Before a Board of Inquiry
Transmission Gully
Notices of Requirement and Consents

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under: the Resource Management Act 1991

in the matter of: Notices of requirement for designations and resource consent applications by the NZ Transport Agency, Porirua City Council and Transpower New Zealand Limited for the Transmission Gully Proposal

between: **NZ Transport Agency**
Requiring Authority and Applicant

and: **Porirua City Council**
Local Authority and Applicant

and: **Transpower New Zealand Limited**
Applicant

Statement of evidence of Pathmanathan Brabhaharan (Brabha) (Geology and geotechnical engineering) for the NZ Transport Agency and Porirua City Council

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Dated: 18 November 2011

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CHAPMAN TRIPP

STATEMENT OF EVIDENCE OF PATHMANATHAN BRABHAHARAN (BRABHA) FOR THE NZ TRANSPORT AGENCY AND PORIRUA CITY COUNCIL

QUALIFICATIONS AND EXPERIENCE

1 My full name is Pathmanathan Brabhaharan (Brabha).

2 I hold the following positions:

2.1 I am Technical Principal (Geotechnical Engineering & Risk) and a Partner with Opus International Consultants Limited (*Opus*);

2.2 I am Resource Group Manager for the Wellington Geotechnical Engineering & Risk Group, in the Wellington Civil Engineering Team of Opus; and

2.3 I am currently a member of the executive of the Management Committee of the New Zealand Society (*NZ Society*) for Earthquake Engineering.

3 My qualifications are summarised below:

3.1 I hold a Bachelor of Science of Engineering with Honours, specialising in Civil Engineering, from the University of Peradeniya, Sri Lanka (1982), a Master of Science of Engineering in Foundation Engineering from the University of Birmingham, United Kingdom (1986), and a Master of Business Administration from Deakin University, Australia (1998);

3.2 I am a Chartered Professional Engineer in New Zealand, and a Fellow of the Institution of Professional Engineers New Zealand; and

3.3 I am also a member of the NZ Society for Earthquake Engineering, the New Zealand Society for Risk Management, the New Zealand Structural Engineering Society and the New Zealand Geotechnical Society, and I am affiliated to the International Society for Soil Mechanics and Geotechnical Engineering and the International Society for Rock Mechanics.

4 On 15 August 2011 the NZ Transport Agency (*NZTA*), Porirua City Council (*PCC*) and Transpower New Zealand Limited (*Transpower*) lodged Notices of Requirement (*NoRs*) and applications for resource consent with the Environmental Protection Authority (*EPA*) in relation to the Transmission Gully Proposal (*the Proposal*).

5 The Proposal comprises three individual projects, being:

5.1 The 'NZTA Project', which refers to the construction, operation and maintenance of the Main Alignment and the Kenepuru Link Road by the NZTA;

5.2 The 'PCC Project' which refers to the construction, operation and maintenance of the Porirua Link Roads by PCC[1]; and

5.3 The 'Transpower Project' which refers to the relocation of parts of the PKK-TKR A 110kV electricity transmission line between MacKays Crossing and Pauatahanui Substation by Transpower.

6 My evidence is given in support of the NZTA and PCC Projects. It does not relate to the Transpower Project. For the purposes of my evidence, I will refer to the NZTA Project and the PCC Project collectively as the "Transmission Gully Project" (*the TGP* or *the Project*).

7 My experience relevant to the Project is summarised below:

7.1 I have 29 years' experience in geotechnical, earthquake and civil engineering and risk management, in New Zealand, Malaysia, Singapore, Sri Lanka and the United Kingdom;

7.2 In Sri Lanka, I was an Engineer with Swedish contractor, Skanska Cementgjuteriet, on a hydropower project involving the construction of a 150 m high rockfill dam, rock tunnels and an underground power station;

7.3 In Malaysia, I was Site Agent with local contractor, Aqthal Jasmeg Construction, and was responsible for construction of infrastructure including earth dams, water treatment plants and a cocoa processing factory;

7.4 In the United Kingdom, I was a Geotechnical Engineer with consultant Over Arup & Partners, and worked on the investigation, geotechnical and risk assessment, and mitigation of the risk to urban development, from abandoned limestone caverns in the West Midlands;

7.5 I have been based in Wellington and practiced in New Zealand since 1989 (over the past 22 years), and during this period have provided geotechnical advice, design, investigations and construction monitoring for a variety of infrastructure projects, and in particular for motorways, expressways, highways, roads and bridges;

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1 The Porirua Link Roads are the Whitby Link Road and the Waitangirua Link Road.

7.6 I was a member of the Learning from Earthquakes Team from the NZ Society for Earthquake Engineering that carried out reconnaissance of the damage to the built and natural environment in the Sichuan Province of China, as a result of the 2008 Richter Magnitude 8.0 Wenchuan Earthquake, and presented findings to the profession;

7.7 I was engaged by the NZTA to carry out field reconnaissance of damage to highways and bridges and to gather lessons on geotechnical aspects of the observed performance, following the 2010 Richter Magnitude 7.1 Darfield Earthquake that affected Canterbury. I have been actively involved in the emergency response and recovery after the 2010-2011 Canterbury Earthquake Sequence, and continue to be involved in developing repair and reconstruction solutions;

7.8 My experience includes a variety of highway projects in the Wellington and Nelson-Marlborough Regions that have involved design and construction of large earthworks in geological conditions similar to those encountered along the TGP route, including:

(a) State Highway (*SH*) 58 Realignment between Pauatahanui and Judgeford (cuts and fills up to 30 m high);

(b) SH6 Whangamoa North Deviation, Nelson (cuts and fills up to 30 m high);

(c) SH1 Newlands Interchange (cuts and fills up to 45 m high);

(d) SH2 Kaitoke to Te Marua Realignment (cuts and fills up to 30 m high);

(e) SH60 Ruby Bay Bypass (cuts, fills and reinforced fill embankments up to 25 m high);

(f) SH2 Muldoon's Corner Realignment (cuts, fills and reinforced fill embankments up to 55 m high); and

(g) Double tracking of the North Island Main Trunk (*NIMT*) Railway Line between MacKays Crossing and Waikanae (review role);

