ASSESSMENT OF THE HISTORIC SEISMIC PERFORMANCE OF THE NEW ZEALAND BRIDGE STOCK

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INTRODUCTION

New Zealand is a seismically active country, and the effects of earthquakes on infrastructure can be significant. The New Zealand distributed infrastructure network have little or no redundancy throughout the country. With the reliance on transport networks for essential services, it is critical to ensure the network remains functional after a seismic event. Bridges are a key part of the road network, and yet there are currently many unknowns related to the actual seismic response. On top of that, there has been an absence of systematic collation of bridge seismic demand and performance across historic earthquake in New Zealand. The objective of this study is to assess the performance of NZTA state highway bridges in historic earthquake in New Zealand.

SEISMIC BRIDGE DESIGN STANDARDS IN NEW ZEALAND

Bridge design in New Zealand have been controlled by a centralized organization until it was privatized in 1988. The New Zealand Transport Agency (NZTA) currently manages the operation of the State Highway network. Seismic bridge design standards have been developing along with the changes in the organizations controlling the design and construction. These standards, published by NZTA and its preceding organizations, defined the requirements for traffic, wind, flood, temperature and seismic loading. The development of bridge design standards in New Zealand can be classified into six eras.

Era 1 Pre-1930s
No Seismic Standards — 7.8%

Era 2 1930s to mid-1960s
Early Seismic Standards — 49.5%

Era 3 mid-1960s to mid-1970s
Preliminary Ductile Standards — 13.6%

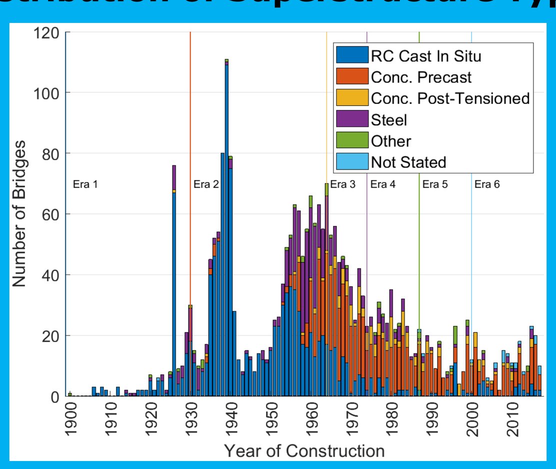
Era 4 mid-1970s to late-1980s
Early Ductile Standards — 10.8%

Era 5 late-1980s to early-2000s
Basis of Current Standards — 6.8%

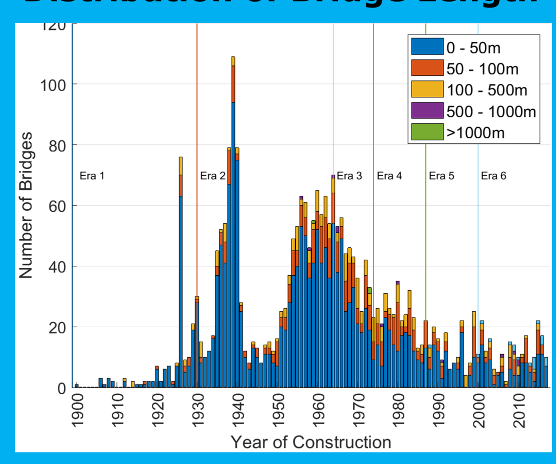
Era 6 early 2000s to present
Current Standards — 11.3%

