Before a Board of Inquiry
Basin Bridge Proposal

Under the Resource Management Act 1991 (the Act)

In the matter of a Board of Inquiry appointed under section 149J of the Act to consider the New Zealand Transport Agency's notice of requirement and five resource consent applications for the Basin Bridge Proposal.

Statement of Evidence of Pathmanathan Brabhaharan for the New Zealand Transport Agency (Geotechnical and Earthquake Engineering)
Dated 25 October 2013
STATEMENT OF EVIDENCE OF PATHMANATHAN BRABHAHARAN
FOR THE NEW ZEALAND TRANSPORT AGENCY

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1 Introductions

1.1 My full name is Pathmanathan Brabaharan.

1.2 My evidence is given on behalf of the New Zealand Transport Agency (Transport Agency) in support of the Notice of Requirement (NoR) and the five associated applications for resource consent lodged with the Environmental Protection Authority on 17 June 2013 in relation to the construction, operation and maintenance of the Basin Bridge Project (Project).

Qualifications and Experience

1.3 I am Technical Principal, Geotechnical & Earthquake Engineering, and Infrastructure Resilience at Opus International Consultants Limited (Opus). I am also Resource Group Manager for the Wellington Geotechnical Engineering and Resilience Group, in the Wellington Civil Engineering Team of Opus.

1.4 I have the following qualifications and experience relevant to the evidence I shall give:

a) Bachelor of Science of Engineering with Honours, specialising in Civil Engineering, from the University of Peradeniya, Sri Lanka (1982).

b) Master of Science of Engineering in Foundation Engineering from the University of Birmingham, United Kingdom (1986).

c) Master of Business Administration from Deakin University, Australia (1998).

d) Chartered Professional Engineer in New Zealand.

e) I have 30 years' experience in Geotechnical, Earthquake and Civil Engineering and Risk Management, in New Zealand, United Kingdom, Malaysia, Singapore and Sri Lanka.

f) I have been based in Wellington and have practised in New Zealand since 1989 (over the past 24 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.

g) 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 environments in the Sichuan Province of...
China, as a result of the Richter Magnitude 8 Wenchuan Earthquake in May 2008, and presented findings to the profession.

h) I was engaged by the Transport Agency to carry out field reconnaissance of damage to highways and bridges and to gather and report lessons on geotechnical aspects of the observed performance, following the 2010 Magnitude 7.1 Darfield Earthquake and the 2011 Magnitude 6.3 Christchurch 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.

i) My experience includes a variety of highway projects in the Wellington, Nelson-Marlborough and other Regions, which have involved design and/or construction of large structures and earthworks in geological conditions similar to those encountered at the Basin Bridge site, including:

i The Tunnel-Link project (alluvium and complex groundwater regime) of 1.2 km length between the south portal of the Terrace Tunnel and the west portal of the Mt Victoria Tunnel, for development of the scheme; my role included detailed assessment of the groundwater regime and its interaction with the proposed cut-and-cover tunnel structures, the bridge at the Basin Reserve area and associated retaining walls and earthworks;

ii Wellington Inner City Bypass (alluvium and complex groundwater regime), for development of the scheme, detailed design, construction and maintenance management; my role included detailed assessment of the groundwater regime and its interaction with the road structures, development of solutions to mitigate any risks and monitoring during construction to demonstrate compliance;

iii Mt Victoria Tunnel Strengthening and Duplication (fractured rock), involving strengthening of the portal structures, development of options for duplication of the Mt Victoria Tunnel as part of the Ngauranga to Airport Strategy Study, and peer review of the scoping study for the duplication of the tunnel;

iv Transmission Gully expressway including 29 bridges (sand dunes and inter-dunal peat deposits at the north end, estuarine deposits at State Highway 58, alluvium at the southern end and along the many stream
valleys, and predominantly greywacke rock), for the preliminary
gеotechnical investigations and assessment, scheme assessment,
development of designs for consents, assessment of environmental
effects and preparation and presentation of evidence at the Board of
Inquiry; and subsequently the development of tender design for a PPP
consortium;

v Christchurch Southern Motorway (liquefiable and compressible
alluvium), as reviewer for the scheme development, detailed design and
construction stages;

vi Peka Peka to Otaki Expressway (alluvium, sand and inter-dunal peat
deposits), as lead geotechnical designer, for the scoping and scheme
assessment stages, and preparation and presentation of evidence to
the Board of Inquiry;

vii Newlands Interchange including overbridge (fill, alluvium and rock), as
lead geotechnical designer, for concept, scheme assessment, detailed
design and construction;

viii the Western Link Road including several bridges, between Raumati
South and Waikanae (sand and inter-dunal peat deposits), for the
design and consenting stages;

ix Wellington East Girls College (fractured greywacke rock), seismic
assessment and master planning project, and currently developing
strengthening works at the school.

