

Resilience assessment of state highways in New Zealand

D. Mason & P. Brabhakaran

Opus International Consultants, Wellington.



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ABSTRACT: Understanding the resilience of infrastructure to natural hazards including earthquakes is important to be able to take initiatives to enhance resilience. A national level resilience framework was developed and the resilience of all the state highways have been assessed for the New Zealand Transport Agency. The resilience assessments were focused on low probability high impact natural hazard events, rather than more routine events.

Resilience metrics developed by Brabhakaran (2006) comprising the Availability and Outage states to reflect the reduction in level of service and the period of reduced service were adopted and the Disruption State (combination of availability and outage) was used as a single metric to represent resilience or the lack of it. The resilience was assessed for the natural hazards of earthquakes, tsunamis, storms, and volcanic eruptions. The roads were characterised through targeted site reconnaissance, and mainly by desk-top analyses using geology and hazard maps, aerial photographs and state highway imagery.

The road characterisation was mapped using a Geographical Information System platform, and then the resilience was assessed by relating the characterisation to the resilience metrics, and combined using GIS to develop the disruption state. The results were presented as spatial GIS maps. The resilience assessment provides a valuable insight into the resilience of the whole state highway system in New Zealand, and is valuable for consideration of resilience as part of the business case studies being carried out by the Transport Agency.

1 INTRODUCTION

Road controlling authorities (RCA), including the New Zealand Transport Agency (NZTA) and territorial authorities, have a responsibility to proactively manage the risks to their road networks from natural hazards. The Civil Defence Emergency Management Act 2002 identifies roads as one of the key lifeline utilities, and requires its operators to be able to demonstrate that they have assessed the risks to its networks, and taken proactive measures to ensure that the lifelines (roads) are able to function to the fullest extent possible after natural hazard and other events (Ministry of Civil Defence Emergency Management, 2002).

The Transport Agency is developing its approaches and processes to better understand and enhance the resilience of its state highway network. The first stage of this strategy was to assess and map the resilience of the whole state highway network in New Zealand at a national screening level. This involved mapping the resilience of the network to the low frequency, high impact natural hazard events of large storms/hurricanes, earthquakes, tsunamis and volcanic eruptions. The second stage involved development of a methodology for detailed corridor assessments at regional level.

The national resilience assessment enables the Transport Agency to manage the natural hazard risks through understanding the distribution and extent of critical areas of vulnerability and the likely duration of outage throughout the national network. The project has involved collection of published national data on natural hazards from GNS Science, NIWA, local authorities and university research departments for use in the assessment of the resilience of the state highway network. This paper presents the approach used, and the results of the study.

2 ROAD RESILIENCE & PERFORMANCE

Resilience of lifelines such as roads is the ability to minimise loss of service and readily recover and return to its original form from adversity.

Knowledge of the resilience of the road network in natural hazard events is important to understand the impact on society – the people, emergency services, economic activity etc. This would also enable the estimated natural hazard resilience to be compared against desired level of service targets, and help develop resilience enhancement measures.

The concept of resilience of road transportation lifelines is dependent on their vulnerability to a loss of quality or serviceability, and the time taken to bring them back into original usage state after a reduction or loss of access. This is shown conceptually in Figure 1, where following an adverse event there is a loss of service that requires a period of recovery time to restore the road or network back to its pre-event level of service. Thus, the smaller the shaded area, the more resilient is the asset. The greater the area, the poorer is the resilience.

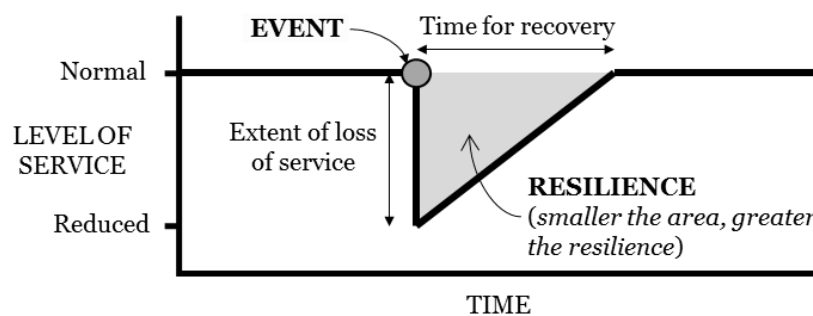


Figure 1. Resilience of route/network

3 STUDY METHODOLOGY

3.1 Objectives

The methodology for assessing the resilience of state highways at a national screening level was developed for the following objectives:

