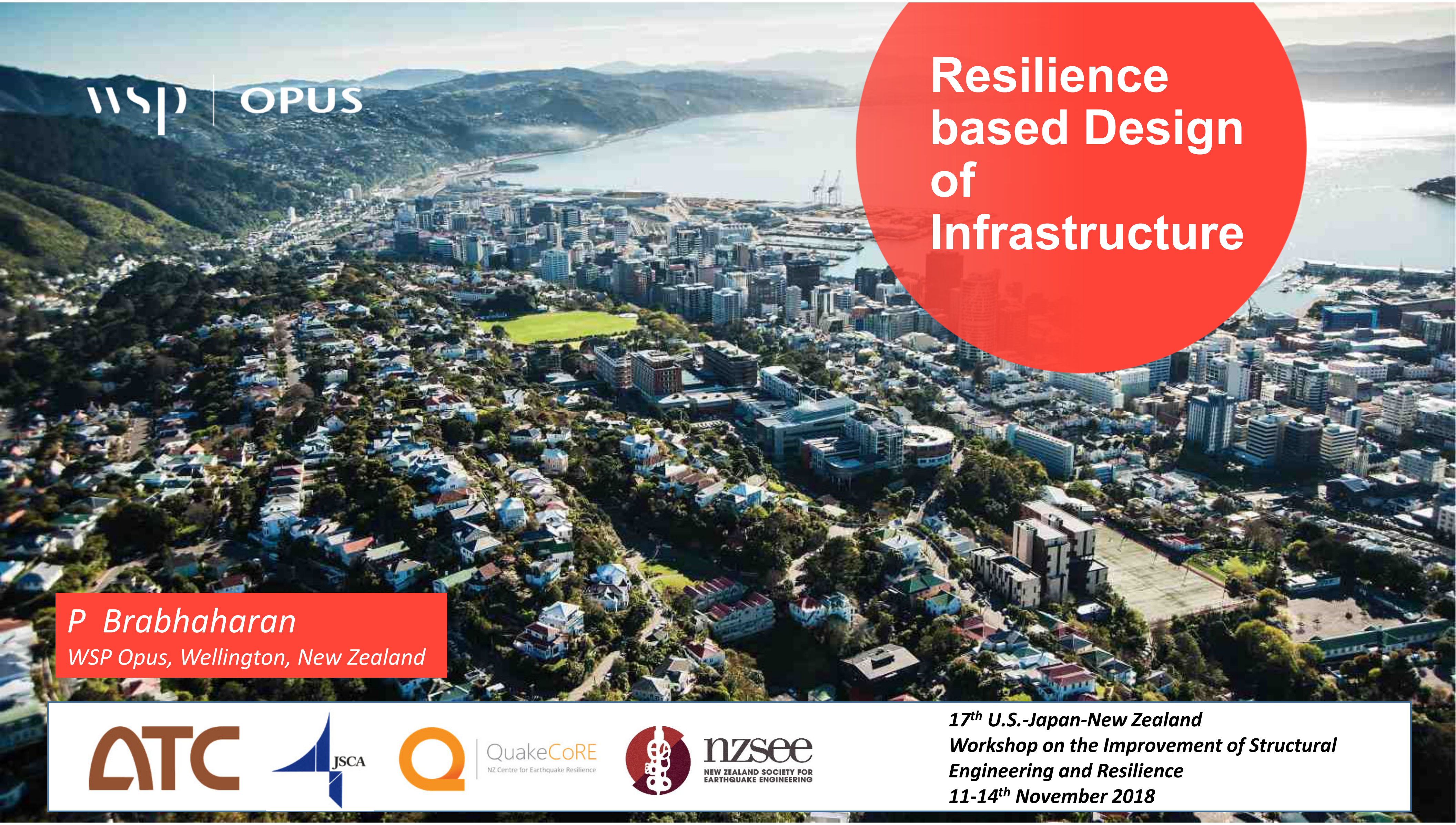


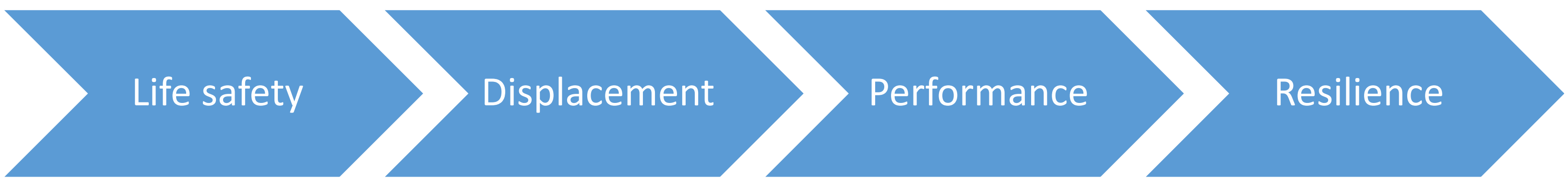
Resilience based Design of Infrastructure

P Brabhaharan
WSP Opus, Wellington, New Zealand

ATC JSCA QuakeCoRE NZ Centre for Earthquake Resilience nzsee NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING

17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience
11-14th November 2018

Evolution of resilience based design



Life safety design

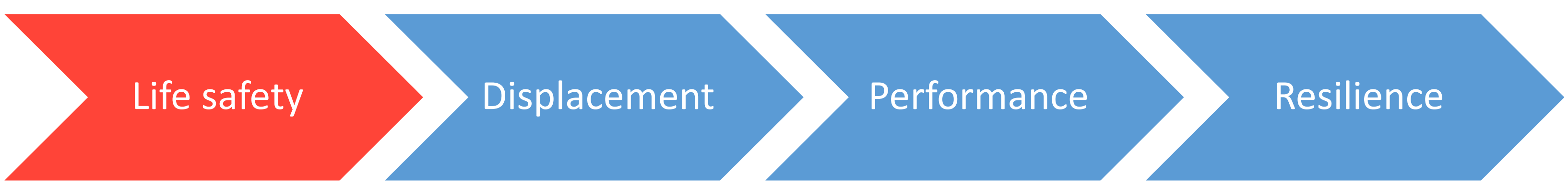
Life safety was important when lots of people were killed in earthquakes

Early focus on life safety

Codes focussed on life safety

Remains No 1 priority . . . But should not be only focus

Practitioners use life safety design routinely



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Displacement based design

1990s saw development of design based on displacement

RRU Bulletin 84 and in Retaining Wall Design Notes 1990 edition (Works now WSP Opus)

Used for design of retaining walls . . . and then slopes

Enshrined into the NZ Bridge Manual.

Now extended for bridges

Practitioners now use this routinely for geotechnical design.

Life safety → Displacement → Performance → Resilience

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Performance based design

2000s saw the development of performance based design

Adopted for retaining walls and embankments and then bridges

Enshrined into the NZ Bridge Manual in early 2010s

Practitioners now use this routinely.

Life safety → Displacement → **Performance** → Resilience

Performance based design - Retaining walls

Research
- 1980s Canterbury University and Ministry of Works; overseas universities

Uptake by lead practitioners – trial on projects
- 1990s – early 200s Wellington EQ strengthening and design

Enshrine into client specific design standards
- ~2005 NZ Transport Agency Bridge Manual

Widespread use by practitioners in specific sector
- 2005 - Use for transport and infrastructure sectors

Government – industry guidance
- 2017 MBIE Module 6 – still only for residential sector and implicit