j) I have also been involved in the seismic assessment and retrofit of bridges
in New Zealand including development of innovative retrofit solutions for
abutments, either as lead geotechnical engineer or peer reviewer, including:

i Thorndon Overbridge (preliminary assessment and then peer review);

ii Auckland Harbour Bridge (detailed seismic assessment peer review);

iii Melling Bridge, Hutt City (detailed assessment and retrofit);

iv Waikanae River Bridge (detailed assessment);

v Paekakariki Overbridge (detailed assessment);

vi Otaki River Bridge (detailed assessment and retrofit);
vii SH3 Cobham Bridge, Wanganui (detailed assessment, and retrofit including ground improvement);

k) I led the earthquake hazard assessment studies, including liquefaction and slope failure hazards for the Wellington region (1992-1995), which resulted in the publication of earthquake hazard maps for the Wellington region. This included the Basin area in which the proposed bridge will be constructed.

l) I have also led a number of studies to assess the resilience and develop risk management strategies for the State highways in the Wellington Region and the local authority road networks in Kapiti Coast, Wellington City, Hutt Valley, Upper Hutt, and Porirua. The resilience of priority roads within the greater Wellington area under earthquake and/or storm conditions has been assessed as part of these studies.

m) I was involved in a study for the Transport Agency to identify critical sections along State Highway 1, State Highway 2 and State Highway 58 that would be affected in a major earthquake in the region, develop emergency response plans and in particular assess the likely time required to reopen the coastal route between Pukerua Bay and Paekakariki.

n) I have advised the Wellington Lifelines Group in the consideration of emergency access following a major earthquake in the region.

1.5 I am a member of a number of relevant associations including:

a) Fellow of the Institution of Professional Engineers New Zealand;

b) New Zealand Society for Earthquake Engineering;

c) New Zealand Society for Risk Management;

d) New Zealand Geotechnical Society, and am affiliated to the International Society for Soil Mechanics and Geotechnical Engineering and the International Society for Rock Mechanics; and

e) Structural Engineering Society.

My role in the Project

1.6 I am familiar with the area the Project relates to and have carried out numerous site visits. I have led geotechnical investigations in the area in 1989-1992 for the Tunnel-Link project and in 2010-2012 for the current Basin Bridge Project. I am
also familiar with the earthquake and geotechnical hazards, having led the seismic hazard studies for the Greater Wellington region including this area. In addition, I led a series of studies to assess the resilience of the road network including state highway and local arterial roads through a study of the road networks in the region.

1.7 I was the author of the Preliminary Geotechnical Appraisal (Opus, 2010\(^1\)) for the Basin Bridge Project, led the geotechnical investigations and assessment in 2011-2012, and contributed to the Geotechnical Engineering section of the Design Philosophy Statement that formed part of the Assessment of Environmental Effects (AEE) lodged in support of the Project (Technical Report 1).

1.8 I provided advice to the Transport Agency in 2012-2013 on the effects of the bridge and its pile construction on the existing groundwater regime.

**Code of Conduct**

1.9 I have read and am familiar with the Code of Conduct for Expert Witnesses in the current Environment Court Practice Note (2011), have complied with it, and will follow the Code when presenting evidence to the Board. I also confirm that the matters addressed in this Statement of Evidence and in Chapter 7(Geotechnical Engineering) of Technical Report 1 are within my area of expertise, except where relying on the opinion or evidence of other witnesses. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

**Scope of Evidence**

1.10 This Statement of Evidence provides the following (the relevant subheading is noted in brackets in each case):

a A summary of my evidence (**Executive Summary**);

b An overview of the key points of Chapter 7 (Geotechnical Engineering) of Technical Report 1 (**Previous Report**);

c Comments on submissions lodged in relation to the Project (**Response to Submissions**); and

d **Conclusions.**

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2 Executive Summary

2.1 The proposed Basin Bridge will be constructed in an area which was previously a low lying swamp and has been investigated to ascertain the ground and groundwater conditions. This has confirmed the loose and soft alluvium deposits to be underlain by medium dense to very dense alluvium and Wellington Greywacke bedrock. The layering of the soil and the topography of the wider area also results in a complex groundwater regime, comprising three aquifers.

