Seismic Performance of the Seismically Isolated Los Caras Bridge

Dr. Enrique Morales
Professor and Chair of the Department of Civil Engineering at ESPE University
Marcelo Romo M.S.
Professor of ESPE University and Consultant of Ecuador Army Corps of Engineers

OUTLINE

INTRODUCTION AND SEISMIC HAZARD
Ecuador Location • Seismic Hazard • Site-Specific Ground Motions

LOS CARAS BRIDGE DESCRIPTION AND SEISMIC DESIGN CRITERIA
Seismically Isolated Bridges • Project Description • Structural Systems Selected • Seismically Isolated Structure Design Criteria

SEISMIC PERFORMANCE OF ISOLATED SYSTEM
Relevant Recorded Ground Motions • Seismic Performance of the Isolation System

SEISMIC PERFORMANCE OF NON-ISOLATED SYSTEM
Seismic Protection System Components • Displacement Control Devices • Seismic Performance of Displacement Control Components

MONITORING AND MAINTENANCE
Isolation System • Non-Isolation System

SEISMIC PERFORMANCE IN OTHER BRIDGES

ACKNOWLEDGEMENT AND CONCLUSIONS

Ecuador

Seismic Hazard of Ecuador
Geodynamic Setting of Ecuador, the Galapagos Islands and the Carnegie Ridge

Response Spectrum and Code-Based Design Spectra NEC-2015

Ground motions provided by the Seismology Department, Instituto Geofísico, Escuela Politecnica Nacional, Ecuador with details in their report Singaucho, J., Laurendeau, A., Viracucha, C., Ruiz, M. (2016) “Observaciones del Sismo del 16 de Abril de 2016 de Magnitud Mw 7.8”

The Ecuador 2016 Muisne Earthquake

Seismically Isolated Bridges in Ecuador

Seismically Isolated Bridges in Ecuador

Source Ecuador Army Corps of Engineers (EACE)
Source Aguiar R
Source El Universo
Source Google Earth
Seismic Protection Industry

Location of the Seismically Isolated Los Caras Bridge

Project Description

Site-Bridge

<table>
<thead>
<tr>
<th>PROJECT LENGTHS</th>
<th>COLOR</th>
<th>DESCRIPTION</th>
<th>LENGTH</th>
<th>WIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BAHIA ACCESS</td>
<td>Orange</td>
<td>120.5 m</td>
<td>6.2 m</td>
<td></td>
</tr>
<tr>
<td>CENTRAL SECTION</td>
<td>Orange</td>
<td>171.67 m</td>
<td>6.2 m</td>
<td></td>
</tr>
<tr>
<td>SAN VICENTE ACCESS</td>
<td>Orange</td>
<td>153.95 m</td>
<td>6.2 m</td>
<td></td>
</tr>
</tbody>
</table>

Source (EACE)
**TYPICAL SECTION OF THE PIER**

**Structural System Selected**

- Base Isolation on Top of Piles and Under the Bridge Deck
  Triple Friction Pendulum (TFP) by Earthquake Protection Systems (EPS)

- Frictional Pile Deep Foundation

- Pile Driving Analyzer (PDA) for Testing Piles

**Soil Condition**

- Pier Stability Through Redundant Pile Lines and Redundant Pier Frames

- Bridge Deck Continuity: 180 m (4 spans) and 90 m (2 spans)

Source (EACE)
Seismically Isolated Structure Design Criteria

- **GLOBAL**
  - Seismic System and Structural Elements Above Isolation System
    - R=1.0
  - Seismic System and Structural Elements Below Isolation System
    - R=1.25

- **SUPERSTRUCTURE**
  - Movement Synchronizers: Local Design
  - Large Displacement Seismic Joints: Local Design

- **SUBSTRUCTURE**
  - Basic Ductility Detailing
  - Frictional Pile Deep Foundation

---

Seismically Isolated Structure –Design Criteria

- **SEISMIC DESIGN HYPOTHESIS**
  - Seismic Hazard Local Study
  - Seismic Provisions (CEC 2002)
  - Peak Rock Acceleration (from seismic hazard map and from seismic hazard study):
    - \( a_r = 0.40 \text{ g} \); \( a_r = 0.42 \text{ g} \)
  - Peak Ground Acceleration:
    - \( a_g = 0.80 \text{ g} \); \( a_g = 0.84 \text{ g} \)

---

Isolator Idealization for Design

**Target Properties**

- Bearing Capacities Lateral Displacement Capacity = 23.0 inches +/- 0.3 inches.
- Average Vertical Dead Load = 600 kips used for bearing property tests.
- Maximum Vertical D+L Load Capacity = 1200 kips maximum.
- Maximum Vertical D+L+E Load Capacity = 1900 kips maximum.
- Maximum vertical load capacities are based on concave plates bearing against 5000 psi concrete.
- Minimum Rotation Capacity = +/- 2 deg.

