City Rail Link

Structural Engineer

Technical Expert Report

Structural Review: Vibration Effects, Settlement and Ground Movement
(City Rail Link Notice of Requirement)

August 2012

PLEASE NOTE:

This document supports and should be read in conjunction with the City Rail Link Noise and Vibration Assessment and Built Heritage Assessment which support the CRL Notice of Requirement Assessment of Environmental Effects.

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Technical Response Revision History

Revision Nº	Prepared By	Description	Date
0	E C Stevenson	Initial Draft	**30 March 2012**
1	E C Stevenson	2nd Draft	**8 June 2012**
2	E C Stevenson	3rd Draft for Review	**2 July 2012**
3	E C Stevenson	Revision	**20 July 2012**
4	E C Stevenson	Issue for comments	**30 July 2012**
5	E C Stevenson	Final Issue	**13 August 2012**
6	E C Stevenson	Final Issue (removal of NoR 7, optimisation of NoR 6)	**10 December 2012**

Technical Report Review and Acceptance

Action	Name	Signed	Date
Prepared by	E C Stevenson		**13 August 2012**
Reviewed by	N W Lea		**13 August 2012**
Approved by	Bill Newns		**13 August 2012**
on behalf of	**Aurecon New Zealand Limited**		

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Appendices

Glossary of Terms

Term / Acronym	Meaning
AEE	Assessment of Effects on the Environment
AT	Auckland Transport
APB&B	Collaboration between AECOM, Parsons Brinckerhoff, Beca and Hassell
CDR	Concept Design Report
CRL	City Rail Link
EMF	Environmental Management Framework
EMP	Environmental Management Plan
MDA	Marshall Day Acoustics
NAL	North Auckland Line
NoR	Notice of Requirement
PPV	Peak Particle Velocity. For Peak Particle Velocity (PPV) is the measure of the vibration attitude, zero to maximum. Used for building structural damage assessment.
Resonance	When a forcing frequency is the same as a resonant frequency of the structure, the structure is said to be in resonance.
RMA	Resource Management Act 1991
N&V Report	City Rail Link Noise and Vibration Report prepared by Marshall Day Acoustics.
BH Report	Built Heritage Technical Expert Report by Salmond Reed Architects
Strata (designation)	Designation of land layer between the ground surface and the sub-strata designation. This starts at a nominated distance below the surface and extends down to meet the sub-strata designation (the tunnel envelope)
Sub-strata (designation)	Designation of land starting below the strata designation to the centre of the earth (provides for the rail tunnels)
Surface (designation)	Designation of the ground surface (including air space above the land below to the centre of the earth).
TBM	Tunnel Boring Machine

1 Introduction

Auckland Transport requires the expert advice of a Structural Engineer to assist with analysing the potential effects from the construction and operation of the City Rail Link (CRL) in relation to the Notice of Requirement (NoR) to designate the alignment and station locations.

This report provides a technical assessment of the potential effects in relation to the NoR of ground borne vibration and ground settlement associated with the CRL construction upon the built environment along and adjacent to the CRL corridor.

Assessment of the potentially induced strains in existing buildings and structures have been made in accordance with industry practice and in view of the typical building stock influenced by the tunnel construction. It is considered that the settlement affects along the tunnel alignment are generally less than minor in terms of potential structural damage (i.e. of a superficial extent). It is expected that further development of the geotechnical models, refinement of the design and construction methods and detailed assessment of the vulnerability of existing buildings and structures may further limit the potential settlement effects assessed herein and further reduce the influence zone of the tunnels and cut and cover excavations.

2 Project Description

The City Rail Link (CRL) is a 3.4km underground passenger railway (including two tracks and up to three underground stations) running between Britomart Station and the North Auckland Line (NAL) in the vicinity of the existing Mount Eden Station. The CRL also requires an additional 850m of modifications within the NAL. For ease of reference in this report, the stations included in the CRL NoR have been temporarily named Aotea Station, Karangahape Station and Newton Station. The stations will be formally named in the future.

A fuller description of the CRL is provided in the Assessment of Environmental Effects (AEE) which supports Notices of Requirement (NoR) and the Concept Design Report[1].