2.2 There is potential for liquefaction in the area during moderate to large earthquakes, and consequent subsidence of the ground.

2.3 Ground improvement measures and deep large diameter piled foundations embedded in bedrock or very dense alluvium are proposed, and will provide a robust foundation solution for the Basin Bridge. These solutions will be designed for the current seismicity and earthquake design standards as stipulated in the Transport Agency Bridge Manual.

2.4 The piles are proposed to be constructed using bored piling techniques and not driven piles, and therefore will minimise any disturbance and noise to the urban area. The measures that have been proposed to manage construction through the artesian aquifers present in the area will minimise any effect on these aquifers. Any groundwater changes during construction are not expected to cause more than minor localised subsidence, and are not expected to cause subsidence of the ground sufficient to cause damage to the nearby buildings.

2.5 I recommend that structural conditions surveys including monitoring of any existing cracks and settlement of buildings, and monitoring of groundwater pressures and ground subsidence be carried out as a precautionary measure, and to allay any concerns that the buildings may be affected by the proposed works.

2.6 The Basin Bridge will be designed for a 1 in 2500 year return period earthquake ground shaking, to the current earthquake design standards, and can therefore be expected to perform well in such design earthquakes. The observation of performance of bridges in the Canterbury area indicates that well designed and constructed bridges perform well in large earthquakes.

2.7 The proposed Basin Bridge, together with the proposed second Mt Victoria Tunnel and stabilisation works at the tunnel portals, will enhance resilience of access in Wellington, by providing an alternative to the low lying land below that which may be affected by liquefaction and potential tsunami inundation.
3 Previous Report

3.1 Subject to the contents of this Statement, I confirm the contents of Chapter 7 (Geotechnical Engineering) of Technical Report 1.

Geology of the Project Area

3.2 A key part of my role as the geotechnical advisor to the Project has been to assess the existing geological context for the Project, which has formed the basis of my input to the Project design and my assessment of the environmental effects of the Project. A brief summary of the geology is set out below.

3.3 The Basin Bridge project site is underlain by the following main geological units:

a) Reclamation fill;

b) Late Quaternary Holocene age recent alluvium;

c) Pleistocene age older alluvium;

d) Late Triassic age Wellington Belt Greywacke, which generally comprises sandstone, siltstone and mudstone.

The geological units are shown in a cross section through the area shown on Figure A1 in Annexure1.

3.4 The Basin Reserve area is bound by Mt Cook to the west, and the much higher Mt Victoria to the east. The surrounding hills drain towards the Basin Reserve area. The Basin Reserve area was a low lying swamp prior to the 1850s. The 1855 Wairarapa Earthquake led to a regional uplift of the area, which then led to drainage of the area to the harbour.

3.5 Historical maps by Bastings (1936) and the New Zealand Company (c.1840) indicate a number of small streams crossing the area. These streams are now culverted.

Ground and Groundwater Conditions

3.6 The ground and groundwater conditions in the Basin Bridge area have been characterised by geotechnical investigations carried out in 1990 and 2011-2012. The generalised stratigraphy and ground conditions are summarised in Table 1.
Table 1 – Ground Conditions

<table>
<thead>
<tr>
<th>Depths</th>
<th>Description of Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1.5 m to 3.5 m</td>
<td><strong>Existing Fill</strong>&lt;br&gt;Generally silty and sandy gravels.</td>
</tr>
<tr>
<td>2 Typically 3 m to 7 m, and up to 9 m.</td>
<td><strong>Recent Alluvium</strong>&lt;br&gt;Interbedded loose to medium dense sandy gravel, gravelly sand and silty sand with firm to stiff silt and organic silt layers.</td>
</tr>
<tr>
<td>3 9 m to up to 40 m max penetrated.</td>
<td><strong>Older Alluvium</strong>&lt;br&gt;Interbedded medium dense to very dense sand, gravels and silts with some organic silt layers.</td>
</tr>
<tr>
<td>4 11 m to 45 m penetrated</td>
<td><strong>Bedrock</strong>&lt;br&gt;Highly to completely weathered sandstone, siltstone and mudstone, extremely weak to moderately strong at depths greater than 35 m, with crushed and shattered zones.</td>
</tr>
</tbody>
</table>

3.7 The stratigraphy and ground conditions summarised above and the interbedded layers of fine grained and lower permeability clay / silt layers have led to a complex groundwater regime under the Basin Reserve area, including sub-artesian and artesian groundwater pressures. Artesian groundwater is where the groundwater pressures in an aquifer at depth are equivalent to a hydraulic head above the existing ground level. Sub-artesian pressures are where the groundwater pressures in an aquifer at depth have a higher head than the shallower groundwater level, but lower than the existing ground level.