THE NEW ZEALAND HIGHWAY BRIDGE STOCK

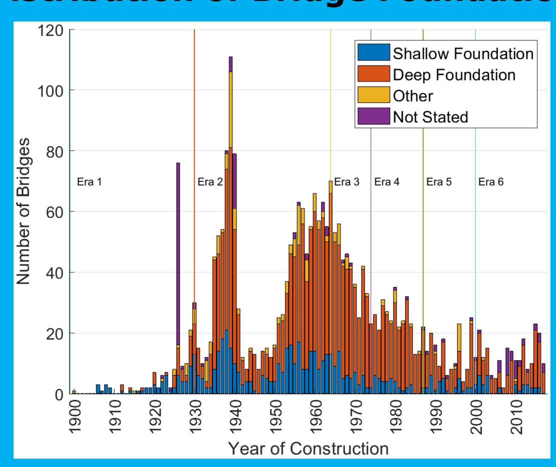
Distribution of Superstructure Types



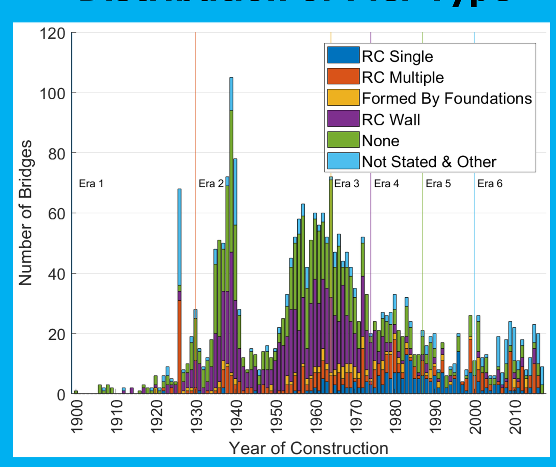
Distribution of Bridge Length



Distribution of Bridge Foundation



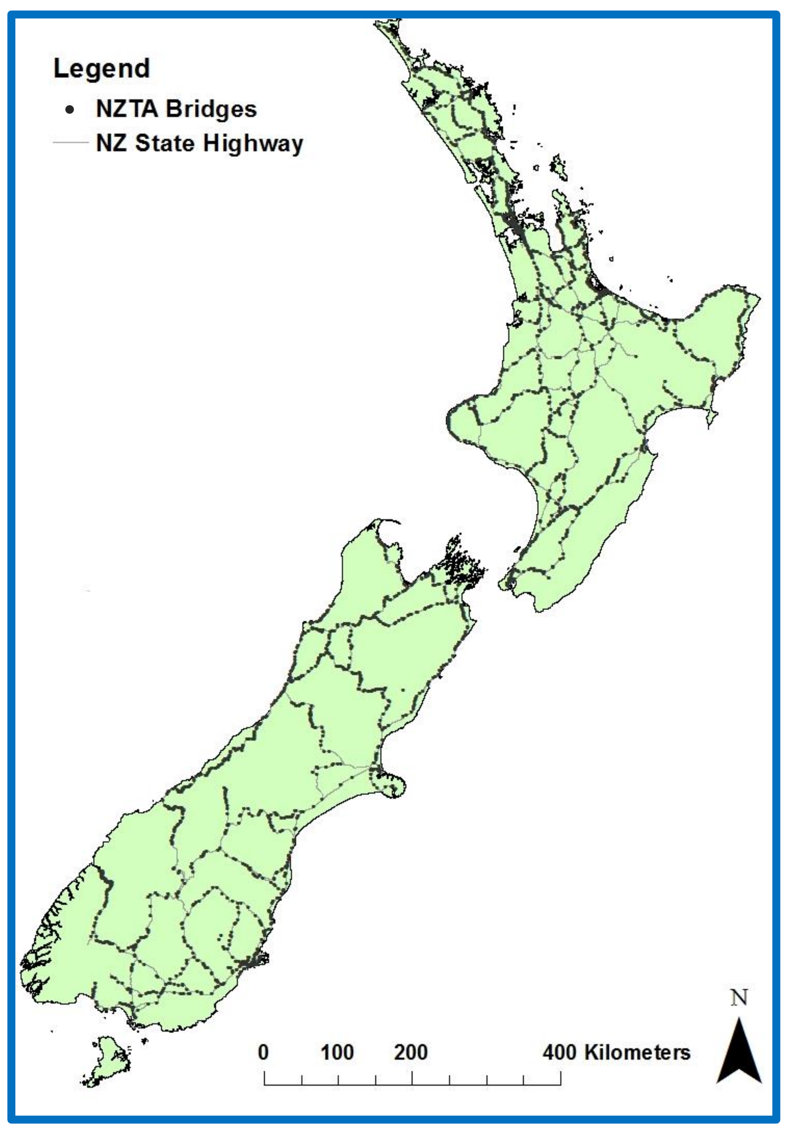
Distribution of Pier Type



A large number of bridges in New Zealand are similar and regular in form. Most bridges have cast in-situ concrete superstructure, 50m bridge length, deep foundation and single span (no piers).