This Technical Report – Structural Engineer supports and should be read in conjunction with both the "City Rail Link Noise and Vibration Assessment Report" (N&V Report) dated August 2012 prepared by Marshall Day Acoustics (MDA)[2] and the "Built Heritage Technical Expert Report" (BH Report) dated August 2012 prepared by Salmon Reed Architects (SRA)[3]. Both of these reports are appendices to the AEE which supports NoR to be served by Auckland Transport on Auckland Council to designate the CRL for future construction, operation and maintenance. The NoR covers surface land (surface), land only below surface (sub strata), and protection designations (strata) within the Auckland City District Plan (both Isthmus and Central Area Sections).

Aurecon confirms that the content of this report has been written with reference to the Key Project Parameters set out in the Concept Design Report.

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[1] 2012 Concept Design Report;

[2] CRL Noise and Vibration Assessment

[3] CRL Built Heritage Technical Expert Report

3 Limitations of Study

This report has relied on the available project information to date and other existing documentation, including the Noise and Vibration Assessment Report[4], Built Heritage Technical Expert Report[5], Concept Design Report and previous project studies. Reliance has been placed on the accuracy and veracity of the documents made available and referenced within this study. The study is limited to desktop research and walking visual surveys (exterior only) of representative buildings along the proposed route. Detailed reviews of the construction and condition of existing buildings and detailed assessments of risks and mitigation options for individual properties do not form part of this assessment. This detailed work will inform part of the further design and construction phase and site specific mitigation will be addressed in the Environmental Management Plan (EMP) as outlined in the Environmental Management Framework (EMF) in the Assessment of Environmental Effects[6].

The study undertaken and the resulting report on the assessment of vibration and settlement effects is general in nature and concentrates on assessment of risk of damage to the general receiver types rather than individual buildings.

[2] CRL Noise and Vibration Assessment
[5] CRL Built Heritage Technical Expert Report
[6] CRL Environmental Management Framework

4 Purpose of this Report

It has been identified that existing buildings, within the construction vibration threshold contours relating to the appropriate category as identified in the N & V Report[7] may be at risk of sustaining damage from vibration during construction and operation of the CRL. It is noted in the N&V Report however the damage criteria from DIN 4150-3:1999 are conservative and the anticipated effects should be limited to superficial damage such as cracking plaster, lengthening of existing cracks in brickwork etc.”[8]. In addition, existing buildings are also potentially at risk from ground settlement and movement during its construction. As such this report, using information from the vibration and heritage technical experts and from the Auckland CRL Principal Advisors, addresses building structures along the CRL corridor that may be adversely affected by vibration and settlement effects and undertakes a “high level” or preliminary assessment of the potential risk of structural damage to these buildings. Settlement caused by consolidation of soils due to groundwater drawdown or diversion is not explicitly covered in this report. It is expected that this will be comprehensively assessed as part of future resource consents.

[7] CRL Noise and Vibration Assessment

[8] CRL Noise and Vibration Assessment (page 25)

5 Existing Environment

The existing built environment along and adjacent the CRL corridor has been identified in the N & V Report.

In summary the types of buildings encountered along and adjacent to the CRL route are many and disparate. They range from modern multi-storey piled structures to low-rise heritage brick masonry buildings on shallow foundations. Building use comprises a mix of residential, historic, religious, entertainment, commercial and retail.

Site inspections comprising walking visual surveys along the CRL alignment were undertaken over a number of days during April to June 2012, with visits to certain locations with AT and other experts to observe, identify and discuss matters relating to the CRL.

6 Vibration Assessment Methodology

6.1 Vibration Assessments

Assessment of vibration effects of this project have been undertaken by MDA and are relied upon in this assessment. Reference is to be made to the N&V report[9] for details of the vibration performance criteria adopted for the project, during both construction and operational phases, and the methodology of assessing the effects of vibration.

The N&V report notes *that "The risk of building damage exists primarily during the construction phase because the machinery involved… deliver more energy into the ground… than a train, and are often in closer proximity to receivers"*[10].

It also identifies that the proposed performance standards and target vibration criteria or limits relating to train operation are "*an order of magnitude below the most stringent building damage criterion* (applicable to the construction stage)…, *so compliance with the limits….indicates there is no risk of vibration induced building damage from operation of the CRL"*[11].