3.8 I have broadly characterised the groundwater regime into three aquifers – shallow, middle and deep aquifers, as shown on Figure A2 in Annexure 1. The lower permeability silt and clay layers are not necessarily continuous and the aquifers are likely to be ‘leaky’.

a) The shallow aquifer is in the Holocene Age deposits and the upper Pleistocene age deposits, and extends down to depths of about 12 m. This is an unconfined aquifer, and the groundwater level is typically at the ground surface. The ground conditions in this aquifer are typically loose to medium dense sand, silt and gravels with soft to firm silty clay layers.

b) The ‘Middle Aquifer’ is generally between depths of 15 m and 25 m below ground surface. This is a confined aquifer separated from the ‘Shallow’ and ‘Deep’ aquifers by low permeability clay and silt layers, which may not be continuous. The ground conditions are typically medium dense to dense silt, sand and gravel, with stiff clay / silt layers of Pleistocene Age. The
groundwater level in this aquifer is artesian, with a groundwater head of between 6 m and 9 m above ground surface level.

c) The ‘Deep Aquifer’ comprises the upper part of the weathered bedrock sequence and the ground immediately overlying the bedrock. The aquifer is characterised by dense gravels, sand and silt and weathered bedrock. The artesian groundwater level in this aquifer is typically about 3 m to 6 m above ground level.

3.9 More detailed descriptions of the aquifers and groundwater conditions are given in the evidence of Dr McConchie on Groundwater issues.

Seismicity

3.10 The Basin Bridge is located in the Wellington Region, in an area of high seismicity in New Zealand. The region has a number of active faults and a subduction zone which are capable of producing large Richter Magnitude 7.0 to 8.4 earthquakes. The closest active fault with the lowest recurrence interval is the Wellington Fault which runs along the north-western margin of Wellington City Centre, and is located at a distance of about 2.5 km from the Basin Bridge. This fault is capable of producing Richter Magnitude 7.6 earthquakes at an average recurrence interval of about 800 years.

3.11 The actual ground shaking from earthquakes at any site is dependent on the magnitude of the earthquake as well as distance from the epicentre, direction of fault rupture and the ground conditions in the area. The probabilistic seismic hazard at any site is assessed by considering the various sources of earthquakes, and is derived from the National Probabilistic Seismic Hazard Model for New Zealand by GNS Science, and is the basis of the seismic hazards presented in the Bridge Manual 3rd edition (NZTA, 2013)\(^2\).

3.12 The Basin Bridge and its foundations will be designed for earthquake ground shaking with a 2,500 year recurrence interval given the importance of this bridge in accordance with the Bridge Manual. Given the value and importance of the bridge, a site specific seismic hazard study will be carried out for the bridge site to specifically assess the seismic hazard at the bridge site prior to detailed design.

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**Earthquake Induced Hazards**

3.13 Slope Failure Hazard: I led an earthquake induced slope failure hazard study for the region which was published by Wellington Regional Council (1995)\(^3\). The study indicated high slope failure susceptibility at the Mt Victoria Tunnel portal areas in a Wellington Fault rupture earthquake. The west portal of the Mt Victoria Tunnel is located some 200 m away from the eastern abutment of the Basin Bridge, and hence the slope failures will not affect the bridge. The bridge itself is located on flat and gently sloping ground that is not prone to slope failure.

3.14 Liquefaction Hazard: I also led a study of the liquefaction hazard in the region, which was published by the Wellington Regional Council (1993)\(^4\). This indicated a moderate liquefaction ground damage potential at the Basin Bridge site, with a likely subsidence of the ground of the order of 100 mm to 250 mm in a Wellington Fault rupture earthquake event, see Illustration 1 for liquefaction ground damage zones.

![Illustration 1 Liquefaction Hazard](after Wellington Regional Council, 1993)

3.15 This order of subsidence of the ground has been confirmed by a detailed assessment using the geotechnical investigations for the Basin Bridge project. The detailed liquefaction assessment indicates that the layers of soil with a

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\(^3\) Wellington Regional Council (1995). Earthquake induced slope failure hazard map 1:40,000 with notes. 1st Ed. Wellington, New Zealand.

potential for liquefaction are highly variable across the site and with depth. Most of the ground that is susceptible to liquefaction is within the upper 10 m depth below ground surface, but there are localised layers up to a depth 23 m to 30 m that may liquefy.