- Enable assessment of the resilience across the whole state highway network.
- Assess at a broad brush high level, efficiently and quickly.
- Assess resilience to large natural hazard events, which have a low frequency but high impact.
- Use a consistent basis applied across the country.
- Used to screen and understand the resilience of the network, to appreciate differences, and identify areas of concern.
- To inform Business Case studies, and enable resilience to be considered in identifying problems associated with highway corridors, and developing improvement initiatives.
- Enable further consideration of areas with poor resilience, and inform more detailed assessments at corridor levels by regional Agency teams.

3.2 Resilience metrics

State highways provide access for communities, and in evaluating their resilience, it is important to represent the availability or lack of access in the event of natural hazards. Therefore, it is appropriate to use metrics that reflect the level of service, and be understandable to stakeholders such as road controlling authorities, emergency management personnel and local communities. The metrics used underpin decision making relating to actions to enhance the resilience of the state highway corridors, as well as related local road routes, such as emergency preparedness measures or appropriate mitigation

measures.

The two key dimensions of resilience (refer Figure 1) are:

- The degree of access available following a reduction in access as a consequence of the event, and
- The time taken for access to be restored, or the duration of access impairment.

Resilience metrics or “resilience states” representing the performance of road networks were developed by Brabhaharan *et al.* (2006) to consider the impact of various natural hazards on roads on a similar basis. The states used in this national-level resilience assessment are summarised in Table 1.

Table 1. Resilience states

Resilience state	Description
Availability state	Availability State indicates whether the road section would be able to be used either at full level, at various reduced levels or not at all. This gives an indication of the degree of access on a link after an event.
Outage state	Outage State indicates the duration over which the road will be in the Availability State above. This gives an indication of the duration of loss or reduced access in links along the road network.

The availability states have been represented as the following levels given in Table 2 (after Brabhaharan, 2006).

Table 2. Availability state

Availability Level	Availability State	Availability Description
1	Full	Full access (perhaps with driver 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 for normal vehicles 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.

The outage states have been represented as the following levels given in Table 3 (after Brabhaharan, 2006). These represent anticipated outage times for increasing levels of damage, and have been developed to link to levels of service used in other network assessment tools being developed by the Transport Agency.

Table 3. Outage state

Outage Level	Outage State	Outage 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

A ‘Disruption state’ combines the availability and outage states, to provide a single parameter indicating the level of disruption caused by the hazard event at each road section (Brabhaharan *et al.*, 2006). The disruption state levels and their derivation from the availability and outage states are provided in Table 4.

Table 4. Disruption states & levels

		Outage						
		1 Open	2 Minor (<1 day)	3 Moderate (1-3 days)	4 Short term (3 days – 2 weeks)	5 Medium term (2 weeks – 2 months)	6 Long term (2-6 months)	7 Very long term (>6 months)
Availability	1 Full	1 None	1 None	1 None	1 None	1 None	1 None	1 None
	2 Poor	1 None	2 Limited	2 Limited	2 Limited	3 Moderate	4 High	4 High
	3 Single lane	1 None	2 Limited	2 Limited	3 Moderate	4 High	5 Severe	6 Extreme
	4 Difficult	1 None	2 Limited	2 Limited	3 Moderate	4 High	5 Severe	6 Extreme
	5 Closed	1 None	2 Limited	3 Moderate	4 High	5 Severe	6 Extreme	7 Catastrophic

3.3 Hazard events

As described in section 3.1, this study is focused on the impact of low frequency, high impact natural hazard events. The hazards considered were large earthquakes, large storms/floods, volcanic eruptions and tsunamis.

Hazard event levels were chosen to be consistent with common design levels (e.g. Bridge Manual requirements) subject to the return periods associated with the available hazard assessment data. These and the typical impacts considered in assessing the resilience of road corridors are shown in Table 5.