Consequently assessment of the risk of damage to buildings along and adjacent the CRL corridor in this report considers only the impact of vibration from the construction phase of the project. Damage due to operational vibration has not been addressed in this report as it is not considered a significant effect and is adequately addressed through compliance with the targeted operational vibration criterion as outlined in the N&V report.

6.2 Structural Damage Vibration Impact Criteria

The German standard DIN 4150 "Structural Vibration Part 3: Effects of Vibration on Structures"[12] has been adopted by MDA to address building damage risk in their N & V report. Reference shall be made to this report for further details.

The key criteria of DIN 4150-3:1999 (Table 1 and 3 of the standard) are listed below. The criteria are expressed as peak particle velocities (PPV) in mm/second.

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[9] CRL Noise and Vibration Assessment

[10] CRL Noise and Vibration Assessment (page 12)

[11] CRL Noise and Vibration Assessment(page 16)

[12] DIN 4150-3 1992 "Structural Vibration Part 3: Effects of Vibration on Structures"

Table 6.2.1 - DIN 4150.3: Table 1: Guideline values for vibration velocity to be used when evaluating the effects of long-term vibration on structures.

Type of Structure	Guideline values for Peak Particle Velocity (PPV) in mm/s			
	Vibration at the foundation at a frequency of:			**Vibration at horizontal plane of highest floor at all frequencies**
	1Hz to 10Hz	**10Hz to 50Hz**	**50Hz to 100Hz**	
Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20mm/s at 10Hz to 40mm/s at 50Hz	40mm/s at 50Hz to 50mm/s at 100Hz	40mm/s
Dwellings and buildings of similar design and/or occupancy	5	5mm/s at 10Hz to 15mm/s at 50Hz	15mm/s at 50Hz to 20mm/s at 100Hz	15mm/s
Type of Structure	**Guideline values for Peak Particle Velocity (PPV) in mm/s**			
	Vibration at the foundation at a frequency of:			**Vibration at horizontal plane of highest floor at all frequencies**
	1Hz to 10Hz	**10Hz to 50Hz**	**50Hz to 100Hz**	
Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	3	3mm/s at 10Hz to 8mm/s at 50Hz	8mm/s at 50Hz to 10mm/s at 100Hz	8mm/s

Table 6.2.2 - DIN 4150.3: Table 3 - Guideline values for vibration velocity to be used when evaluating the effects of long-term vibration on structures.

Type of Structure	Guideline values for Peak Particle Velocity (PPV) in mm/s in horizontal plane of highest floor at all frequencies
Buildings used for commercial purposes, industrial buildings, and buildings of similar design	10
Dwellings and buildings of similar design and/or occupancy	5
Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	2.5

The most relevant criteria in this standard which have been adopted by MDA in their assessments are the long-term vibration limits of DIN 4150-3 Table 3, as the majority of the CRL construction vibration activities would be classed as long term in accordance with the definition in the standard.

DIN 4150:3 states that: "*Experience has shown that if these values are complied with, damage that reduces the serviceability of the building will not occur. If damage nevertheless occurs, it is to be assumed that other causes are responsible".*

DIN 4150:3 also states that "*exceeding the values above does not necessarily lead to damage. Should these values be significantly exceeded, however, further investigations are necessary".*

In practice even cosmetic damage such as the forming of cracks does not always occur from typical construction activities below 15mm/s. The British Standard BS 7385 -2 1993 "Evaluation and Measurement for Vibration in Buildings - Part 2: Guide to Damage Levels from Ground borne Vibration"[13] suggests that the probability of damage tends towards zero at 12.5mm/s PPV.

[13] BS 7385 -2 1993 "Evaluation and Measurement for Vibration in Buildings- Part 2: Guide to Damage Levels from Groundborne Vibration"

6.3 Adjustment Factors

The criteria of Table 3 of DIN 4150-3 are applicable to the upper floors of a building and not necessarily to ground borne vibration at foundation level. The building structure will have some effect on the level of vibration that propagates up through a building.

Ground vibration entering building foundations is dependent on the coupling of the building to the soil. Coupling losses can usually be expected. The general rule is the heavier the building construction the greater the coupling loss or reduction in vibration entering a building.