7.9 Design review of cuttings up to 25 m high in sand dunes and embankments on inter-dunal peat deposits for the Western Link Road, and the Peka Peka to North Otaki Expressway. Review for development of embankments and interchange structures on liquefiable and compressible ground for the Christchurch Southern Motorway;

7.10 I led earthquake hazard assessment and mapping studies, including liquefaction and slope failure hazards for the Wellington region (1992-1995), Western Bay of Plenty region (2002), Queenstown-Lakes district (2002) and Otago region (2004), which resulted in earthquake hazard maps for each of the regions;

7.11 I have also completed a number of studies to assess the risk and develop risk management strategies for road networks in Wellington City (1998-2000), Hutt Valley (2008), Upper Hutt (1999), Porirua (2011) and the Wellington State highway Network (2008). These studies have assessed the resilience of priority roads within the Greater Wellington area under earthquake and storm conditions;

7.12 I provided technical direction to studies for the NZTA to identify critical sections along SH1 that would be affected in a major earthquake in the Wellington region, develop emergency response plans and in particular assess the likely time required to reopen the coastal route between Pukerua Bay and Paekakariki; and

7.13 I have provided geotechnical engineering to the seismic assessment and retrofit of bridges throughout New Zealand, including development of innovative retrofit solutions for abutments. This includes a number of the bridges in the Wellington Region, including along SH1 in the vicinity of this Project.

8 I am familiar with the area that the Project covers and the State highway and local roading network in the vicinity of the Project.

9 I am the author of Technical Report No 3: Geotechnical Engineering Report, which was lodged as part of the Project's Assessment of Environmental Effects (*AEE*).

10 I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Consolidated Practice Note (2011), and I agree to comply with it as if this Inquiry were before the Environment Court. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

11 My evidence will deal with the following:

11.1 Background and role in relation to the Project;

11.2 Description of the geology of the Project area;

11.3 Route security of existing routes for access into and out of Wellington and in particular, along the existing coastal route;

11.4 Route security of the TGP route;

11.5 A description of the geotechnical engineering design measures proposed to achieve enhanced resilience along the TGP route;

11.6 A description of the Project's earthworks;

11.7 Groundwater effects assessment;

11.8 Response to submissions; and

11.9 Conclusions.

SUMMARY OF EVIDENCE

12 The TGP is in an area of 'greywacke' bedrock – hard interbedded sandstone and argillite (siltstone / mudstone), which has been folded and faulted, variably weathered, and with very strong to extremely weak rock strengths. The greywacke rock typically has closely to very closely spaced joints, with widespread fault zones, shear zones, shattered rock zones and gouge zones.

13 The overburden soils overlying bedrock are generally less than 2 m to 5 m in thickness, except when overlain by alluvium, swamp and sand dune deposits. Thicker overburden soil deposits are present between MacKays Crossing and the SH1 crossing at Paekakariki; between Battle Hill and the proposed SH58 interchange; the proposed Kenepuru Link Road crossing of the NIMT railway line and Porirua Stream; and in stream / gully crossings.

14 One of the NZTA's objectives for the NZTA Project is "to provide an alternative strategic link for Wellington that improves regional network security". This route security objective provided the basis for the design philosophy adopted for the Project, so as to ensure that the TGP provides an access into Wellington, which is more resilient to natural hazards, compared to the existing routes.

15 In the event of a large local earthquake, such as a characteristic Richter Magnitude 7.5 earthquake on the Wellington Fault, current road access into Wellington is likely to be prevented for a long period of time (three to six months or more). This will be due to the closure of SH1 as a result of large landslides between Pukerua Bay and Paekakariki, and liquefaction and lateral spreading along the Porirua Harbour section. Access from the north-east along SH2 is also likely to be closed due to landslides in the Rimutaka Hill section.

16 The Wellington region is an area of high seismicity, with steep terrain and a number of active faults. Therefore, the elimination of the hazard arising from earthquakes is not possible in the region's context. Damage and closure resulting from earthquakes are still possible on the TGP route.

17 However, through careful focus on resilience and route security, an alignment, road form and concept design have been developed for the TGP, which provides enhanced resilience and a good level of route security.

18 This includes selection of an alignment which crosses the active Ohariu Fault only once, on an earth embankment that can be reinstated quickly, and using reinforced soil embankments where the alignment is close to active faults or close to steep natural or cut slopes. Also, the cut slope design has been chosen with a focus on earthquake performance, with 40 to 45 degree cut slopes in rock, and 25 to 35 degree cut slopes in soil.

19 It is my opinion that, in the event of a large local earthquake, there will still be significant slope failures in the Te Puka Stream and upper Horokiri Stream sections of the route (north of Battle Hill Farm Forest Park), and possibly also at the southern end of the Main Alignment through the Ranui Forest area. These could close the new road. However, limited access could be restored to these sections within two weeks, and the section between Battle Hill and MacKays Crossing could be opened within a period of two weeks to three months. The remaining sections of the road are expected to remain open for access.

20 In small to moderate earthquake events and storms, the TGP is expected to remain open, possibly with reduced capacity, and hence will provide a much higher level of route security than the existing routes.

21 The new route will also not be affected by tsunamis, in comparison to the existing coastal route.

22 Overall, the Project route will significantly enhance the resilience of north-western access into Wellington, and improve the security of

access into the greater Wellington area, in the event of a large earthquakes or storms in the region.

23 I consider it important that the focus on resilience and route security should be continued during the Project's detailed design and construction phases, with an adequate level of geotechnical investigations, design and active surveillance and monitoring during construction, to achieve a resilient state highway with good route security performance.

24 Turning to earthworks associated with the Project, the majority of the materials from the cuttings for the roads will be rockfill derived from weathered and fractured rock, which will be good material suitable for the construction of the road embankments. Selected materials from the less weathered rock will be suitable for the construction of the Reinforced Soil Embankments (*RSE*). The materials will also provide a good subgrade for the road pavement. Exceptions to this are the alluvial materials that will be encountered between Battle Hill Farm Forest Park and the SH 58 interchange, and possibly the James Cook Drive and Interchange areas. These materials are variable, and a significant proportion may require drying and cut to waste and be used as landscaping fill. . The subgrade along this section may require treatment (undercut or stabilisation) and a thicker road pavement.

25 Some of the materials from the rock cuttings and rock sources along the Project route may be able to be used for road aggregate and possibly concrete aggregate, subject to appropriate processing.

