Lessons Learned from the Performance of Highway Bridges in Recent Earthquakes

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Outline

- Background – recent earthquakes
- Observations of bridge performance
- Lessons / design implications
- Conclusions
- Acknowledgements

Recent Earthquakes

- **Chile**
  - Off-shore Maule Earthquake, February 27, 2010 (M8.8)
- **New Zealand**
  - Darfield and Christchurch Earthquakes, September 2010 and February 2011 (M7.1, M6.3)
- **Japan**
  - Great East Japan Earthquake, March 2011 (M9.0)

US Bridge Reconnaissance Teams

Chile:
Tony Allen, Daniel Alzamora, Juan Arias, Ian Buckle, Jeffrey Ger, David Tau, Wen-huei (Phillip) Yen
assisted in field by
Ministry of Public Works and Catholic University of Chile

New Zealand:
Michel Bruneau, Scott Ashford, Ed Kavazanjian
assisted in field by
University of Canterbury and University of Auckland

Japan:
Ian Buckle, Shideh Dashti, David Frost, Lee Marsh, Eric Monzon, Wen-huei (Phillip) Yen
assisted in field by
Tokyo Institute of Technology, PWRI, CAESAR and RILIM

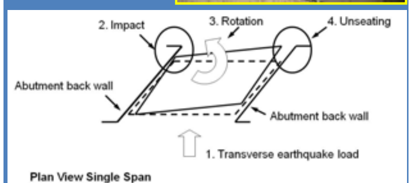
Observations (Chile)

Observations

Unseating in skew bridges, due to in-plane rotation; unseating initiated in acute corner.

Many bridges lacked diaphragms and adequate transverse shear keys

Vespucio
Lo-Echevers



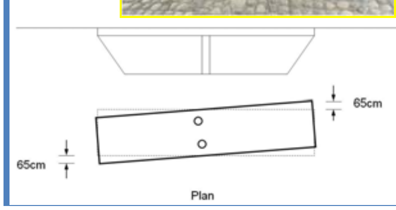
Observations (Chile)

Observations

Unseating at abutments of straight symmetric bridges, due to in-plane rotation.

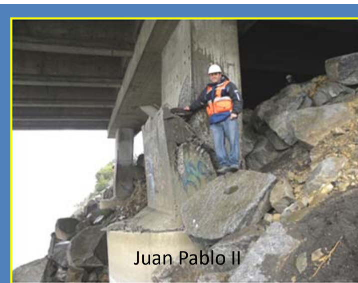
No diaphragms and adequate transverse shear keys (only vertical seismic bars)

Rt. 5 Paso
Las
Mercedes



Observations (Chile)

Observations
Column failure due to liquefaction-induced ground movement
Span unseating due to liquefaction –induced ground movement.

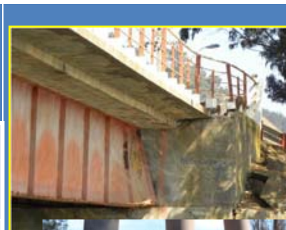


Juan Pablo II

Bio Bio River Bridge

Observations (Chile)

Observations
Girder distortion in single span bridge overtopped by tsunami
Foundation scour due to tsunami
Damage to pile bent due to debris impact during tsunami



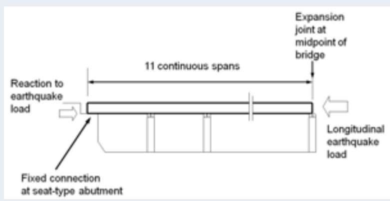
Iloca

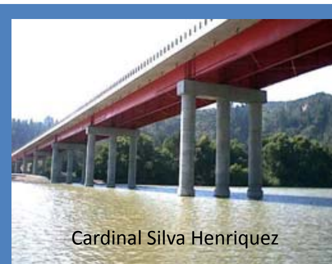
Cardinal Silva Henriquez

Observations (Chile)

Observations

Rupture and buckling of plate girders in multi-span continuous bridge built in 2 segments




Cardinal Silva Henriquez

Observations (New Zealand)

Observations

Liquefaction-induced movement of abutment fills damaged piles and caused compressive failures in superstructures of pedestrian bridges


Kaiapoi Pedestrian Bridge



South Brighton Rd Bridge

Observations (Japan)

Observations

Despite magnitude and duration, bridges built since mid-1990s performed very well. Damage was relatively light and confined to specialized cases (Sendai-Tobu Viaduct)