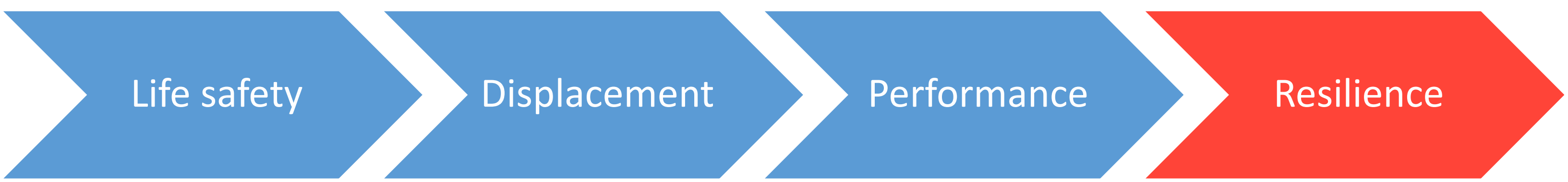
Resilience based design

2008 + development of resilience based design . . .

Adopted for a number of projects

Formally proposed in guidance for design of cut slopes for transport infrastructure.

Yet to become routine design practice



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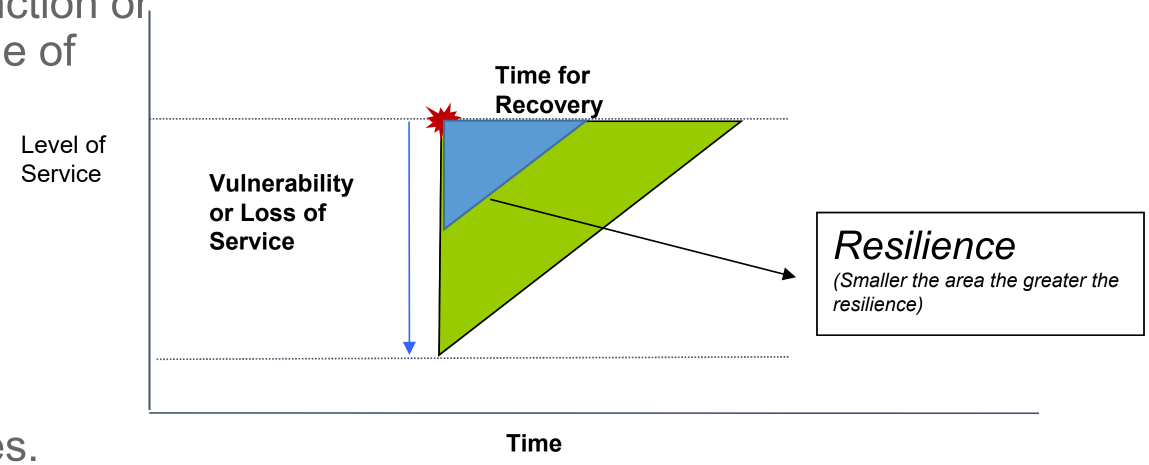
Resilience

Resilience is the ability to continue to function or return to functionality quickly after a range of adverse events.

Resilience would ideally focus on;

- minimising the loss of access and
- enabling quick recovery

after adverse events such as earthquakes.



Resilience metrics

Availability State

Level	State	Description
1	Full	Full access except condition may require care.
2	Poor	Available for slow access, but with difficulty by normal vehicles due to partial lane blockage, erosion or deformation.
3	Single lane	Single lane access only with difficulty due to poor condition of remaining road.
4	Difficult	Road accessible single lane by only 4x4 off road vehicles.
5	Closed	Road closed and unavailable for use.

Outage State

Level	State	Description
1	Open	No closure, except for maintenance
2	Minor	Condition persists for up to 1 day
3	Moderate	Condition persists for 1 day to 3 days
4	Short term	Condition persists for 3 days to 2 weeks
5	Medium term	Condition persists for 2 weeks to 2 months
6	Long term	Condition persists for 2 months to 6 months
7	Very long term	Condition persists for greater than 6 months