BACKGROUND AND ROLE

26 The NZTA selected Opus to provide preliminary geotechnical assessment as part of the Scheme Assessment phase of the Project in 2007-2008. My role during that phase was as Geotechnical Team Leader. In this capacity, I developed the scope of the geotechnical investigations, co-ordinated their implementation, led the preliminary geotechnical assessment and reporting, and provided geotechnical engineering and route security advice during the development of the scheme. I also participated in the workshops held to develop alternative alignments and options, discuss and select options and then develop the selected alignments.

27 The NZTA then engaged Opus to prepare a report to compare the route security of the existing SH1 Coastal Route and the proposed Transmission Gully road. I prepared this assessment and report in

June 2009[2], with review input from Graham Hancox of the Institute of Geological and Nuclear Sciences (GNS Science).

28 Following this, the NZTA engaged a team of consultants to prepare and lodge the AEE for the TGP, and Opus was engaged to assist with the Project's road design and structure design, including geotechnical engineering. I led the geotechnical engineering for this phase of the Project, and as recorded above, prepared Technical Report No 3[3].

29 I attended selected workshops and meetings to discuss issues with inter-related disciplines, such as with **Mr Edwards** on road and structures design, **Mr Lister** on landscape, **Mr Martell** on waterways and **Mr Fuller** on ecology.

GEOLOGY OF THE PROJECT AREA

30 The entire Main Alignment route, as well as the Porirua Link Roads, will be located in an area formed of 'greywacke' bedrock – hard interbedded sandstone and argillite (siltstone / mudstone).

31 The greywacke bedrock has been folded and faulted, and is variably weathered, ranging from slightly weathered to completely weathered, with rock strengths varying from very strong to extremely weak. The greywacke rock is typically highly fractured (closely to very closely spaced joints) with widespread fault zones, shear zones, shattered rock zones and gouge zones.

32 Varying thicknesses of old and recent alluvium, estuarine, dune, loess, fan and colluvium deposits overlie bedrock. Except where alluvium and estuarine deposits are present, the overburden soils overlying bedrock are generally less than 2 m to 5 m in thickness.

33 The Main Alignment runs parallel to (and crosses) a number of active faults (refer **Figure A**, **Appendix A**). The alignment crosses the active Ohariu Fault in the Te Puka Stream valley, an active splinter of the Ohariu Fault in the upper Horokiri Stream valley, and the less active Moonshine Fault in the Duck Creek valley.

34 A more detailed description of the geology along the TGP route is given in Technical Report No 3[4].

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2 Transmission Gully and Existing State Highway 1 Coastal Route. Route Security in Earthquake Events. June 2009 (Opus 2009). [http://www.nzta.govt.nz/projects/transmission-gully/docs/route-security.pdf]

3 Transmission Gully Project, Assessment of Environmental Effects. Technical Report No 3 Geotechnical Engineering Report (Opus, 2011).

4 Refer to page 7 of Transmission Gully Project, Assessment of Environmental Effects. Technical Report No 3. Geotechnical Engineering Report (Opus, 2011).

ROUTE SECURITY OF EXISTING ROUTES INTO AND OUT OF WELLINGTON

The existing seismic environment in Wellington

35 New Zealand is located at the boundary of the Australian and Pacific Plates, with the plate boundary located on the western side of the South Island and the eastern side of the North Island. The subduction zone associated with the plate boundary crosses from the west to the east through the Cook Strait area south of the Wellington region. As such, Wellington is in an area of high seismicity, with a number of active faults and a subduction zone capable of producing large earthquakes of Richter magnitude 7 to 8.

36 Among the major active faults in the region are the Wairarapa Fault (which ruptured in 1855 leading to a Richter magnitude 8 earthquake), the Wellington Fault (which runs through Wellington and the Hutt Valley) and the Ohariu Fault (which runs through Porirua and Kapiti).

Wellington earthquake hazard studies

37 Earthquake induced liquefaction hazards in the Wellington Region were assessed and mapped in a study I led for Wellington Regional Council in 1992-1993. The study[5] identified the areas in the region which were at risk of significant liquefaction and ground damage in the event of moderate to large earthquakes.

38 The study showed that the sections of SH1 through the Mana to Porirua area, along the Wellington Harbour edge, and through the Kilbirnie area are subject to significant hazards from liquefaction and lateral spreading (refer **Figure B**, **Appendix A**).

39 Earthquake induced slope failure hazards were also assessed and mapped by a combined Opus-GNS Science team that I led for the Wellington Regional Council in 1993-1995. Our study[6] confirmed that earthquake induced slope failures is a major hazard for the region (refer **Figure C**, **Appendix A**).

40 Since 1998, I have carried out a number of studies to assess the vulnerability to natural hazards of the priority local road networks in Wellington, Lower Hutt, Upper Hutt and Porirua, as well as the State highways in the region. Given Wellington's terrain, seismicity and weather, the notable hazards are earthquakes, storms and landslides. The resilience of the priority road network (except Porirua which was completed in 2011) was combined into one

[5] Liquefaction Hazard Study, Wellington Region. Prepared by P Brabhaharan & DN Jennings (Works Consultancy Services, 1993).

[6] Earthquake Induced Slope Failure Hazard Study, Wellington Region. Prepared by P Brabhaharan, GT Hancox, ND Perrin & GD Dellow (Works Consultancy Services, 1994).

resilience map in 2009[7]. This map shows the vulnerability of the combined road network to large earthquakes (refer **Figure D, Appendix A**).

41 Resilience is defined as a function of the loss of access after an event, and the time taken for access to be restored (refer **Figure E, Appendix A**). The smaller the degree of loss of service and the shorter the time taken to restore functionality (smaller area in **Figure E, Appendix A**), the greater the resilience. The resilience of road links are represented by an "Availability State" (level of access available) and "Outage State" (the duration of the reduction or loss of access) (refer **Figure E, Appendix A**).