Retrofitted bridges performed very well. Damage to older bridges occurred when retrofitting was not yet undertaken, or was incomplete

Sendai-Tobu Viaduct

Fuji-hashi

Observations (Japan)

Observations

Many steel bearings in older bridges were not designed for large lateral loads or displacements

Bearing failures lead to unanticipated load paths and unexpected demand on other components (and consequential damage)

Yuriage-ohashi

Shida-hashi

Observations (Japan)

Observations
Inadequately tied-down beam-type superstructures lifted off cap beams and swept upstream due to buoyancy and hydrodynamic forces
Distance swept upstream factor of weight and whether deck overturned and lost buoyancy
Deck slabs of (some) wharf structures failed in flexure/shear due to excessive hydrostatic pressure

Koizumi-hashi

JR Viaduct Tsuya R.

Observations (Japan)

Observations
Many bridges with integral superstructures survived inundation
Approach fills susceptible to erosion
Foundation scour can undermine piers leading to tilting and, in some cases, complete loss

Nijyu-ichihama-hashi

JR-Bridge at Nijyu-ichihama

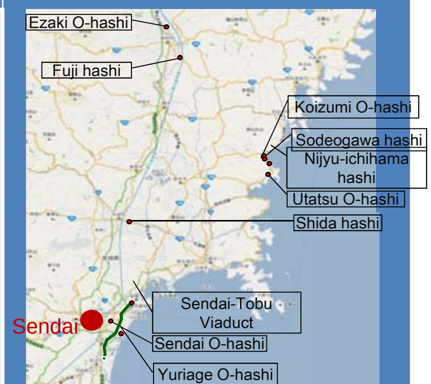
Observations (Japan)

Observations

Tsunami inundation can be extremely punishing on highway and rail networks, and the communities they serve, due to:

- complete loss of bridge spans
- erosion of highway pavements
- closure of many (hundreds) miles of highway and railway on coastlines where alternate routes may be few and far between, and
- delay in emergency response and slow recovery time.

Direct and indirect costs maybe crippling.



Lessons

Lessons / Design Implications – capacity design and retrofit programs

Capacity design principles and inelastic analysis are effective	Japan
Retrofit programs are effective at protecting older structures. Owner agencies need encouragement/incentives to complete retrofit programs. Validates FHWA/Caltrans 30-year effort in US to retrofit bridge inventory	Japan (New Zealand)
Check the load path for surprises… and the back-up load path	Chile New Zealand Japan

Lessons

Lessons / Design Implications – bearings, shear keys, seat widths	
Bearings and shear keys are the most vulnerable element in a bridge. AASHTO requirements that all connections be designed for a minimum design force, regardless of level of seismicity, is justified.	Japan Chile
Replace older steel bearings with elastomeric bearings, or new steel bearings designed for large lateral loads and displacements and detailed for low maintenance.	Japan New Zealand
Generous seat widths are best defense against span collapse in both straight and skewed bridges	Chile New Zealand Japan

Lessons

Lessons / Design Implications – liquefaction	
Liquefaction-induced ground movements can unseat spans and damage substructures. If site remediation is not feasible, provision of adequate support lengths and/or articulation in superstructure is required to accommodate these movements.	Chile New Zealand

Lessons

Lessons / Design Implications - tsunami	
• Integral superstructures preferred. • Add vertical restrainers to non-integral superstructures. • Design lateral shear keys for seismic and hydrodynamic loads • Vent superstructures to reduce buoyancy effects and equalize hydrostatic pressure on deck slabs • Protect fills against scour with rip-rap or concrete slabs • Use piled footings or drilled shafts to depths below anticipated scour	Japan Chile

Lessons

Lessons / Design Implications - tsunami	
Develop and implement design strategies for tsunami-resistant bridges and approaches through a coordinated research program, involving • Numerical and experimental modeling • Development of design details for new and existing bridges • International collaboration.	Japan Chile

Conclusions

- Bearings, shear keys, and support lengths are critical to good performance
- Liquefaction-induced movements must be estimated and accommodated, if site remediation impractical
- Retrofitting works… reduced damage and improved performance of older bridges can be achieved
- Tsunami inundation
  - is destructive but not impossible to survive
  - tsunami-resistant bridges appear feasible

Acknowledgements

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- National Institute for Land and Infrastructure Management, Japan