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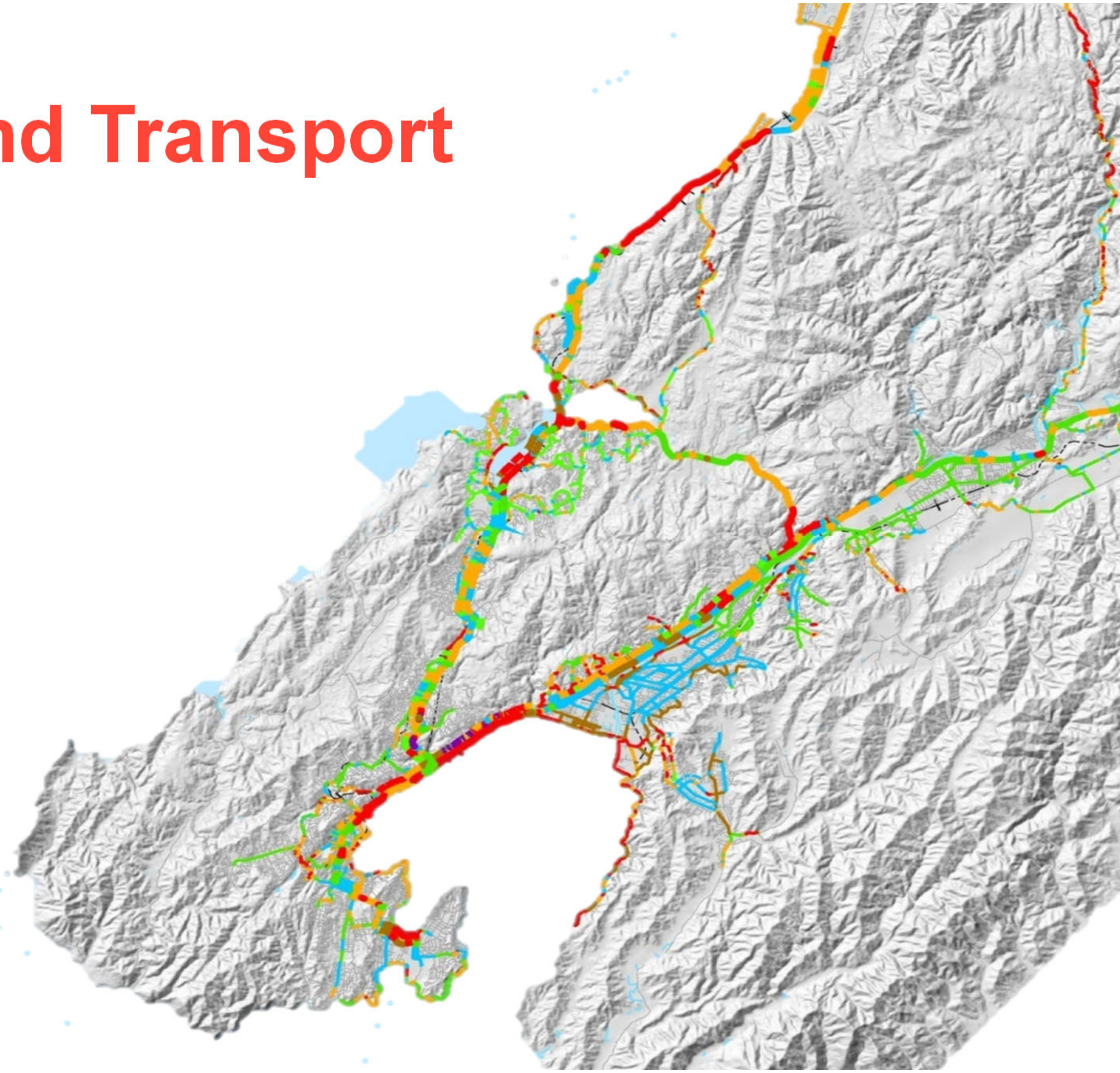