42 The combined resilience map clearly shows that access into and out of Wellington will be cut off, and access between the urban centres will also be severely disrupted after a large local earthquake event (refer **Figure D, Appendix A**). In particular:

42.1 The access from the north-east will be cut off in the rugged Rimutaka mountain range through which SH2 is located. Indeed, in the 1855 Wairarapa Earthquake, the limited access which existed at the time was closed by landslides; and

42.2 SH1 access along the western corridor is expected to be cut off at a number of locations. These locations were identified in the Earthquake Response Plans developed by Opus (2011) for the NZTA[8]. Major areas of concern include the coastal sections of the highway between Pukerua Bay and Paekakariki, which are subject to major landslides along the sea cliff, and the section between Mana and Porirua, which is vulnerable to liquefaction and lateral spreading.

Vulnerability of the coastal route

43 The study of the route security of the existing SH1 Coastal Route as compared to the Transmission Gully Route (Opus, 2009)[9] indicated that the coastal section of SH1 would be closed for three to six months in a Wellington Fault event and possibly for more than six months in an Ohariu Fault earthquake event. This time scale for restoration of all vehicle access was confirmed by a later, more detailed, study of this section of SH1 (Opus, 2011)[10].

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[7] Opus (2009). Meshing Road Network Lifelines Data for the Wellington Region. March 2009.

[8] Opus International Consultants (2011). Emergency Response Pre-Plans for State Highway 1. Prepared for the New Zealand Transport Agency. August 2011.

[9] Opus International Consultants (2009). Transmission Gully and Existing SH1 Coastal Route. Route Security in Earthquake Events. Prepared for the New Zealand Transport Agency. June 2009.

[10] Opus International Consultants (2011). Post-Earthquake Response Plan. SH 1 Pukerua Bay to Paekakariki, Wellington. Risk Study Report. Issue 2. October 2011.

44 It should be noted that this timeframe will depend on a number of factors, such as availability and prioritisation of resources and the ongoing aftershock sequence. The destabilising effect of aftershocks is apparent in the Canterbury Earthquake Sequence following the 4 September 2010 Darfield Earthquake, as was the case after the 2008 Wenchuan Earthquake in China.

45 I observed the catastrophic effect of large scale landslides on highways and the long time required for re-opening them, during my reconnaissance visit to the Sichuan Province of China, six months after the 2008 Wenchuan Earthquake.

46 The existing SH1 route is also vulnerable to closure along the Porirua Harbour section between Mana and Porirua, due to liquefaction and lateral spreading. Examples of damage to roads from liquefaction and lateral spreading in the 1931 Napier Earthquake and the 2011 Christchurch Earthquake are shown in **Figure F**, **Appendix A**.

47 The Paremata Bridges (i.e. the two SH bridges and the NIMT Rail Bridge) along the existing SH1 route are built across or in the vicinity of the Ohariu Fault (see **Figure A**, **Appendix A**). In the event of rupture of the Ohariu Fault, the bridges are likely to be severely damaged with complete loss of access, until alternate temporary bridges can be erected. The existing SH1 route is also close to the Pukerua Fault at Pukerua Bay.

48 The existing coastal route is also at risk from tsunamis, particularly between Pukerua Bay and Paekakariki, with major scouring, erosion and deposition of debris caused by large events with run up heights greater than 5 m. Such events have a recurrence interval of about 400 to 650 years[11].

49 In summary, following a large local earthquake, access into Wellington will be prevented for a long period of time along the western access corridor, due to closure of SH1 as a result of large landslides between Pukerua Bay and Paekakariki, and liquefaction and lateral spreading along the Porirua Harbour section. Access from the east along SH2 will also be closed due to landslides in the Rimutaka Hill section. The Wellington region is likely to be isolated, and this will severely restrict the ability to respond to and recover after such an earthquake event.

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[11] Cochran (2002). What evidence for paleotsunami triggered by local earthquakes in the Wellington Region.

ROUTE SECURITY OF THE TRANSMISSION GULLY PROJECT ROUTE

50 This Project provides an important opportunity to improve the security of access into and out of Wellington, after large local earthquake events, storms and tsunami. The NZTA's objective for the NZTA Project is "to provide an alternative strategic link for Wellington that improves regional network security." Therefore, route security has been a key consideration in the development of the current alignment, road form and design concepts.

51 Because the Wellington region is an area of high seismicity, with steep terrain and a number of active faults, total elimination of earthquake associated hazards is not possible. Damage and closure of the TGP following a large earthquake is still possible. Accordingly, the focus has been on developing an alignment, road form and concept design that would enhance resilience of the route and hence improve route security to an appropriate level.

52 The route security philosophy adopted for the Project is:[12]

a) Highway is open for full access with minimum structural damage in small hazard events with a short return period;

b) Highway suffers limited repairable damage in moderate hazard events, with continued limited access, or highway reopens after a short period of closure, say 12 hours to 3 days;

c) Highway suffers major damage, but does not collapse, in large long return period events, and limited access can be restored within a reasonable period (say 3 days to 2 weeks).

Fault rupture

53 The Main Alignment crosses three active faults - the Ohariu Fault, a splinter of the same fault, and the Moonshine Fault (refer **Figure A, Appendix A**).

54 The Moonshine Fault has a recurrence interval of over 11,000 years. That is, the rupture of this fault has less than 1% probability of occurring in 100 years. Therefore, this fault does not pose a significant risk to the security of the TGP route.

55 The active Ohariu Fault, with a recurrence interval of about 2,200 years is located through the Te Puka Stream valley and the Wainui Saddle. An active splinter of the Ohariu Fault is also located in the upper Horokiri Stream valley, and is considered to have a

[12] Refer to page 30 of Transmission Gully Project, Assessment of Environmental Effects. Technical Report No 3. Geotechnical Engineering Report (Opus, 2011).

recurrence interval similar to the Ohariu Fault. There is a 4% to 5% probability that these faults will rupture in 100 years.

56 It is impractical to avoid crossing the active Ohariu Fault along the western corridor access into Wellington. This is because of the terrain, and this active fault traversing the western corridor obliquely in a southwest to northeast direction with Kapiti Coast to the north and Wellington City to the south, being located on opposite sides of this active fault (refer **Figure A**, **Appendix A**).

57 The focus has therefore been on ensuring that rupture of this fault does not severely compromise the security of the route. The Main Alignment has been carefully refined and located on the western flank of the Te Puka Stream valley in order to limit the number of crossings of the Ohariu Fault to just one. This crossing is slightly north of the Wainui Saddle in the Te Puka Stream valley.