Table 5. Hazard event levels for resilience assessment

Hazard	Impacts considered	Recurrence interval for resilience assessment	Bridge Manual design levels
Storm / Flooding	<ul style="list-style-type: none"> • Flood inundation • Storm induced landslides • Erosion • Deposition of sediments and debris • Loss of bridge due to scour/erosion • Coastal inundation/erosion 	1 in 100 years	1 in 100 years
Earthquake	<ul style="list-style-type: none"> • Earthquake induced landslides • Liquefaction and lateral spreading • Bridge/structure damage due to ground shaking 	1 in 1,000 years	1 in 500 to 1 in 2,500 years
Volcanic hazards:			
Lahar	1 in ~250 years (specific to lahar source)	1 in ~250 years (specific to lahar source)	
Ash fall	1 in 500 years	1 in 500 years	
Eruption / lava flow	1 in ~1,000 years (depends on eruption source and type)	1 in ~1,000 years (depends on eruption source and type)	
Tsunami	<ul style="list-style-type: none"> • Inundation • Scour of road surface/structures • Deposition of sediments and debris • Collapse of bridges/structures 	1 in 500 years	

3.4 Characterisation of the road network

The state highway routes have been characterised based on the vulnerability of the road to each natural hazard following the approach developed by Brabhakaran *et al.* (2001, 2006). Characterising the road network requires identification of the susceptibility of the road corridor to the particular hazards identified in Table 5, and assessment of the potential impacts of the hazards and the consequences to the level of service of the road.

The roads were characterised mainly through desk-top analyses using available spatial information such as terrain information (e.g. LINZ digital elevation models), geology maps (e.g. GNS QMaps), hazard maps (e.g. Wellington Region earthquake hazard maps), aerial photographs and state highway imagery (e.g. state highway corridor video). The desk-based mapping was supplemented by targeted site reconnaissance of hazard-prone corridors such as SH1 Taupo to Waiouru and SH6 Buller Gorge.

The process followed in this characterisation is as follows:

1. Characterise the road corridor based on the terrain, geology, hydrology, hazards etc., distinguishing the terrain on separate sides of the road;
2. Assess potential damage impacts for the various road categories (e.g. rock fall from steep cut slopes inundating the road) and consider the location and extent of areas of loss of service.

4 STATE HIGHWAY NETWORK RESILIENCE MAPPING

4.1 Resilience states

The information collected during the road characterisation comprised qualitative assessment of the road form and vulnerability of the routes. This required consideration of the size or return period of the natural hazard events of interest, assessment of the effects of the hazards on the availability of access along the route, and assessment of the potential duration of outages.

Performance or resilience states discussed in Section 3.2 have been used to map the resilience of the entire national state highway network, using the approach developed by Brabhaharan *et al.* (2001) and the performance criteria developed by Brabhaharan *et al.* (2006).

This was carried out by assigning scores of availability (from 1 to 5) and outage (from 1 to 7) to each road category used in the road characterisation. The availability and outage scores were derived from the assessment of the potential hazard impacts on the road segment, in terms of the location, extent and type of damage, and the type of work and time required to remedy the damage and restore access. The resilience states were then derived from the road characterisation spatial database using ArcGIS. The disruption state was then derived in GIS for each road segment from the availability and outage states, as described in Table 4.

4.2 Spatial mapping

The resilience states were spatially mapped and displayed in GIS at 1:20,000 scale, so that the results can be visually displayed in its regional and national context. The results of the resilience assessment for the road networks are able to be presented on individual maps for the natural hazards considered in this study.

4.3 Identification of key resilience issues

The resilience maps show critical sections of the road that are vulnerable to a number of natural hazards that could result in closure of the road for long periods. Examples of the resilience mapping are shown in Figures 2-4.