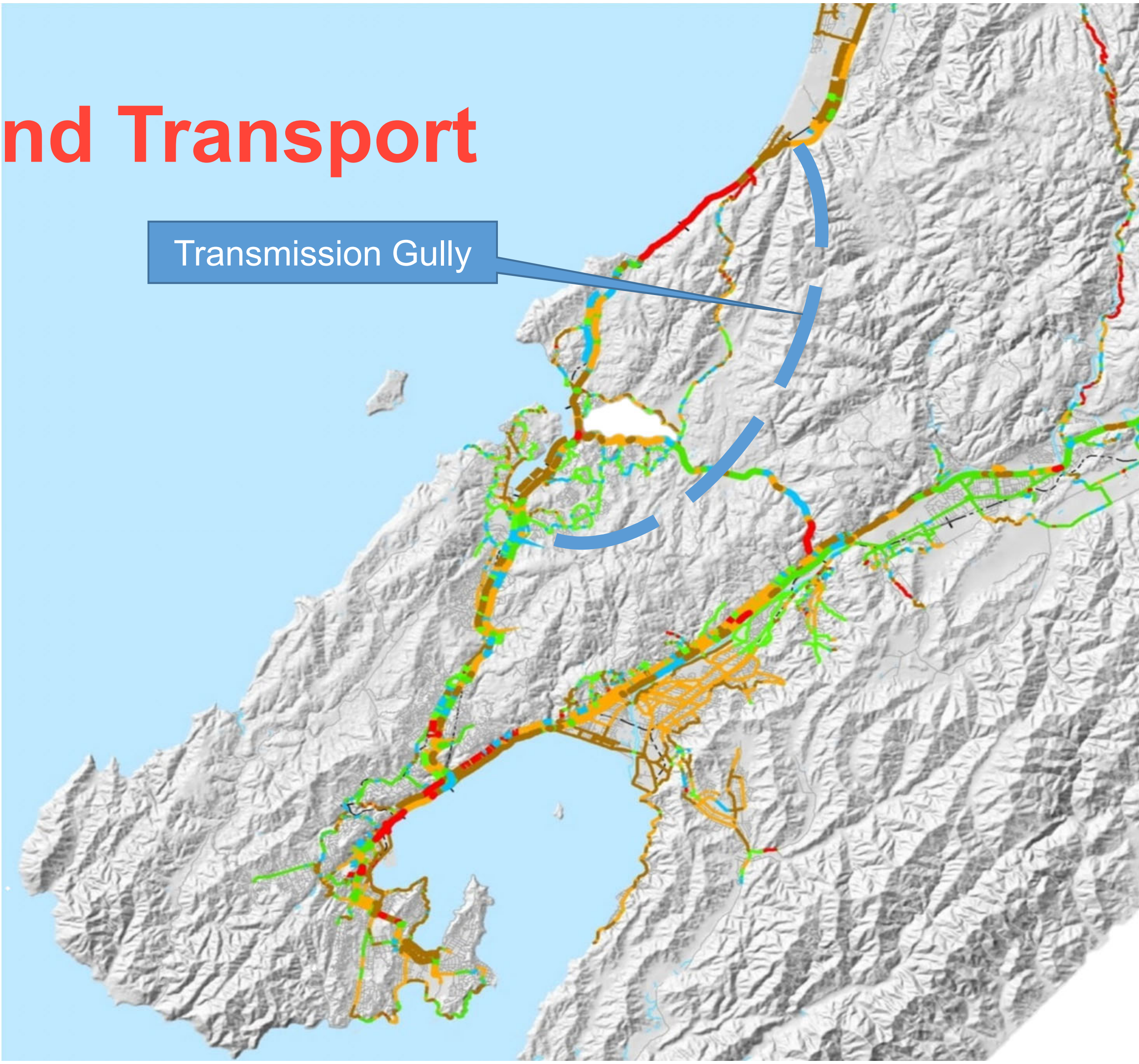
Resilience of Land Transport