---

Isolator Geometry and Bearing Capacities (FPT0836/14-12/10-7)

- \( R_i \) = Radius of curvature sliding surface i.
- \( \mu_i \) = Friction coefficient of sliding surface i.
- \( h_i \) = Height of sliding interface i.
- \( d_i \) = Displacement capacities of sliding interface i.

---

Earthquake Protection Systems (EPS)
Prototype Bearing Real-Time Dynamic Test Program
(Total 152 Bearings)

Earthquake Protection Systems (EPS)

Relevant Recorded Ground Motions
During the Ecuador 2016 Muisne Earthquake
E-W Pedernales Ground Motion (PGA = 1.43 g)

N-S Manta Ground Motion (PGA = 0.53 g)

Seismic Performance of the Isolation System
During the Ecuador 2016 Muisne Earthquake

Total Displacement (cm) of the TFP

Seismic Performance of the Isolation System
During the Ecuador 2016 Muisne Earthquake

Source (EACE)
Seismic Protection System Components

- Seismic Movement Synchronizers – Shock Absorbers

Source (EACE)

Seismic Protection System Components

- Large Displacement Seismic Joints and Joint Seals

Source (EACE)

Seismic Protection System Components

- Seismic Movement Synchronizers

Source (EACE)

Seismic Performance of Displacement Control Components

- Seismic Large Displacement Joints and Joint Seals

Source (EACE)
**Monitoring and Maintenance of Isolation System**

- Bolts
- Grout

**Monitoring and Maintenance of Isolation Components**

- Seismic Movement Synchronizers
- Bolt rust
- Impact traces in neoprene
- Superficial overheating

**Monitoring and Maintenance of Isolation Components**

- Large Displacement Seismic Joint and Joint Seal
  - More than 35 cm displacement in any direction
  - Vertical displacement

**Seismic Performance of Non-Isolated Accesses**

- Longitudinal Neoprene Shock Absorbers
- Steel Bar Vertical Anchorages
Seismic Performance of Non-Isolated Components

- Transversal Seismic Shear keys
- Neoprene Bearings in San Vicente Access

Seismic Performance in Other Bridges

- Esmeraldas Bridges (PGA = 0.23 g) /Major displacements (Δ < 15 cm)

Acknowledgement

Contributions are gratefully acknowledged:

- Ecuador Army Corps of Engineers.
- ESPE University.
- Buffalo University.
- Earthquake Protection Systems (EPS).
- Professor Michael Constantinou.
- General Pedro Mosquera, Jorge Landazuri and Francisco Beltran.

Conclusions

The Las Caras Bridge at 2 km length is the longest bridge in Ecuador.

- It stretches across the Bahia de Caraquez's bay and was significantly affected by the April 16, 2016 M7.8 earthquake offshore the west coast of northern Ecuador.
- It is seismically isolated with a triple FP isolation system designed to have a displacement capacity of 585 mm.
- The bridge remained functional during and after the earthquake and it represented a significant link in reaching the most affected cities by the earthquake for providing aid.
- Records of ground shaking at stations before and after the bridge in the direction of propagation of the earthquake rupture show peak ground accelerations between 0.5g and 1.4g.
- It was evident that was significant variability in the ground shaking from pier (within about 120 m) as the bearing displacement recorded varied from about 100 mm to about 650 mm. This was without doubt the largest ever recorded motion of a seismically isolated structure.
The Mw 7.8 Earthquake in Muisne, Ecuador in 2016 produced large transversal movements on seismic joints in Los Caras Bridge, up to 32 cm, equivalent to 90% of DE intensity level.

Seismic joints designed for Los Caras Bridge worked as expected.

Vertical movements of seismic joints proved to be important for major earthquakes.

Synchronizers employed in isolated bridges, designed according to a conceptual method behaved adequately under a major Mw 7.8 earthquake, with ground accelerations similar to a DE earthquake.

It demonstrated the significance of a proper philosophy for design that ensures a small enough risk of damage and collapse.

Conclusions