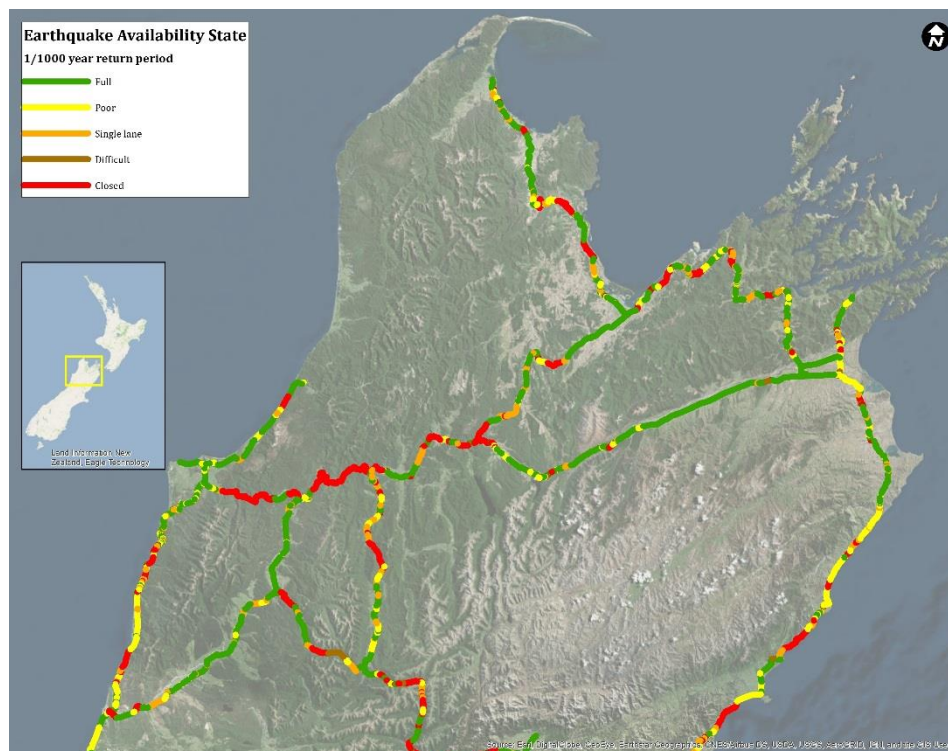


Figure 2. Availability state map of state highways in the upper South Island for earthquake hazards.

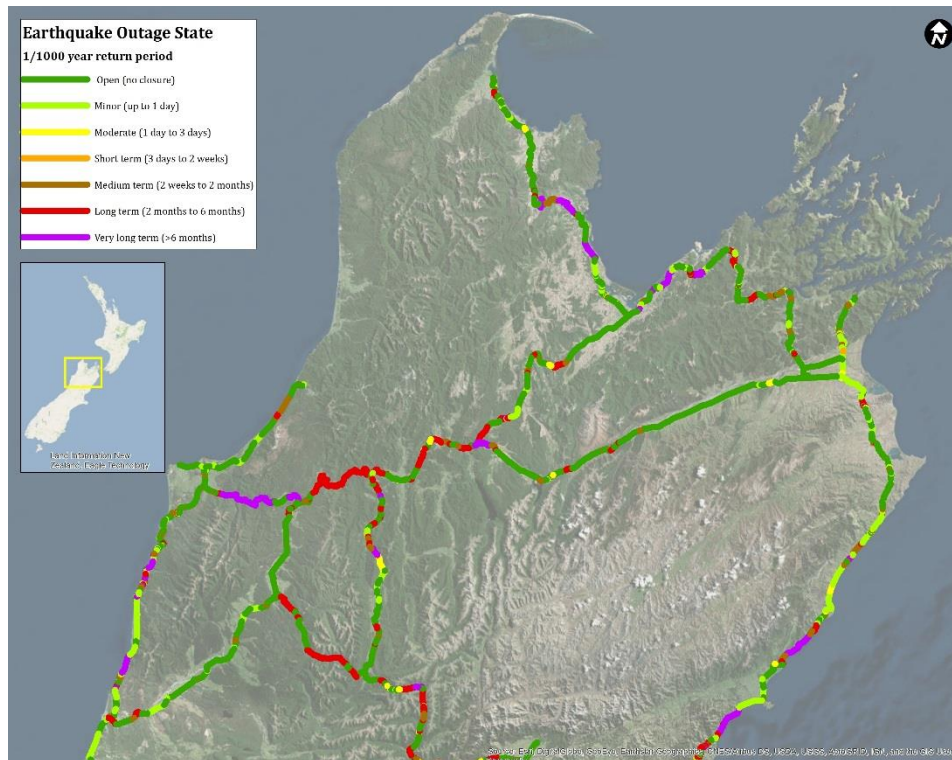


Figure 3. Outage state map of state highways in the upper South Island for earthquake hazards.