Vibration generally reduces in level as it propagates through a building, with dispersion and attenuation of the driving vibration energy as it dissipates through the building. Counteracting this, resonance of the building structure, particularly the floors, will cause some amplification of the vibration. The amplification will vary greatly depending on the type of construction. It is dependent on both the frequency spectrum of the vibration and the natural frequency of components of the building structure.

For the purpose of assessing the impact of vibration on existing buildings and developing a reasonable complete inventory of vibration impacted buildings, the criteria of Table 3 of DIN 4150-3 have been adopted by MDA as that appropriate to ground-borne vibration at building foundation level. This is considered a reasonable, if not conservative approach, for a general assessment of vibrations effects. These threshold criteria are similar to recommendations of FTA-VA-90-1003-06[14] and somewhat less than the guide values of BS7385-2:1993 which are judged to give a minimal risk of vibration induced damage.

6.4 Vibration Assessment Results

The results of the vibration propagation assessments undertaken by MDA are detailed in their N & V Report. Contour maps have been produced by MDA from the results of their assessment of expected vibration emission along the CRL route resulting from construction activities. Contours have been plotted of setback distances from the edge of excavation of the CRL route for the vibration thresholds of 2.5mm/s, 5mm/sec and 10mm/sec, these being the vibration criteria or threshold appropriate to historic, residential and commercial buildings respectively.

Contours have been calculated and documented at both ground level and at 20 m below ground. The ground level contours are relevant to shallow founded buildings whilst those at 20 m depth are also judged relevant to piled buildings or buildings with significant basement structures that may be closer to the tunnel at depth. The contour maps are incorporated in Appendix H of the N & V Report.

[14] "Transit Noise and Vibration Impact Assessment" FTA-VA-90-1003-06, Federal Transit Administration, May 2006.

7 Assessment of Vibration Effects on Impacted Buildings of the Study Area

7.1 Inventory of Impacted Buildings

An inventory of those buildings that are within the setback distances from the edge of excavation of the CRL where the vibration threshold criterion are exceeded and have the potential to be impacted by ground borne vibration has been made. These at risk buildings have been categorised as built heritage (as identified in the BH Report), residential or commercial consistent with the project criteria categories for which predicted propagation contours have been produced and present in the N&V report. Potentially impacted receivers in the vicinity of the rail corridor have been identified in the aerial photographs incorporated in Appendix A.

An inventory of these buildings has been included in Appendix B, separately tabulated for built heritage, residential and commercial buildings. Buildings that are required to be acquired as part of the project that fall within the setback distances have not been included in the inventory of buildings.

7.2 Effects Categorisation

The predicted level of physical effects on at risk buildings have been assessed and categorised using the widely accepted Burland Classification shown in Table 7.2.1 below.

Table 7.2.1 - Building Damage Classification

Category of Damage	Normal Degree of Severity	Description of Typical Damage (Building Damage Classification after Burland (1995), and Mair et al (1996))	General Category (after Burland - 1995)
0	Negligible	Hairline cracks	**Aesthetic Damage**
1	Very Slight	Fine cracks easily treated during normal redecoration. Perhaps isolated slight fracture in building. Cracks in exterior visible upon close inspection. Typical crack widths up to 1 mm.	
2	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible, some repainting may be required for weather-tightness. Doors and windows may stick slightly. Typical crack widths up to 5 mm.	
3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Brick pointing and possible replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired. Typical crack widths are 5 to 15 mm or several greater than 3 mm.	**Serviceability Damage**
4	Severe	Extensive repair involving removal and replacement of walls especially over door and windows required. Window and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably. Some loss of bearing in beams. Utility services disrupted. Typical crack widths are 15 to 25 mm but also depend on the number of cracks.	
5	Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing walls lean badly and required shoring. Windows broken by distortion. Danger of instability. Typical crack widths are greater than 25 mm but depend on the number of cracks.	**Stability Damage**

The above have been adopted in presenting the expected order of effects on at risk buildings located within the setback distances.

7.3 Effects and Risks on Impacted Buildings

An assessment of the order of effects on buildings in the vicinity of the alignment has been undertaken on the basis of experience, visual walkovers, desktop analysis and general understanding of age, construction type and condition of each building. It is recognised that the applied damage criteria adopted by MDA is conservative in respect to the onset of damage. Exceedance of the threshold criteria may at worst, but not necessarily, result in some damage to buildings.

