Crossing
Retrofit with Isolation Bearing

Hysteretic Response of Isolator Bearing

Isolation Bearing Quality Control Test at EPS

• Isolator Bearings design parameters matched by EPS Inc. during design phase
• Isolation Bearing manufactured at Earthquake Protection System and quality assurance testing at UCSD
• Procured and Tested to save time during construction
Description of Retrofit

**East – West Trestle**
- Install Piles/Cap @ Bents
- Widen Seat Width at Abut1 & 44

**Main Channel Crossing**
- Footing Overlay P17 to Pier 30
- Pier Cap Strengthening Pier 16 to Pier31
- Strengthen Steel Cross Frames Pier 17 to 30
- Construct New Steel Cross Frame Pier 16 & 31
- Replace Bearings with Isolation Bearings
- Construct Seismic Joint at Pier 16 & pier 31
- Hinge retrofit @ Span21 & 25

**East – West Approach Retrofit Removed**
- Bent Cap Strengthening
- Column Concrete Jacket
- Pedestal Retrofit
Description of Bridge Retrofit

Seismic Retrofit of Dumbarton Bridge

Office of Structure Design
Bridge Aesthetics

- Design and Bridge Aesthetics during design phase

- Trestles

- Main Channel
Friction Pendulum Isolation Bearings
Fabricated at EPS, Vallejo, CA

Fabrication and testing of all 96 Isolation Bearings was Done at EPS Inc.

Isolation Bearing Data:
- width: 9’ - 4”
- Height: 9.5” and 10”
- Weight: 15000 lb
- Rated loads: 1,100,000 lb
- Max Displacement: 42”

The QA testing of 9 bearings at University of San Diego (UCSD).
Low Height Friction Isolator Bearing

Quality Assurance Testing at UCSD

Shear Ring Failure

Wind Lock Bolt

Minimal Visible Sheeting of Bearing Liner Material
Retrofit Challenges

• Installation of Isolator Bearings
  • Tight spaces, low vertical clearance – req’d sleek Isolator Bearings
  • Connection Details – Full scale Mockups

• Construction Sequence
  • Steel Cross Frame Retrofit for Jacking
  • Seismic Isolation Joint Construction during 79 hour bridge closure
  • Steel Barrier
  • Bridge Jacking to install Isolator – relative vertical displacements at piers

• Welding inside the steel box girder, NDT
• Deck Openings to bring the members inside steel box

• As-built member measurements and new member fit-up tolerances
Contractor’s Out Reach

- To encourage contractors to bid
- Clarify Complexity of Design
- Interpretation of plans, details and specifications
- Address any questions from bidders
Dumbarton Bridge
Seismic Safety Retrofit Project

1. Description of Retrofit
2. Deck Access Openings
3. Raise Bridge
4. Steel Box Retrofit and Mock up
5. Seismic Joint at Pier 16 and 31

Contractor’s Outreach - April 30, 2010
Dumbarton Bridge - Seismic Safety Retrofit Project
Dumbarton Bridge - Seismic Safety Retrofit Project

CROSS FRAMES @ BENT 16 AND 30

CONSTRUCTION SEQUENCE
Dumbarton Bridge
Seismic Safety Retrofit Project

PIER 16 & 31, JOINT & DECK RETROFIT

1. Barrier Retrofit: New barrier height (tapered)
2. Shoulder Retrofit: Beef up overhangs
3. Re-grade Deck on Approaches: Poly Concrete Overlay
4. Install Seismic Joint: Tapered Deck Plates
5. Place new Steel Barrier Assemblies at Joint

Contractors Technical Outreach - April 30, 2010
Dumbarton Bridge - Seismic Safety Retrofit Project

3 Day Closure: Deck Joint Installed

Place Stage 3 Barrier/Blockout and Steel Barrier Assemblies

INSTALL SEISMIC JOINT. STEEL BARRIERS & STAGE 3 BARRIERS

Plan 1/4" = 1'-0"
Retrofit Construction

Trestle retrofit work consisted of installing CISS piles, column and pier caps
Construction of Main Channel - Mock up 1

Bearing to Steel box connection

Complicated welding inside the box with 100%UT
Construction of Main Channel - Mock Up 2

New Steel Cross Frame and Seismic Isolation Joint
Retrofit Construction

Install 16 Temporary Platforms for Pier cap widening and Isolation Bearings Installation
Pier cap strengthening on the Main Channel from pier 16 to 31

Widen pier caps to allow for the new Isolation Bearings
Steel Jacking Frame Construction

Install in-place steel jacking frames

Deck Opening for Hauling Material

Stresses in Cross Frame Members during Steel Box Girder Jacking

Before

After
Stress-Strain Monitoring

Strain gauges were installed at pier 23
Trial lift conducted to verify the design stress calculation with Contractor Jacking operations
Bridge Jacking

Main Spans permanently raised by 5” at piers 16 through 31.
Isolation Bearings Installation

The installation of the 96 Isolation Bearings for Main Channel Pier 16 to 31
6 Isolation Bearing per Pier
Construction of Seismic Isolation Joints

Completed in two full Bridge Closures - Pier 16 and 31

Main Construction Activities

• Cut existing steel box girder to allow 42 inch seismic movement
• Weld channel section assembly

• Raise bridge
• Install seismic joint
• Install seismic steel barrier
• Polyester concrete overlay
Footing Retrofit

Retrofit the footing pile cap at Pier 17 through 30 and Fender retrofit at pier 23 & 24
Retrofit Cost Analysis

• First Cost Estimate - $220,000,000
• Removed Approaches Retrofit - $50,000,000
• Engineer Estimate - $75,000,000 (after Antioch)
• BATA Funded $90,000,000
• Bid $51,406,236 - ~38% under
• Final Retrofit Cost (w/CCO’s) $62,000,000
Conclusions

• Retrofit with Friction Pendulum Isolation Bearings eliminated need for new foundation piles and resulted in significant savings in cost and time.

• Seismic safety of important bridge for traveling public achieved early (no new piles, permits, reduced construction time etc).

• Testing of large scale models of as-built bridge bent lead to understanding of the complex behavior of structural members and joints for effective retrofit.

• Prudently allowing some ductility in the foundation piles with known ductile behavior could be used to reduce retrofit cost, time and environmental impacts.

• Comparison of site specific ARS and NLTH results helped in assessing the appropriate level of seismic demands. Use of different ARS curves in the two principal directions would be more appropriate.
Acknowledgement:

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Special Studies During Design - Consultants

• Verification of Non Linear Time History Results - Using ADINA – SC Solutions, CH2MHILL.,

• Foundation Reports – Earth Mechanics Inc. & Nigel Priestly

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