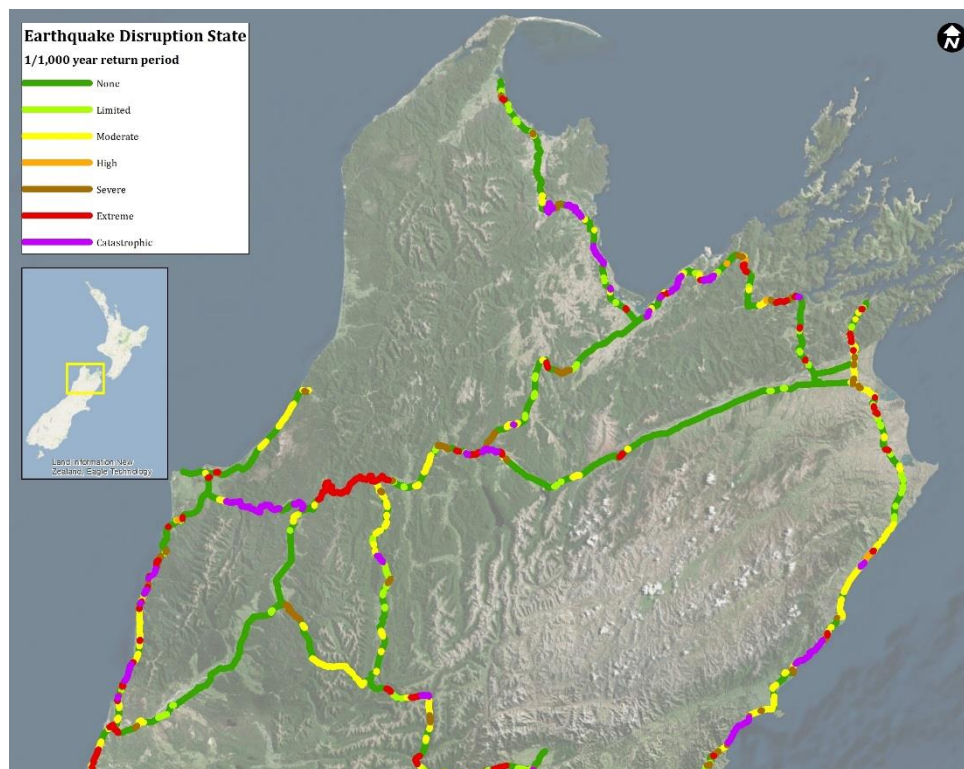


Figure 4. Disruption state maps of state highways in the upper South Island for earthquake hazards.

The resilience maps can be used at various scales to identify route- and network-level resilience issues. For example, the recent Kaikoura earthquake caused extensive damage to the coastal section of state highway 1 to the north and south of Kaikoura, highlighting the vulnerability of that route to damage from earthquakes and large storms, but has also drawn attention to the potential resilience gap in the wider network, as the remaining alternative routes also cross steep terrain that is prone to damage and lengthy closures from natural hazards. A more detailed study comparing the observed performance of

state highways in north Canterbury and Marlborough with the pre-earthquake resilience assessment is currently in preparation.

4.4 Route prioritisation

The results of the resilience assessment and the Transport Agency's One Network Road Classification (ONRC) provide the basis for identifying priority links with low resilience where more regular road closures have significant impacts. Prioritisation of routes for resilience enhancement are being carried out separately, including factors that are not captured in the ONRC, such as:

- Availability of alternative routes
- Importance for lifeline activity
- Importance for post-disaster response and recovery

5 CONCLUSIONS

Assessment of the resilience to low frequency high impact natural hazard events has been carried out for the national state highway network. The resilience mapping was carried out at a broad scale to screen the national network and identify state highway links with poor resilience.

The national resilience study captures the current resilience of the national network and identifies sections of state highways with poor resilience. The low resilience of sections of these highways pose a significant risk to access in these areas in the aftermath of one or more types of hazard events. Consideration of the resilience and the availability of alternative routes will help identify links where the lack of resilience would have a severe effect on the communities in the area, and in some cases with regional and possibly national consequences.

The resilience study provides maps that can be used during consideration of the development of these routes, as well as enable asset management and emergency response planning. The second stage of the study involved development of a methodology for detailed corridor/regional assessments, and this national level assessment forms the basis for considering the resilience at a more detailed regional level, with particular focus on areas that have been identified as having a low resilience from this national resilience screening assessment.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

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