58 More importantly, the design has been refined so as to cross the Ohariu Fault on an earth embankment (as opposed to a viaduct or bridge structure as previously proposed). This means that, following a possible rupture of the Ohariu Fault with perhaps a 4 m horizontal and 1 m vertical displacement, limited access can be quickly restored within days by earthmoving machinery. Long-term, full access can be restored by further earthworks, within weeks to a few months. In comparison, a bridge or a viaduct would take a longer time (some years) to reconstruct following damage or collapse due to fault rupture.

59 The Main Alignment route follows the active splinter of the Ohariu Fault immediately south of Wainui Saddle, on the western flank of the Horokiri Stream valley. The road form concept adopted along this section is a reinforced soil embankment. While this would be damaged or displaced due to rupture of the splinter fault, access can be quickly restored within days, using earthmoving machinery.

60 The design philosophy described above, and adopted for crossing active faults was reinforced by my observations of damage to highway infrastructure in the 2008 Wenchuan Earthquake. There, I observed two roads, one where the road crossed the fault on a bridge where there was still no access six months after the earthquake, and another road, where access had been quickly restored by ramping across the fault using earthworks (see **Figure G**, **Appendix A**).

61 During the consideration of alternatives and options, a short tunnel was considered for use in the Wainui Saddle area; however this was discarded partly because it would be difficult to avoid crossing the active faults with a tunnel. In the event of fault rupture (i.e. rupture of the active Ohariu Fault or its active splinter fault) associated with an earthquake, a tunnel across the fault could be

displaced by as much as 4 m to 5 m, and would be likely to collapse. It would take a long time to realign and reconstruct the tunnel across the fault zone. The tunnel option therefore failed to provide the desired route security sought.

62 In my opinion, the proposed road alignment and form provides good resilience and route security by maximising the likelihood that access could be quickly restored after rupture of the known active faults.

Liquefaction

63 The proposed Project route avoids areas with significant liquefaction hazard. My ground investigations have shown that liquefaction hazard does not exist at the proposed SH58 Interchange area near Pauatahanui as previously indicated by the regional hazard studies[13] (refer **Appendix A, Figure B**).

64 There is a limited liquefaction hazard between MacKays Crossing and the crossing of the existing SH1 at Paekakariki. While this risk has been reduced by the Main Alignment being located further to the east, ground improvement will be needed in this section of the Main Alignment. This could include excavation and replacement of the shallow liquefiable soils, or the installation of vibro-densification stone columns to protect any structures against liquefaction. A similar treatment may be required at the Kenepuru Link crossing of the Porirua Stream and NIMT Railway Line. The ground improvement options will be developed as part of the detailed design process, and implemented during construction.

Earthquake induced landslides

65 The TGP route is located through steep terrain, and earthquake induced landslides have the potential to have a significant effect on the security of the route. The earthquake induced slope failure hazard study[14] indicates that some sections of the route have a moderate (and high in localised areas of the hillsides along the route) susceptibility to slope failures during earthquakes (see **Figure C**, **Appendix A**). The alignment and the stability of the natural slopes and the proposed cut slopes have been key considerations in the selection of the road form and concept design of the highway.

66 The road alignment has been carefully chosen to avoid cutting into and destabilising a large historic landslide at the northern end of Te Puka Stream Valley, which now appears to be stable (see **Figure A**, **Appendix A**). The landslide is considered to have been formed by a historic earthquake, perhaps associated with rupture of the Ohariu

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13 Liquefaction hazard, Porirua (Wellington Regional Council, 1993).

14 Earthquake induced slope failure, Map Sheet 2 Porirua (Wellington Regional Council, 1995)

Fault in the past. The proposed earth embankment will form a buttress that further improves its stability.

67 The route for the Main Alignment has been moved to the western flanks of the Te Puka and Horokiri Stream valleys where the natural slopes are generally more stable and less prone to earthquake induced slope failures (see **Figure C, Appendix A**). In comparison, the previously designated Transmission Gully alignment lay on the eastern flanks of these valleys, which comprise steeper slopes, thicker soil overburden (in places) and the existence of another large landslide feature on the eastern flank of Te Puka valley (see **Figure A of Appendix A**).

68 Large viaduct structures alongside the steep hillsides in the Te Puka Stream and Horokiri Stream valleys were proposed as part of the previously designated Transmission Gully scheme. These have been eliminated in this design as they would be vulnerable to destruction by potential rockslides in large earthquake events. Large viaduct and bridge structures were destroyed by landslides in Sichuan Province during the 2008 Wenchuan Earthquake. That experience has informed my recommendations for this Project, such as in this case by avoiding viaduct structures at locations vulnerable to large rock slides in earthquake events.

69 In designs for the previous designations, vertical walls were proposed to be perched on steep slopes. These have also been avoided, as they would be vulnerable to earthquake induced slope failures from both above and below the walls.

70 Instead the TGP now incorporates Reinforced Soil Embankments (RSE) with slopes of 45 degrees (see **Figure H, Appendix A**). These RSE will be robust and resilient to the effects of slope failures onto them. The slip debris from landslides can be readily moved from the highway to restore access.

Tsunami

71 The TGP route is an inland route and thus is not exposed to tsunamis, and is expected to be resilient and remain open even if the existing coastal route is closed due to a tsunami. Even though some surge in the water levels may be experienced in the Pauatahanui Inlet, the Main Alignment will be elevated above the Pauatahanui flats and thus can be expected to remain functional.

GEOTECHNICAL ENGINEERING DESIGN TO ACHIEVE ENHANCED ROUTE RESILIENCE

72 A number of geotechnical engineering design measures are proposed to enhance the overall resilience of the road. Some of these measures are now discussed.

Rock Cut slope design

73 High cut slopes of up to about 60 m are proposed for the Project, with the highest slopes being located in the Te Puka Stream valley. These high cut slopes will be formed in fractured and variably weathered rock.

74 An integrated approach was used in the design of the rock cuttings with relevant considerations being cut slope stability, earthquake performance and rock fall hazard management.

Cut slope stability

75 I used a combination of four approaches in considering the stability of rock cut slopes – the precedent cut slopes and natural slopes, the behaviour of slopes in historical earthquakes, rock defect analyses and rock mass stability analyses.