Availability

- 5 - Closed
- 4 - Difficult
- 3 - Single Lane
- 2 - Poor
- 1 - Full

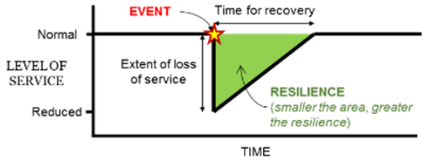


Resilience of Land Transport



Outage

- 5 - Long Term (> 3 months)
- 4 - Severe (2 weeks to 3 months)
- 3 - Moderate (3 days to 2 weeks)
- 2 - Minor (up to 3 days)
- 1 - Open (no closure)



Infusing resilience through early focus

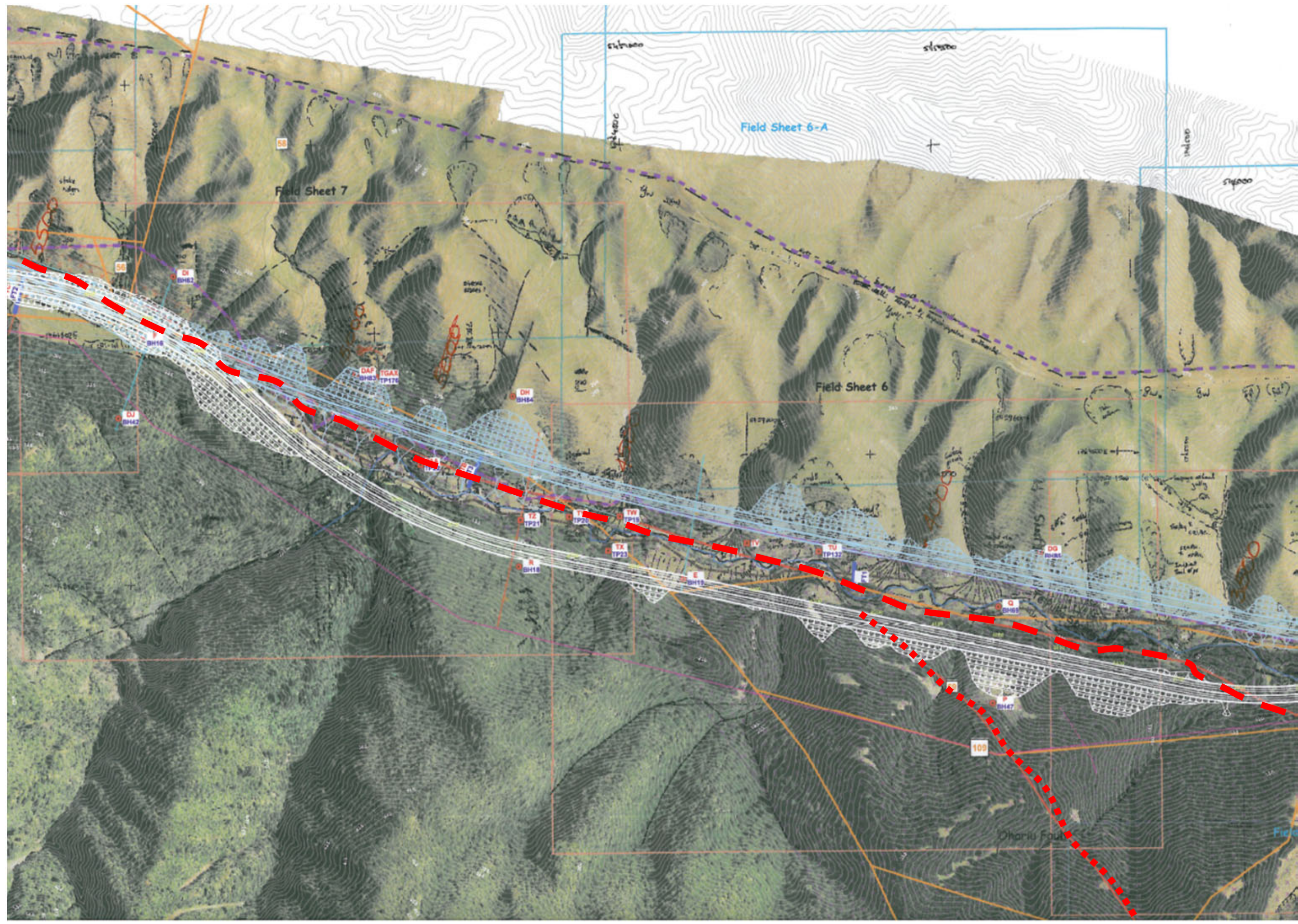
Early focus on resilience

Cross fault on embankment rather than viaduct