It should be noted that a more detailed evaluation will be required at a later stage once the detailed design and technical construction aspects of the CRL have been finalised.

a. Built Heritage

Buildings identified as being or potentially having historic value as identified in the BH Report are a combination of older fragile single and multi-storey unreinforced masonry buildings, the more modern multi-storey framed structures and a number of lightweight single storey residential buildings at the NAL end of the CRL. The unreinforced masonry buildings and residential buildings are typically shallow founded whilst many of the more modern framed structures are pile founded.

It should be noted that many of the older structures, including framed buildings as well as masonry buildings, exhibit some form of existing cracking of a superficial nature to their facades and or structure.

The effects on the shallow founded masonry buildings and residential buildings could reach the Slight category where in close proximity of the alignment. Effects on those buildings at the edge of the 2.5mm/sec PPV threshold contour are expected to be in the Negligible to Very Slight category.

The effects on the more modern structures are expected to be mostly in the Negligible to Very Slight category.

Damage Risks

- Cracking and/or extension of existing cracks of a superficial nature in the facades and walls of more sensitive shallow founded buildings in close vicinity of the alignment.
- Cracking and/or extension of existing cracks of a superficial nature in rigid infill facades to multilevel framed structures.
- Cracking of superficial nature at joints in plasterboard linings to the interior of lightweight residential houses.

b. Residential Buildings

Buildings identified as residential buildings are a combination of the more modern multi-storey framed structures within the city bounds, older low-rise framed structures and lightweight single-storey residential buildings at the NAL end of the CRL. The high-rise structures are typically pile founded whilst the low-rise and light single-storey structures are generally shallow founded.

The effects on the shallow founded low-rise structures and light-weight structures could reach Very-Slight to Slight category where close to the alignment. However more modern structures within the associated contour are expected to be in the Negligible to Very slight damage category.

Damage Risks

- Cracking and/or extension of existing cracks of a superficial nature in the facades and walls of more sensitive buildings in close vicinity of the alignment.
- Cracking and/or extension of existing cracks of a superficial nature in rigid infill facades to multilevel framed structures.
- Cracking of superficial nature at joints in plasterboard linings to the interior of lightweight residential houses.

c. Commercial Buildings

The buildings identified as Commercial buildings are a combination of modern and older multi-storey framed structures, older fragile unreinforced masonry structures, and a number of single-storey portal framed and small light-weight structures in the industrial areas. The unreinforced masonry buildings and industrial buildings are typically shallow founded whilst the majority of high-rise structures are founded on piles.

The effects on the shallow founded unreinforced masonry buildings and older framed buildings could reach the Slight category whilst the effects on the shallow founded portal framed and light-weight structures is most likely to reach only Negligible to Very Slight. The more modern framed structures are expected to be mostly in the Negligible to Very Slight category.

Damage Risks

- Cracking and/or extension of existing cracks of a superficial nature in the facades and walls of more sensitive shallow founded buildings.
- Cracking and/or extension of existing cracks of a superficial nature in rigid infill facades to multilevel framed structures.
- Cracking of superficial nature at joints in plasterboard linings to the interior of lightweight commercial buildings and portal framed structures.

7.4 Mitigation Options

Options for avoiding, remedying or mitigating the adverse effects of ground-borne vibration on buildings have been identified by other appropriate experts (e.g. Noise and Vibration and Built Heritage) and are outlined in the N&V Report and the BH Report. These have not been directly addressed in this report. Monitoring of key at risk buildings would be expected, as a minimum, during construction of the CRL.

8 Settlement and Ground Movement Effects on Buildings.

8.1 Settlement Predictions

Tunnel shaft and cut and cover excavations have the potential to induce surface, subsurface and lateral ground movement with resulting effects on nearby structures and their foundations. The “Settlement and Movement Factual Report” prepared by Auckland Transport’s Principal Advisor and included in Appendix E identifies and details the causes of surface settlement and ground movement.

Initial Tunnel Boring Machine (TBM) tunnelling induced surface settlements have been predicted by Auckland Transport’s Principal Advisor team based on “greenfield” conditions utilising settlement analysis software XDISP. The predicted settlements at surface are typically in the form of a settlement trough. Shaft and cut and cover tunnel induced settlements have been predicted, utilising the computer program WALLAP to assess the deflection of lateral wall/ground movements at the position of the excavation support walls. The deflection of the walls will create a corresponding volume loss to the side of the excavation that is translated at the surface as a settlement trough.