76 Overall, rock cut slopes of about 40 to 45 degrees have been chosen, with some variations based on different rock mass conditions. A notable variation is the adoption of a flatter 35 to 40 degree slope angle in the fault-disturbed rock mass in the Wainui Saddle area which is crossed by the Ohariu Fault and associated splinter fault, as well as the historical and now inactive Horokiri Fault. I note that the AEE[15] refers to 22 to 35 degree cut slopes in this area. These cut slopes apply to the soil overburden and not the rock cut slopes, however, this is not clearly stated.

77 Natural greywacke slopes in the region are characteristically 38 to 43 degrees, and the proposed 40 to 45 degree slopes provide good stability and fit better into the natural landscape than steep cut slopes. The adopted cut slope angles are also consistent with maximum stable cut slope angles which I have observed in the region, and maximum stable slopes near the Wellington Fault observed by Grant-Taylor (1964)[16].

78 Shear surfaces and other dominant rock defects cause a majority of the failures observed in Wellington greywacke. The majority of shear surfaces mapped have dips of greater than about 40 to 45 degrees and are generally parallel to the proposed cut slopes. The formation of cut slopes at 40 to 45 degree slope angles will minimise the destabilising effects of these shear surfaces.

79 Combined failures through defects such as shear surfaces and through the fractured rock mass can also lead to instability, particularly if groundwater pressures are high. The drilling of sub-horizontal drainage holes will be used to reduce the groundwater pressures in the cut slopes and thus improve stability.

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[15] Refer to Section 7.9 and Table 7.2 on Page 150, Transmission Gully Project, Assessment of Environmental Effects report, August 2011 (Beca, 2011).

[16] Grant-Taylor (1964). Stable slope angles in Wellington Greywacke.

80 Given the variable rock mass, there is the potential for localised failures in the cuttings of Wellington greywacke. Accordingly, the TGP will also include stabilisation measures such as rock anchors, mesh and localised shotcrete treatment to improve stability. An allowance has also been made for soil nailing to support the overburden soils above bedrock, as may be required. These will be detailed further and implemented during the detailed design and construction stages of the Project.

Rock fall protection

81 Rockfall protection measures have been incorporated into the design of cut slopes, with the slopes adopted minimising the potential for rock bounce. The rocks are likely to roll at the proposed cut slopes of less than 50 degrees, and 3 m wide benches are proposed generally at 10 m height intervals to catch or slow the rocks that dislodge from the slope close to their source (the bench height will be locally increased to a maximum of 15 m below the first bench to provide a better visual appearance for road users, as noted in **Mr Gavin Lister's** evidence).

82 Rock fall protection fences will be incorporated in selected benches, and a 3 m to 4 m wide berm and a combined rock fall / traffic barrier are provided for at the base of the slope, to further minimise rockfall hazard (see **Figure I**, **Appendix A**).

Earthquake performance of cut slopes

83 Historical earthquakes have led to significant landslides in the Wellington region. Studies[17] have indicated that high cuttings steeper than about 45 degrees will lead to a high to very high susceptibility of earthquake induced landslides.

84 Cuts no steeper than 45 degrees and generally less than 50 m in height (which are consistent with the majority of the cuts adopted for the Project) have been found to have a low to moderate susceptibility to earthquake induced landsliding. However, these cut slopes could still lead to small to moderate failures (approximately 1000 m^3 to 20,000 m^3) in large earthquakes, which can be cleared in a few days to two weeks. Few failures are expected on cut slopes with slope angles of 35 degrees or less.

85 These conclusions of likely earthquake induced slope failures based on historical data are supported by the fact that dominant defects (such as shear surfaces) likely to cause landslides have been mapped to be generally steeper than 40 to 45 degrees. Also my analyses considering cut slope failures, partially along dominant

[17] Brabhaharan et al (1994) Earthquake induced slope failure hazard study. Wellington Region; and Hancox, GT, Perrin, ND, and Dellow, GD (2002) Recent studies of historical earthquake-induced landsliding, ground damage, and MM intensity in New Zealand. Bulletin of the New Zealand Society for Earthquake Engineering, 35(2)59-95, June 2002.

rock defects and partially through the fractured rock mass, suggest that 40 to 45 degree rock slopes would be generally stable, provided groundwater levels are low (refer to Technical Report No 3[18]).

86 The higher cut slopes of 50 m to 60 m height at an average cut slope angle of 45 degrees (as proposed in the Te Puka Stream valley), would have a moderate slope failure susceptibility to earthquakes, and could lead to large (>10,000 m^3) failures in large local earthquakes, but very large failures (>100,000 m^3) are not expected. Failures of the order of 10,000 m^3 can be cleared in a few days to a week or so. This is consistent with the route security outcomes desired for the Project.

Design and construction

87 Rock cuttings in similar geology and with similar heights have recently (2010-2011) been constructed for the SH2 Muldoon's Corner realignment. Some areas of that project required stabilisation with rock anchors and provision of rock fall protection measures.

88 I consider it important that the detailed design of the rock cuttings be informed by further geotechnical investigations. I also consider that close geotechnical monitoring should be employed during construction to identify actual rock defects and rock mass conditions exposed as works proceed. This will enable the implementation of proactive slope stabilisation measures to ensure stability of the cuttings and good seismic performance. Continued focus on route security supplemented by an observational approach is important during the design and construction of the cuttings.

Soil cut slopes

89 Section 7.9 of the AEE[19] "Cut and fill slopes" and Table 7.2 "Cut slope configurations", list indicative cut slopes to be adopted throughout the Project. These refer to the indicative soil cut slopes, as opposed to the rock cut slopes which I have described above.

90 Cut slopes will be predominantly in soil between Battle Hill and the proposed SH58 Interchange. These cut slopes will be formed to a flatter slope of 25 to 35 degrees in a weak weathered alluvium, with 3 m wide benches at 10 m height intervals. Appropriate slope angles and good drainage will be required so as to ensure stability. It is expected that surface drainage, sub-horizontal drainage holes and possibly counterfort drains will be incorporated into the design and construction of these cuttings.

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18 Refer to page 56 of Transmission Gully Project, Assessment of Environmental Effects. Technical Report No 3. Geotechnical Engineering Report (Opus, 2011).

19 Refer to Section 7.9 and Table 7.2 on Page 150, Transmission Gully Project, Assessment of Environmental Effects report, August 2011 (Beca, 2011).