Replaced half bridges with reinforced embankments

Substantially enhanced resilience

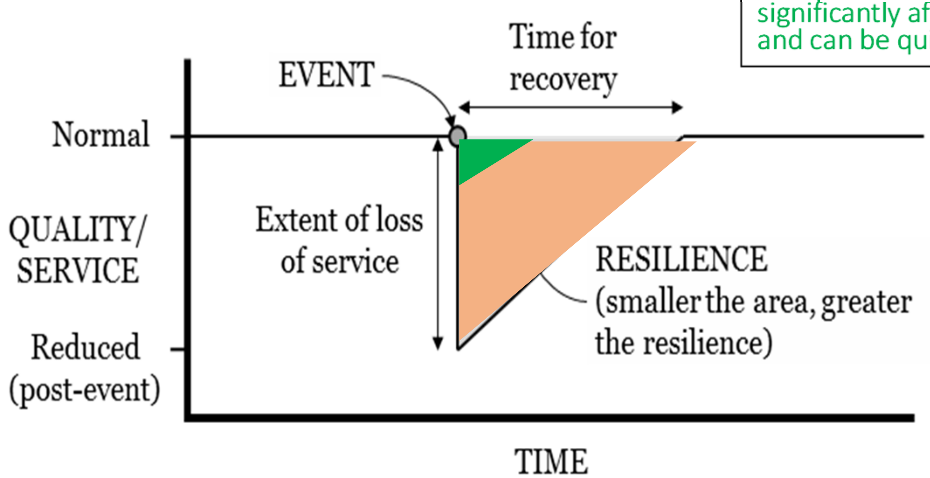
Cost dropped by $ 300M for $1Billion project



Learning from earthquakes

M 8.1 Wenchuan Earthquake, China - 2008

Design for resilience



Accept small failures which do not significantly affect access level of service, and can be quickly restored.

Avoid large failures that compromise access and take a long time to recover.