There are approximately 2700 highway bridges on the State Highway network in New Zealand that are managed by the NZ Transport Agency.

Map of New Zealand with overview of the State Highways and bridge stock



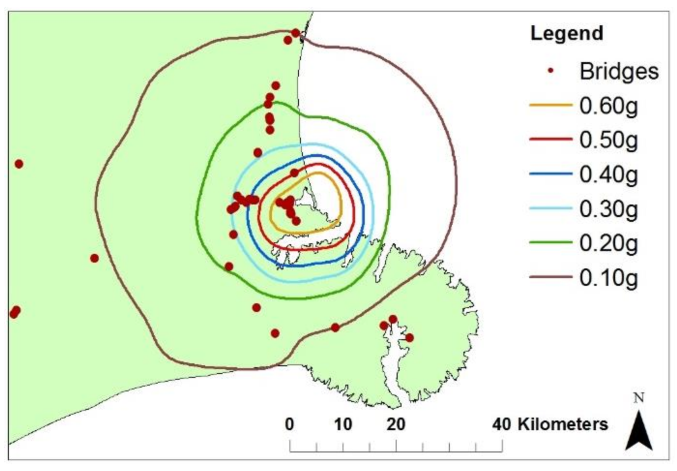
APPROACH

To asses the historic seismic performance of the bridge stock across a range of earthquakes, three main steps were undertaken.

1. Characterization of seismic demand at each bridge location through geostatistical interpolation of recorded and felt data
2. Classification of bridge damage severities
3. Collation of historic bridge performance and comparison of the performance with NZTA seismic screening

HISTORIC SEISMIC DEMAND AT BRIDGE SITES

In this study, the focus was on the performance of the bridge stock during the earthquakes that have occurred in the last 50 years in New Zealand. The ground motion intensity at each bridge location for these 10 earthquakes was defined using PGA contours from the United States Geological Survey (USGS) earthquake catalogue. The PGA at each bridge location, termed event PGA in this research, was approximated using the Empirical Bayesian Kriging interpolation in ArcGIS.



PGA contours of the 2011 Christchurch earthquake and bridge locations

Notable Damage Causing New Zealand earthquakes in the last 50 years

- 1968 Inangahua earthquake
- 1987 Edgecumbe earthquake
- 1993 Ormond earthquake
- 2007 Gisborne earthquake
- 2010 Darfield earthquake
- 2011 Christchurch earthquake
- 2013 Cook Strait earthquake
- 2013 Lake Grassmere earthquake
- 2014 Eketahuna earthquake
- 2016 Kaikoura earthquake

HISTORIC BRIDGE DAMAGE CLASSIFICATION

Bridge damage from historic earthquakes was defined based on details collated from post-event reconnaissance report, commissioned reports and journal articles. The level of detail describing the observed bridge damage from these sources varies according to the age of the earthquake, with information from recent earthquakes being more detailed than that from older earthquakes. Damage descriptions were mostly qualitative, and relate to either structural and/or geotechnical damage. Due to the differences in damage descriptions used across different reports, there will be some uncertainties in the classification, therefore a qualitative approach was used. Damage severities were classified into three categories, none – minor, moderate and major.

Classification of Damage Severity

None – minor
Damage does not affect structural integrity and no loss of bridge functionality