Debris flows

91 The Te Puka Stream and Horokiri Stream valley sections of the route are exposed to debris flow and debris flood events. In concentrated high intensity rainfall events, soil and gravel deposits can be mobilised and flow as a mix of water, mud and gravel. Such events were observed in 2005 and 2006, when SH1 was closed in Paekakariki and the motel along the highway was inundated by the debris flood. Debris flows were also mapped in the tributary gullies crossed by the Main Alignment on the western flank of Te Puka Stream valley.

92 Adequately sized culverts to allow the debris flow to pass below the proposed highway are important to avoid scour damage to the highway from the erosive debris flows, and to ensure security of the route. The culverts need to be large enough to allow for earth moving equipment to enter and clear any mud and gravel deposited in the culverts. **Mr Martell** discusses culvert design further in this evidence.

Projected route security performance

93 I have assessed the resilience of the proposed design concept for the TGP, through an assessment of the likely availability and outage states in two likely earthquake scenarios – a Wellington Fault rupture event and an Ohariu Fault rupture event. This data is presented in map format in **Figures J to M**, **Appendix A**.[20]

94 Under both scenarios, the Availability state maps show that there will be significant slope failures north of Battle Hill, and possibly at the southern end through the Ranui Forest area, that could close parts of the Main Alignment. The remaining sectors of the TGP are expected to remain open for access. The Outage state maps show that limited access can be restored within two weeks (between Linden and Battle Hill), and the section between the SH1 crossing at Paekakariki and Battle Hill is able to be opened within a period of two weeks to three months. This is summarised in Table 2.2 of the AEE report.[21]

95 The availability and outage state maps show how the Project route will perform in very large earthquake events. As noted elsewhere in my evidence, I consider the Project route performance level in such large earthquakes to be appropriate and a significant improvement on the existing situation. The route will perform much better in small to moderate earthquake and storm events, which are more frequent. The Project route is less likely to be closed by small to moderate events given the wide road corridor, and small slope

[20] These maps are reproduced from: Opus (2009). Transmission Gully and Existing SH1 Coastal Route. Route Security in Earthquake Events. Prepared for the New Zealand Transport Agency. June 2009.

[21] Refer to Page 35 of Transmission Gully Project, Assessment of Environmental Effects report, August 2011 (Beca, 2011).

failures are not likely to affect all four or in places six lanes, compared to the two lanes along the present SH1 and SH2 routes through steep terrain.

96 In my view, the TGP route will considerably improve the resilience of access into and out of Wellington, compared to the existing routes.

97 The presence of two routes also improves access into and out of Wellington. Small natural hazard events or even traffic accident events can block one route, but are less likely to close both routes.

EARTHWORKS

98 The majority of the materials from the cuttings for the roads will be rockfill derived from weathered and fractured greywacke sandstone, siltstone and mudstone, which will be good material suitable for the construction of the road embankments. Selected rockfill materials from the less weathered rock will be suitable for the construction of the RSE.

99 Some of the materials from the rock cuttings and rock sources along the Project route may be able to be used for road aggregate and possibly concrete aggregate, subject to appropriate processing, by crushing and screening using mobile crushing plants.

100 The cut platforms and the embankments formed of materials from the rock cuttings will also provide a good subgrade for the road pavement.

101 From an earthworks perspective, the rock fill materials can also be excavated, placed and compacted throughout most of the year, as they can be worked even under wet conditions, except when working in the base of the gullies, where the base materials would include colluvium and alluvium, and with significant water inflows.

102 Exceptions to this are the alluvial materials that will be encountered between Battle Hill Farm Forest Park and the SH 58 interchange, and possibly in the James Cook Drive and interchange areas. These materials will be variable and a significant proportion of these materials will require drying to reduce the moisture contents for use in the embankments, and cut to waste and used as landscaping fill or deposited in disposal sites.

103 The earthworks along this section with alluvial materials would preferably need to be constructed during the drier months of the year. The subgrade along this section may require treatment (undercut or stabilisation) and a thicker road pavement.

104 The section of the Main Alignment between MacKays Crossing and the crossing of the existing SH1 at Paekakariki will be constructed

on peat and soft ground, and will require ground improvement using a combination of undercut and preloading with a surcharge and with vertical geocomposite drains, to reduce post-construction settlements and ensure long term performance of the highway embankment.

GROUNDWATER EFFECTS

105 The earthworks in the rural hilly sections of the TGP route, will involve drainage measures such as sub-horizontal drainage holes, surface drains, sub-soil drains and possibly counterfort drains installed to permanently lower the groundwater pressures in the ground and improve stability. The installation of such drainage measures is common for earthworks, and has been used along SH58 as well as along SH2 between Te Marua and Kaitoke. These have caused no adverse effects on the environment.

106 The lowering of the groundwater in the areas underlain by shallow bedrock north of Battle Hill and in the Ranui Forest, is unlikely to affect the ground surface as the water levels are generally already well below the rural land surface.

107 Where thick soil overburden is present such as between Battle Hill and SH58, the drainage may make the ground surface drier, but because of the generally low permeability, the extent of groundwater level lowering is likely to be localised. Therefore, these groundwater level changes are not likely to cause any material effects, because of the rural nature of the areas.

108 The groundwater is not likely to be affected significantly by the construction of the Project in the flat areas in the vicinity of the proposed crossing of the existing SH1 at Paekakariki and near the Kenepuru Link Road. Construction on soft ground may require the installation of vertical wick drains and ground improvement using vibro-densification or stone columns, but these will not materially affect the existing groundwater levels.

109 The proposed road embankment near the existing KCDC water abstract bores at Paekakariki is unlikely to affect the bores as the water is abstracted from the deeper gravel stratum, which is not likely to be affected by the surface construction.

RESPONSE TO SUBMISSIONS

110 I have read the submissions received which relate to geotechnical engineering and route resilience issues, and now respond to the specific issues raised.

111 **Submission 17** states that a second route provides greater diversity as it provides an alternative route into the capital City,

particularly after major disasters. I concur with the view of the submitter.

112 I also concur with the submitter's observation that the current roads already cross active faults and that this is inevitable in the context of the region, as noted above in my evidence.