3.16 Earthquake induced liquefaction will have the following effects on the Basin Bridge:

a) Subsidence of the ground due to the liquefied layers undergoing a reduction in volume following liquefaction;

b) Downdrag forces on the piles through liquefaction resistant ground layers overlying liquefied layers undergoing a reduction in volume and hence downward movement of the ground;

c) Loss or reduction in the lateral restraint provided by the ground to the piles due to liquefaction and consequent loss or substantial reduction of strength and stiffness of the liquefied soil;

d) Lateral spreading of the abutment approaches due to liquefaction of the ground below.

3.17 Given the potential effects of liquefaction, the preliminary design of the bridge has taken into account this hazard, as discussed below.

Deep Piled Foundations

3.18 The bridge will be supported by deep, large diameter (900 mm to 1200 mm or larger) bored piles, founded at depths of 30 m to 36 m in the bedrock, or where the bedrock is deeper than 35 m founded in dense to very dense gravel. The piles will be founded well below the potentially liquefiable layers of ground.

3.19 Large diameter bored piles are proposed instead of driven piles, because:

a) Bored piles will be less noisy to construct in a busy urban environment;

b) The large diameter bored piles can be constructed through intermediate dense layers and founded in bedrock or dense to very dense gravel, below potentially liquefiable layers of the ground;

c) The large diameter piles can be designed to resist any additional pile downdrag forces through the fill and any liquefaction resistant layers that overlie the liquefiable layers that may compress following liquefaction.
d) The large diameter piles will have adequate structural capacity to resist the lateral loads and limit displacements.

e) The piles will have permanent steel casing through the upper liquefiable layers which will provide additional resilience against ground deformations, in variable ground conditions with liquefiable layers.

f) Bored piles can be constructed through artesian aquifers with appropriate precautions, and avoid leakage of groundwater along the pile-soil interface.

3.20 The bridge substructure will also be designed for the lateral seismic loads from the bridge, taking into account the significant loss of lateral restraint and strength due to liquefaction of the soils. The fact that the deeper layers of soil susceptible to liquefaction are small layers separated by liquefaction resistant dense gravelly materials means that these layers will have little effect on the lateral capacity of the piles.

3.21 The piles at the abutments would be sleeved through the approach embankments using oversize casing to prevent lateral loads on the pile due to displacement of the embankments during earthquakes.

Ground Improvement

3.22 Liquefaction could lead to subsidence and lateral spreading of the ground at the bridge abutments and hence damage to the approach embankments and the bridge abutments. It is proposed that ground improvement may comprise partial undercut and removal of the liquefiable soils and replacement with compacted dense gravel materials, and deeper ground improvement where the liquefaction extends to a greater depth than about 3 m at these locations.

3.23 Deeper ground improvement may be required to a depth of up to 16 m, and may comprise techniques such as stone columns, deep soil mixing or continuous flight auger piles. The ground improvement would be designed to provide stability to the abutment and approach embankments so that the bridge is not damaged by liquefaction effects. I have used similar approaches to strengthen bridges in areas with significant liquefaction and lateral spreading hazard, such as the State Highway 3 Cobham Bridge in Wanganui (Brabhaharan et al, 2009)\textsuperscript{5}, and the Christchurch Southern Motorway, where the abutments, protected by ground improvement and under construction, survived the 2010-2011 earthquakes.

3.24 Some residual displacement of the embankments can be accommodated through sleeving the piles supporting the bridge as discussed above.

3.25 Some residual subsidence and deformation of the approaches are possible in large earthquakes due to lateral displacement of the embankment or liquefaction of the ground below. However, this can be readily and quickly repaired by topping up the approach embankment with fill materials to restore access. This would ensure that the bridge and its approaches would provide resilience of access in the event of a large earthquake (resilience is the ability to quickly recover after events).

3.26 There are also some compressible silt and clay soil layers present below the abutment and approach embankments. Preloading by construction of the approach embankments early, together with some additional surcharge fill, are also proposed to make settlement happen early during construction, so that the post-construction settlement of the embankments will be small.