Settlement contour maps have been produced from the settlement prediction data with contours plotted along the length of the CRL corridor, overlaid with existing building footprints. The contour maps are presented in Appendix C. It should be noted that the contours are based on empirical analysis and are approximate. It is expected that development of the geotechnical models, refinement of the design and construction methods and detailed assessment of the vulnerability of existing buildings and structures may reduce the potential settlement contours presented.

Additional settlement due to consolidation of soils arising from groundwater drawdown during construction may also occur. This is dependent on the geological conditions at or near the excavations and the degree of water tightness of the excavations. We highlight that the potential for adverse effects arising from settlement is directly related to settlement curvature, relative to the dimensions of the structure at risk and the resulting strains induced in the buildings. Therefore a greater magnitude of consolidation settlement arising from additional residual soil consolidation has a much lower potential for adverse effects in comparison to settlement associated with ground deformation (volume loss). This becomes a more complicated issue at a detailed assessment stage, i.e., when individual structures are assessed for their vulnerability if structures have complex foundations such as a mix of pile and simple spread/pad foundations and/or whether the thickness of compressible alluvium significantly varies across a given structure.

8.2 Effects Categorisation

The Burland Building Damage Classification utilised for categorising the predicted level of physical effects on buildings as the result of vibration (refer Table 7.2.1) is also adopted to categorise damage resulting from the effects of settlement. Limiting criteria based on building settlement, ground slope and induced tensile strains at the base of the building are used to categorise the predicted risk of building damage. These criteria are presented in Table 8.3.1.

8.3 Effect of Settlement on Buildings

The buildings along and adjacent to the CRL alignment are founded on a mixture of both shallow foundations (pad and strip footings) and deep foundations (short and long piles). These building are a combination of unreinforced masonry structures, multi-storey framed structures and light-weight single-storey structures including those identified in the BH Report.

a. Shallow Founded Structures

In general terms, buildings with shallow foundations are not impacted structurally by a uniform settlement across a site. However they can suffer damage when subject to significant curvature due to settlement or a tensile strain as a result of significant lateral ground movement. Unreinforced masonry buildings are particularly sensitive to these effects.

When assessing the potential of damage to buildings, it is common practice to adopt a staged approach to the prediction of the likely building response.

In the first stage assessment, structures at risk can be rapidly identified from simple predictions of "greenfield" ground slope and settlement, ignoring the influence of the stiffness of the structure, and the application of the limiting criteria of both ground slope and building settlement of Table 8.3.1. as recommended in CIRIA (1996) PR30[15]. Where assessed settlements and slopes do not exceed 10mm and 1:500 respectively, no further assessment is generally necessary as the physical effects are considered to be Negligible to Very Slight.

A second stage assessment of structures identified at risk in stage 1 (with risk of damage deemed Moderate or greater) or any especially sensitive structures not necessarily identified at risk in stage 1, is undertaken where the interaction between the ground and building is considered and tensile strains induced on the building are estimated based on an approach developed by Mair Taylor and Burland. The assessed tensile strains are compared against the limiting tensile strains of Table 8.3.1.

A third stage of more detailed evaluations is only then undertaken for all buildings where damage is rated Moderate or higher from the Stage 2 assessment.

The scope of this study has been limited to a first stage preliminary assessment and a second stage assessment to a number of representative locations, typically adjacent to significant heritage buildings, for which predicted settlement profiles have been produced by Auckland Transport's Principal Advisor Team.