Resilience based Design

Early focus on resilience

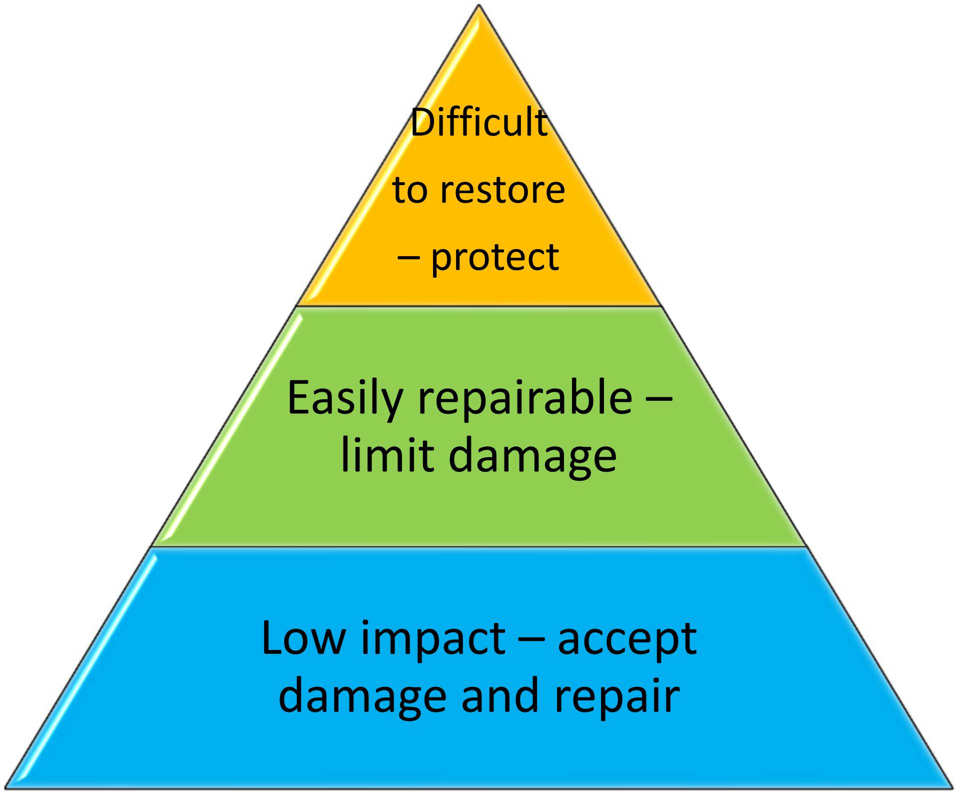
Understand resilience
Context

Develop resilience needs

Focus on performance and
rapid return to functionality

Hierarchy of resilience

Principles for Resilient Design



- Ductility, flexibility (non-brittle systems)
- Difficult – costly – time consuming to repair

. . . . minimise damage (bridges, trunk utilities)

- Easily – quickly repairable

. . . . accept limited damage (roads, distributor pipes)

- Low impact on community

. . . . Accept damage (park areas)

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Adopt Hierarchy of Resilience

	1 in 100 year	1 in 500 year	1 in 1,000 year	1 in 2,500 year
Critical difficult to repair	Continued functionality	Continued functionality	Continued functionality, but some repairs	Some damage requiring repairs, limited functionality
Moderate criticality	Continued functionality	Continued functionality	Short outage, can be repaired	Longer outage and needs replacement
Easily repairable	Continued functionality	Short period of outage	Moderate outage	Longer outage
Low importance facilities	Continued functionality	Short period out of use	Out of use for longer period	Requires reconstruction

Research into design of cut slopes

Guidance developed for design

- A resilience based design approach

Seismic design and performance of high cut slopes
January 2017

P Brabhaharan, D Mason and E Gkeli
Opus International Consultants Ltd

NZ Transport Agency research report 613
Contracted research organisation – Opus International Consultants Ltd

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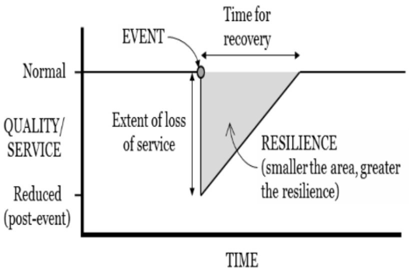
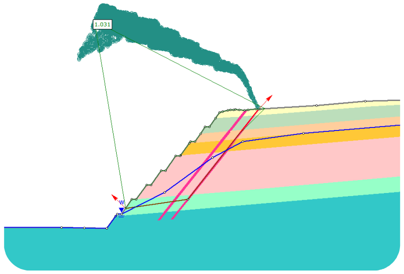
Resilience based Design for Cut Slopes





Resilience importance Category (RIC)

- Reflects Resilience Expectations of the route based on regional context
- Takes into account Importance levels (IL1-IL4)

Design Approach (DA)

- Design approach to suit resilience context
- DA1 to DA4, based on IL and complexity of ground conditions

Topographical Amplification Factor (TAF)

- For ridge and terrace like topographies
- Depending on slope height and angle

Slope location Based Peak Ground Acceleration

- For pseudo static analysis
- Takes into account the location of mechanism of failure on slope

Summary

2016 Kaikōura Earthquake

Design of transport infrastructure has evolved from FOS based design to performance based design

Current development of resilience based design.

Resilience does not need to cost more

Can also extend to other sectors – such as buildings.

Early focus on resilience from an early stage

Research and practice can lead to guidance and eventually government standards.

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Questions?

Brabha@wsp-opus.co.nz

M7.8 Kaikōura Earthquake 2016 New Zealand