Retaining Walls

3.27 Retaining walls are required to provide support to the approach embankments and the bridge abutments. Reinforced soil walls and reinforced soil embankments are proposed. These are flexible forms of construction that can accommodate some subsidence of the ground due to liquefaction and lateral displacement of the walls during large earthquakes.

3.28 These forms of retaining walls performed very well in the 2010-2011 Canterbury earthquakes (Wood and Asbey-Palmer, 2013), as well as in other overseas earthquakes.

Foundation Construction Effects

3.29 There are a number of potential solutions to manage groundwater at the pile locations during construction and in the long term. The exact method of construction will be confirmed through detailed design. Particular measures that could be considered are:

a) Use of telescopic casing for construction of the piles. A larger diameter casing could be installed down to the clay / silt layers between the upper and middle aquifers. Then a smaller diameter casing could be installed below this depth to the required founding depth. A further reduction in pile diameter

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at the interface between the middle and deep aquifer could be considered. Varying the size of the piles would mitigate the risk of leakage along the pile-soil interface.

b) Use of temporary depressurising boreholes drilled immediately in advance of drilling the main pile. This will allow the groundwater response to be controlled and monitored. The main pile could then be excavated under balanced groundwater conditions.

c) A contingency measure if leakage of artesian groundwater occurs along the pile casing – soil interface would be to drill and grout the interface from ground surface down to the base of the shallow aquifer, using tube-a-manchette techniques.

3.30 Construction of the bored piles may lead to some localised effects on the groundwater regime, due to lowering of the groundwater levels during construction. This is likely to be localised as further explained in the evidence of Dr McConchie. Such localised changes for a short duration of a few days to two weeks are not likely to cause significant ground subsidence due to the lower groundwater level, and hence unlikely to cause damage to any adjacent buildings.

3.31 Even in the very unlikely scenario of a long term permanent reduction in the groundwater levels in the middle aquifer by 5 m, this permanent reduction is assessed to give a subsidence of only 25 mm at the Grandstand Apartments, and less than 10 mm at the Basin Reserve Grandstand, Mitsubishi Motors, St Joseph's Church and at the shops along Ellice Street. Such subsidence is not expected to cause an angular distortion of the buildings exceeding 1/400, sufficient to cause damage.

3.32 These assessments are consistent with the minimum subsidence of the ground and associated settlement of buildings which I monitored adjacent to the trench structure at the Wellington Inner City Bypass, where the groundwater level was drawn down several metres for 12-18 months during construction. In that case the ground was broadly similar Holocene and Pleistocene deposits as are present in the middle and deep aquifers in the Basin Reserve area.

3.33 Given the lowering of the groundwater level is actually expected to be localised and of short duration, I conclude that the buildings will not be damaged due to groundwater changes and associated subsidence of the ground during piling. Therefore the effects of pile construction are no more than minor.
It would however be prudent to monitor settlement and groundwater pressures in the area, and carry out pre-construction structural surveys of key buildings in the vicinity of the bridge foundations. This would include the recording of any existing cracks in the buildings, and their monitoring during and at the end of construction. This would be appropriate to allay the perception of possible effects to the buildings due to construction activities, piling, vibration etc.

4 Response to Submissions

4.1 In this section, I address the key geotechnical and earthquake issues raised in the submissions.

Earthquake Performance

4.2 A number of submitters (for example, Ms Alana Bowman #103419) have expressed their concern regarding the earthquake performance of flyovers, and point to elevated bridge structures that collapsed in overseas earthquakes as recently as the 1990s. Some submitters (for example, Ms Rachel MacFarlane #103511) have pointed out that the Basin Bridge is to be built on land which used to be a swamp, and are concerned about the effect of this on the seismic performance of the bridge.

4.3 This is an understandable concern given that collapses of large elevated structures in overseas earthquakes have been highlighted by the media, and the recent heightened awareness on the effects of earthquakes after the Canterbury earthquakes of 2010-2011 and the recent (July and August 2013) Cook Strait and Lake Grassmere earthquakes which also were experienced in Wellington.

4.4 Engineering of structures and in particular infrastructure to be resistant to earthquakes has only developed over the past century, and in particular over the past four decades. It is therefore inevitable that there are structures which were designed and constructed in an era when the earthquake performance of such structures was less well understood. Some of these were damaged severely and some collapsed when earthquakes happened. That is why the Transport Agency has an ongoing programme of assessing existing older highway structures built before modern bridge design standards were developed, and strengthening them to perform better in earthquakes. An example is the Thorndon Overbridge – an elevated structure in Wellington – which was strengthened to avoid collapse.