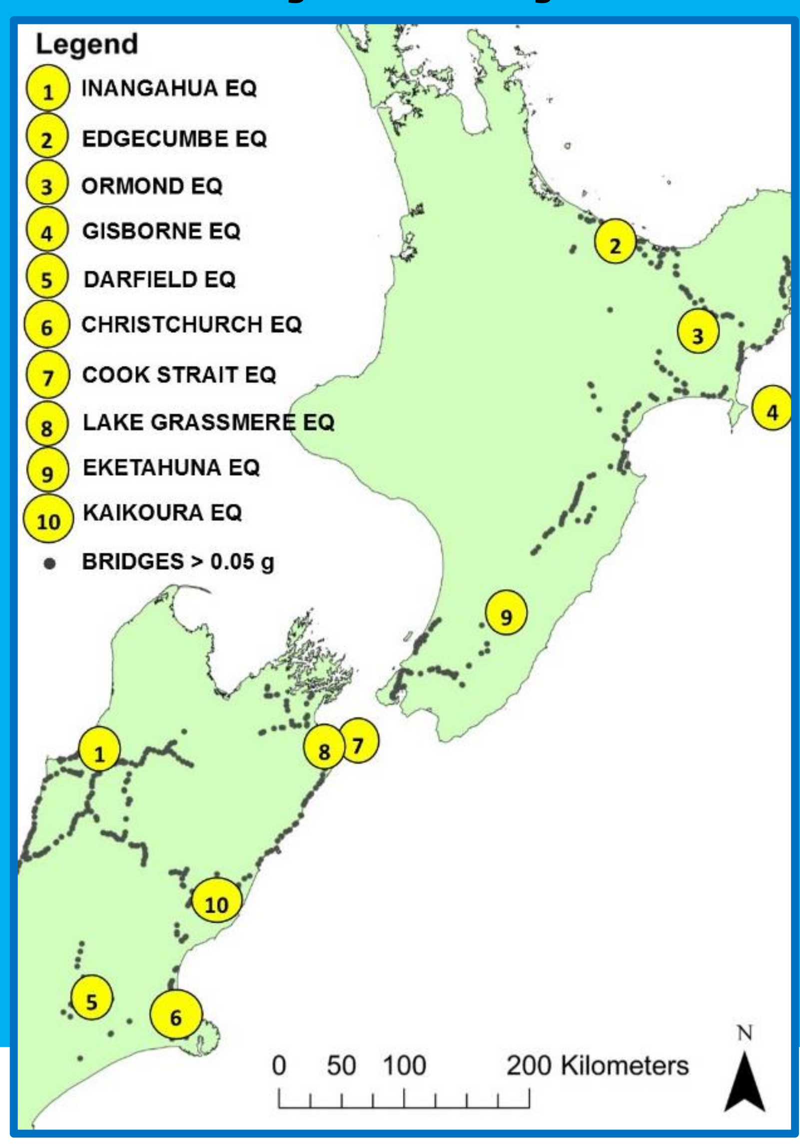
Moderate
Damage results in some loss of structural integrity and/or limited reduction of functionality

Major
Damage results in loss of structural integrity and/or loss of functionality

SEISMIC DEMAND AT BRIDGE LOCATIONS

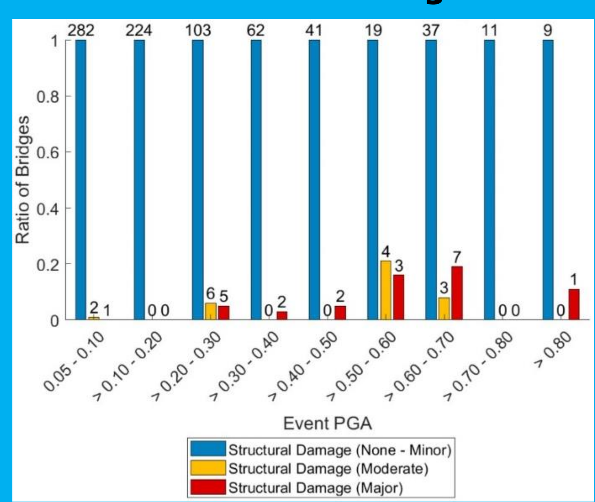
An event PGA of 0.05g was exceeded 824 times across the historic earthquakes assessed. They are mostly distributed along the eastern to the southern part of North Island and the northern part of the South Island, which aligns with the regions with the highest seismic hazard across the country based on the National Seismic Hazard Model.

Epicentres of the Ten Historic Earthquakes Assessed and Locations of Bridges With Event PGAs Larger Than 0.05g

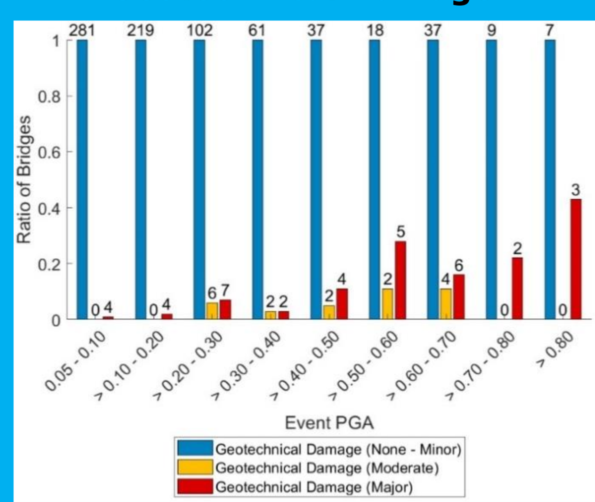


Most bridges have none to minor damage at low PGAs (between 0.05g and 0.10g). As event PGA increases, the number of bridges with none to minor damage decreases. The number of bridges with moderate and major damage is relatively small across all events considered. Overall, this data suggests that the performance of bridges in terms of structural response is generally good across all events considered.