113 **Submission 19** requests realignment of the highway about 100 m to the east at a location immediately south of Battle Hill Farm Forest Park. The submitter suggests that because the proposed shift will place the alignment between the previous designation and the proposed alignment, there should be sufficient geological information, and that the maximum cut heights will be much less than the 45 m which were proposed for the previous designation. The Main Alignment has been carefully developed to maximise resilience given the importance of route security for the region, the rugged terrain and the seismicity of the region. The 100 m shift eastwards would increase the height of the cuttings beyond the 25 m to 30 m height proposed for the current alignment. These increased cut heights may reduce the resilience of this section of the highway. While these cuts would be of a similar height to cuttings proposed elsewhere along the Main Alignment, this would increase the quantity of slip materials that would need to be removed to reopen the route, and such reduced resilience should be avoided, where ever possible. The geometrics and landscape (visual impact) issues associated with the realignment requested is addressed by **Mr Mark Edwards** and **Mr Gavin Lister** respectively, in their evidence.

114 **Submission 23** from the Kapiti Coast District Council concerns the lack of a local road connection between MacKays Crossing and Paekakariki, independent of the proposed Transmission Gully route. The submitter argues that the absence of a two kilometre section of local road between Sang Sue corner and MacKays Crossing seriously undermines the resilience of the Transmission Gully route in the event of a significant event on SH1.

115 The Main Alignment in this section is wider than the current SH1, and hence does provide enhanced route resilience compared to the current situation, particularly in the event of a slope failure along the existing steep slope to the east of the route, between about station 800 m and 1300 m. I agree that in principle, an additional local route would provide even greater resilience. However, in the event of an incident on SH1, traffic can still flow on the Transmission Gully Main Alignment route. SH1 traffic north of the incident can still join the TGP route near the Sang Sue corner. In the event of a significant event on the TGP Main Alignment route south of Sang Sue corner, the SH1 traffic can still join the northern section of the TGP route via the on-ramp near Sang Sue corner and head towards MacKays Crossing and further north. However,

joining SH1 south from MacKays Crossing would not be possible without temporary traffic measures being implemented. I note that the more significant vulnerabilities along both routes are to the south of Sang Sue corner, along Paekakariki to Pukerua Bay on the existing SH1 and the Te Puka valley section of the TGP route.

116 **Submission 34** by The Coastal Highway Group opposes the TGP in favour of upgrading the coastal highway. The submitter states that a 1997 study by Beca Carter Hollings and Ferner showed that both the TGP and the Centennial highway (existing coastal SH1 route) could be affected by a major earthquake. Significant changes have been made to the alignment, road form and preliminary design since the 1997 study, and therefore the comparisons in that report are not directly relevant. In any event, however, the 2009 study[22], which the submitted also notes, also confirms that both routes will be affected by a major earthquake. However, as I have explained elsewhere in my evidence the route resilience of the TGP route is significantly better than that of the coastal route.

117 The submitter notes that the events from the Christchurch earthquake need to be taken into consideration and the 2009 study should be revisited. I have been involved in the response and recovery following the Christchurch earthquakes. The geology of the Christchurch area is quite different from that of Wellington. However, significant failures were experienced along the coastal cliffs in the Port Hills area. In my opinion there is no reason at this stage to revisit the results or conclusions of the 2009 report (which I prepared for the NZTA).

118 The submitter also notes that the Project route only provides an alternative to the Linden to Paekakariki section of the western access corridor from Wellington, and the improved security along the TGP route would be of no use if a seismic event closed roads out of Wellington, and particularly Ngauranga and Ngaio Gorges. As stated earlier in my evidence, I have carried out a number of studies to assess the resilience of roads in the Wellington Region, and the resilience of the road network is summarised in a report I prepared in 2008[23]. Based on these studies, it is my opinion that the greatest vulnerabilities for access into and out of Wellington are along SH1 between Linden and Paekakariki, and hence an enhancement of the resilience of that corridor through the alternative TGP route will significantly enhance resilience and access into Wellington after a major earthquake event. I note that there are alternatives to the Ngauranga and Ngaio Gorge roads, and slope failures along Ngauranga Gorge would not necessarily close the State highway for

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22 Transmission Gully and Existing State Highway 1 Coastal Route. Route Security in Earthquake Events. June 2009 (Opus 2009). [http://www.nzta.govt.nz/projects/transmission-gully/docs/route-security.pdf]

23 Opus (2009). Meshing Road Network Lifelines Data for the Wellington Region. March 2009.

a long period of time. I am also aware of strengthening programmes that have been carried out or are currently being designed for sections of these gorge roads.

119 **Submission 55** opposes the TGP on a number of grounds including "construction of a major highway on a fault line", and requests that more time should be spent on considering other alternatives to the construction of a major highway through a challenging geographical area. There is no explanation given for the position taken in this submission.

120 I have addressed the issue of crossing an active fault in earlier sections of my evidence. I am of the opinion that crossing active faults cannot be easily avoided in the context of the Wellington Region, and that with careful focus on route security, the alignment, road form and preliminary design have been enhanced to maximise the resilience of the TGP route.

121 Finally, I note that **submission 66** from The New Zealand Automobile Association Inc supports the Project route, and agrees with the benefits on a number of aspects, including route security in the event of storm or earthquake events.

CONCLUSIONS

122 The Wellington region is likely to be left isolated following a large local earthquake, because of the poor resilience of the existing SH1 (coastal Pukerua Bay to Paekakariki and Plimmerton to Porirua sections) and SH2 (Rimutaka Hill section). This will severely restrict the ability to respond to and recover after such an event.

123 The Wellington region is an area of high seismicity, with steep terrain and a number of active faults. Therefore, the elimination of the hazard from earthquakes is not possible in the region's context. Damage and closure from earthquakes are still possible along the TGP route. However, through careful focus on resilience and route security, an alignment, road form and concept design have been developed to enhance resilience and hence improve the security of the TGP route.

124 Overall, the proposed TGP route will significantly enhance the resilience of the north-western access into and out of Wellington, and improve the security of access into and out of the greater Wellington area, in the event of a large earthquake in the region.

125 I consider it important that the concepts for the earthworks cut and fill and the structures be followed through with focus on resilience and route security during design and construction. An adequate level of geotechnical investigations, design and active surveillance and monitoring during construction is important, to achieve a resilient state highway with good route security performance.

Pathmanathan Brabhaharan (Brabha)
18 November 2011