4.5 The effect of the Canterbury earthquakes on Christchurch city’s built environment is no exception. The older parts of the built environment in particular, built largely
before modern earthquake design standards were developed, performed poorly in the earthquakes.

4.6 Earthquake engineering and earthquake resistant design continue to evolve and recent highway structures have performed well in earthquakes.

4.7 I was part of a three person study team engaged by the Transport Agency to look at the performance of highway structures after the September 2010 and February 2011 earthquakes in Canterbury to bring back learnings to the design of new structures and assessment and strengthening of existing structures. The bridge structures along the state highways generally performed well. Where structures were damaged, most of the severe damage was attributable to liquefaction of the ground and consequent lateral spreading. These bridges were designed and built when the effects of liquefaction on bridges were not well understood and therefore had not been designed for. There was one bridge, the Moorhouse Avenue Overbridge, which suffered damage to its superstructure, without significant lateral spreading associated with liquefaction, but this was designed and built in the 1960s.

4.8 An example of a large concrete bridge that performed well in an area subject to severe earthquake shaking from the 2010 – 2011 Canterbury Earthquakes is the Port Hills Overpass Bridges shown in Illustration 2. This photograph was taken in August 2011, after the September 2010, February 2011 and June 2011 earthquake events when this area is assessed to have experienced peak ground accelerations of 0.3g to 1.3g, which is similar or larger than what would be expected at the Basin Bridge site in a Wellington Fault earthquake in Wellington.

Illustration 2 – Port Hills Overpass Bridges after the Canterbury Earthquakes

4.9 I have been involved in the design and construction of many highway bridges, some on liquefiable ground, including the recently completed highway bridges on the Christchurch Southern Motorway, which were designed to withstand earthquake loads including liquefaction effects. Those parts that had been built at
the time of the earthquake performed well in the Canterbury earthquakes. I continue to be involved in the reconstruction of bridges damaged in the Canterbury earthquakes.

4.10 The Transport Agency continues to upgrade its seismic design standards. These standards have recently been upgraded and issued as the 3rd edition of the Bridge Manual in 2013, and the Basin Bridge will be designed to this current standard.

4.11 The Transport Agency Bridge Manual requires designers to take the ground conditions into consideration in assessing the expected intensity of ground shaking, and assess and design for conditions such as those that could lead to liquefaction. As discussed in paragraphs 3.6 and 3.15 in my evidence, the ground conditions at the Basin Bridge site have been assessed by carrying out ground investigations including boreholes to over 45 m depth and other tests. These have helped us characterise the ground conditions in this formerly swamp area, and develop measures to perform in the expected large earthquakes in the region.

4.12 As explained in my evidence, this includes proposed measures such as large diameter piles extending to greater than 30 m depth into rock or dense ground below any weak soils susceptible to liquefaction in earthquakes. Ground improvement is proposed at the abutments to mitigate against damage from liquefaction of the ground.

4.13 The Bridge Manual requires the bridge to be designed for earthquake ground shaking with a 2,500 year return period, and in addition to not collapse in earthquakes of 1.5 times this level of ground shaking. The bridge superstructure will be designed and built to current design standards, and the preliminary design has been developed to ensure that the bridge structure will perform when subjected to earthquake shaking from large earthquakes in the region.

4.14 I would therefore expect the Basin Bridge, when designed and built to current standards, to perform well in the design level earthquakes expected in Wellington, despite the presence of poor soils in an area which was once a swamp.

4.15 I trust the above discussion satisfies the concern raised by Ms Margaret Peebles (#103427), that earthquake risk has not been adequately considered.

4.16 Kara Lipski (#103377) raises the fact that Wellington was raised in the 1855 Wairarapa Earthquake, and could very well subside in a Wellington Fault event. I
do understand that this was the case in 1855 and the larger area could go down in a Wellington Fault earthquake. In such a scenario, the Basin Bridge will provide a more reliable connection as it provides access from Mt Cook to Mt Victoria tunnel, even if the basin area below becomes swamplier due to its depression below groundwater levels. I would also note that the Basin Bridge is also likely to provide access even if the basin area is inundated by a large tsunami or seiche as a consequence of a local earthquake, because it is elevated well above the low ground level in the Basin area.