Structural Damage



Geotechnical Damage



Forms of Structural Damage

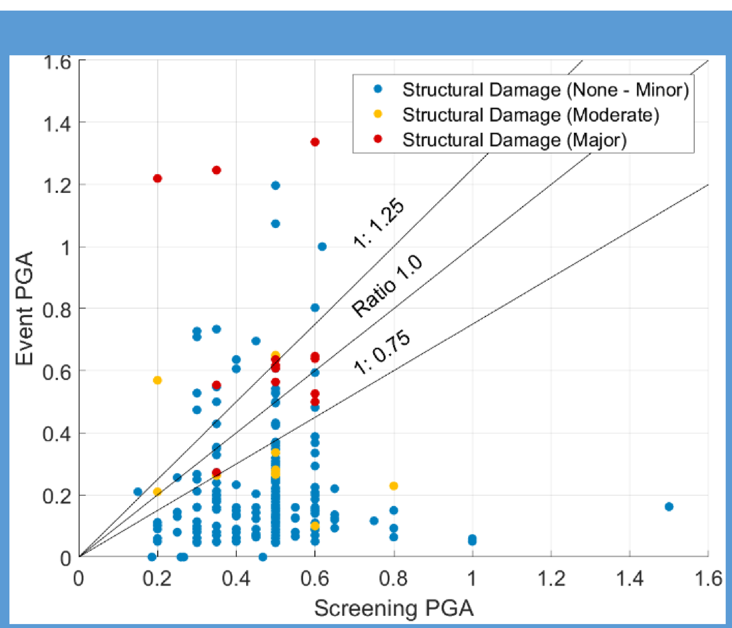
- Spalling and cracking of piers (most common)
- Separation of deck from piers
- Translation and rotation of the superstructure
- Damage to piers - residual displacement, tilt and plastic hinging

Forms of Geotechnical Damage

- Approach settlement (most common)
- Damage to abutments - lateral displacement, tilt and plastic hinging
- Damage to piles - spalling, cracking, and hinging
- Damage to approach embankments - settlement, pavement cracking and gapping
- Damage to abutment wingwalls - residual displacement and cracking

There were no observed differences in geotechnical damage based upon abutment type, with a similar number of bridges damaged for both monolithic and seat-type abutments

COMPARISON WITH SEISMIC SCREENING



Distribution of Data Based on Event PGA and Screening PGA

Seismic screening have been initiated since the late 1990's to assess the seismic performance of State Highway bridges across New Zealand. As part of the screening process, PGA that may potentially result in severe damage in seismic events were estimated for bridges across New Zealand. Out of the 824 bridges, 284 bridges had a Screening PGA assigned as part of the seismic screening process. The Event PGA at the bridge sites were compared with the Screening PGA. Only structural damage were considered as it is the main focus of the screening process. Each point in the figure represents a bridge. Based on this comparison, there is little evidence of poor bridge performance based on this comparison.

CONCLUSION

- 824 occurrence with PGA higher than 0.05g, mostly distributed along the eastern to the southern part of North Island and northern part of South Island
- Three quarter of bridge stock experienced PGA < 0.30g
- Number of bridges with moderate and major damage is relatively small
- Performance of bridges in terms of structural and geotechnical aspects was generally good across all events considered
- Based on comparison with the NZTA seismic screening results, there is little evidence of poor performance of any bridge typologies
- Some shorter bridges may have performed better than expected due to the effects of abutment damping
- Longer bridges might have performed better due to travelling waves effects that results in a phase lag between the seismic input motions at the piers along the length

THE UNIVERSITY OF AUCKLAND Te Whare Wānanga o Tāmaki Makaurau NEW ZEALAND

QuakeCoRE NZ Centre for Earthquake Resilience Te Hiranga Rū