**Unstable Terrain**

4.17 One of the submitters, Ms Helen Corrigan (#103406), expresses her view that the proposed Basin Bridge would be built on ‘unstable terrain’. She does not explain why she considered the area to be ‘unstable terrain’. Unstable terrain is generally used to describe areas prone to slope instability hazards.

4.18 As I have noted in Paragraph 3.13 of my evidence, I led a study of the earthquake induced slope failure hazards which was published by Wellington Regional Council (1995). The area is generally flat and is not prone to slope failure hazards even in earthquakes. The Mt Victoria Portal is prone to slope failure in earthquakes and this is at least 200 m from the eastern abutment of the proposed Basin Bridge, and is not expected to be affected by those failures. As noted above, the nature of the ground including the hazard of liquefaction has been investigated and assessed, and foundation measures are proposed to deal with these conditions as discussed in my evidence.

**Resilience of Access**

4.19 Ms Hayley Robinson (#103425) raises an important issue regarding the resilience of access after a major earthquake event. She correctly points out that a collapsed bridge would take a much longer time to reconstruct after a major earthquake, compared to an at-grade road. She also correctly points out the importance of access after a major earthquake event.

4.20 We do live in a hazardous environment, with Wellington being prone to earthquakes, and we have to design our infrastructure to perform well in large earthquakes and similar hazard events. In my opinion, the Basin Bridge, designed and built to current earthquake design standards as defined by the Bridge Manual and as proposed in Technical Report 1 will perform well, and therefore provide good resilience after a design level earthquake. This bridge together with the proposed second Mt Victoria Tunnel and the stabilisation
measures that are being considered by the Transport Agency for the Mt Victoria Tunnel would provide a resilient access route from the Hataitai side into the City.

4.21 From my study of the resilience of the road network in Wellington, I also consider that there is an alternative route through Newtown that would be quickly available in the event of closure of the route as a consequence of slips closing the road at the Mt Victoria tunnel portals, rather than because of a collapse to the Basin Bridge.

Seismic Damage to Grandstand Apartments

4.22 Mr Robbie Selwyn (#103351) expresses his concern about seismic damage to the ground floor of the Grandstand Apartments during construction. I am unaware of the earthquake vulnerability of the Grandstand Apartments building itself, but agree that it is important for the Transport Agency to ensure that the apartments are not affected by the bridge construction works. The Grandstand Apartments Body Corporate is to be included in the Community Reference Group to be established under proposed condition DC6 and will have input to the Construction Environmental Management Plan and other subsidiary plans in accordance with that proposed condition.

4.23 I also agree that it is prudent that the Transport Agency carries out structural building surveys before and after construction of the Basin Bridge, and if necessary at times during construction, given the proximity of the building to the bridge construction works. This is discussed in paragraph 3.34 of my evidence, and addressed in proposed condition DC 21.

5 Conclusion

5.1 The proposed Basin Bridge will be constructed in an area which was previously a low lying swamp and has been investigated to ascertain the ground and groundwater conditions. This has confirmed the loose and soft alluvium deposits to be underlain by medium dense to very dense alluvium and Wellington Greywacke bedrock. The layering of the soil and the topography of the wider area also result in a complex groundwater regime, comprising three aquifers. There is also a potential for liquefaction in the area during moderate to large earthquakes.

5.2 The proposed ground improvement measures and the deep large diameter piled foundations embedded in bedrock or very dense alluvium will provide a robust foundation solution for the Basin Bridge. These solutions will be designed for current seismicity and earthquake design standards as stipulated in the Transport Agency Bridge Manual.
5.3 The Basin Bridge will be designed for a 1 in 2500 year return period earthquake ground shaking, to the current earthquake design standards, and can therefore be expected to perform well in such design earthquakes. The observation of performance of bridges in the Canterbury area indicates that well designed and constructed bridges perform well in large earthquakes.

5.4 The piles are proposed to be constructed using bored piling techniques and not driven piles, which will minimise any disturbance and noise to the urban area. The measures that have been proposed to manage construction through the artesian aquifers present in the area will minimise any effect on these aquifers. Any groundwater changes during construction are not expected to cause more than minor localised subsidence, and are not expected to cause subsidence of the ground sufficient to cause damage to nearby buildings.

5.5 The proposed Basin Bridge, together with the proposed second Mt Victoria Tunnel and stabilisation works at the tunnel portals, will enhance resilience of access in Wellington, by providing an alternative to the low lying land below, that may be affected by liquefaction and potential tsunami inundation.

Dated 25 October 2013

[Signature]
Pathmanathan Brabaharan
Annexure 1