Table 8.3.1 Damage Assessment Criteria

Building Damage Classification after Burland (1995), and Mair et al (1996)				Approx. equivalent ground settlement and slopes (after Rankin 1988)
Risk Category	**Description of degree of damage**	**Limiting Tensile Strain %**	**Max. Slope of Ground**	**Max. Settlement of Building**
0	Negligible	Less than 0.05		
1	Very Slight	0.05 to 0.075	Less than 1:500	Less than 10
2	Slight	0.075 to 0.15	1:500 to 1:200	10 to 50
3	Moderate	0.15 to 0.3	1:200 to 1:50	50 to 75
4	Severe	Greater than 0.3	1:200 to 1:50	Greater than 75
5	Very Severe		Greater than 1:50	Greater than 75

b. Piled Structures

The approach described above for shallow founded buildings has also commonly been utilised for assessing the effects of settlement of piled buildings. However it is not always appropriate to consider "greenfield"

[15] CIRIA Project Report 30 "Prediction and Effects of Ground Movement Caused by Tunnelling in Soft Ground Beneath Urban Areas" by LM Lake, WJ Rankin & J Hawley

settlements for a building founded on piles as the building will not necessarily settle along the predicted ground settlement trough[16].

Cut and cover and tunnelling induced ground movement will result in both lateral movement and settlement of adjacent piles to nearby buildings. The ground movement induces both bending moments and axial down drag forces on the pile. The magnitude of these additional loads on the piles is largely dependent on a number of factors including, the amount of horizontal and vertical movement resulting from the excavation or tunnelling operation, the distance of the piles from the edge of the open cut excavation or tunnel excavation and the relative position of the pile tip with respect to the depth of the excavation and/or tunnel axis.

Building settlement will be the result of pile settlement and can be expected to be less than that predicted on the basis of the "greenfield" settlement analysis. The maximum settlement will be the maximum pile settlement and the maximum slope or differential settlement will be the differences occurring in pile head settlement between adjacent pile lines.

Pile behaviour, notably the lateral movement, is different for long piles (those with pile tips below the tunnel axis level or open cut excavation level, and short piles (those with pile tips above the excavation level or tunnel axis level).

A detailed evaluation of pile settlement addressing excavation induced pile bending moments and axial forces is outside the scope of this assessment. The preliminary assessment of the effects of ground settlement impacts for piled buildings in this study has been undertaken utilising the same approach used for buildings with shallow foundations.

8.4 Effects and Risks on Existing Building Stock

A preliminary evaluation of the anticipated order of effects on buildings in the vicinity of the alignment has be undertaken based on experience and a limited number of representative settlement profiles developed at different chainage points over the length of the alignment (refer Appendix D).

At all settlement profiles investigated, maximum ground slopes were assessed to be less than 1:500. Accordingly the effects on buildings beyond the 10mm settlement contours are generally expected to be Very Slight to Negligible.

Stage 2 type assessments were then undertaken for representative building types where settlement exceeded 10 mm. It is also recognised that sensitive buildings located in the area of most potentially damaging effects, near the outer edges of the settlement trough where significant hogging or tensile strains occur, may fall in higher damage categories irrespective of the settlement that has occurred. Stage 2 type assessments have therefore also been undertaken on a range of heritage type buildings at this location so that the sensitivity of these building types to the various hogging profiles could be identified. The outcomes of the above assessments are included in the discussion that follows.

Buildings that are required to be acquired and demolished as part of the project have not been assessed for settlement effects.

It should be noted that a more detailed evaluation will be required at a later stage to quantify potential damage to individual existing buildings once the detailed design and technical construction aspects of the CRL have been finalised (refer to the EMF[17]). The detailed evaluation will need to also consider the effects of additional settlement due to consolidation of soils arising from any groundwater drawdown or diversion. The latter have not been explicitly addressed in this study as it has a much lower potential of adverse effects

[16] BP 2009 William Barclay Parsons Fellowship Monograph 25 "An Innovative Method for Assessing Tunnelling- Induced Risks to Adjacent Structures" by Nagen Loganathan.

[17] CRL Environmental Management Framework

in comparison to settlement associated with ground excavation (volume loss) and appropriate mitigation measures can be implemented during the construction phase to minimise this effect.

a. Lower Albert Street and Aotea Station

A top-down cut and cover technique is proposed to form the Aotea station box and the alignment to the existing Britomart station.

The buildings adjacent to the cut and cover works along the alignment are a mixture of more modern piled structures and historic shallow founded structures. The effects on the buildings are generally expected to fall in the Negligible to Slight category. Unreinforced masonry buildings are at greatest risk to settlement due to the high tensile strains, caused by the building hogging, that will be experienced when subject to differential settlement. Negligible effects are expected to be experienced by large framed buildings.

A Stage 2 assessment identified the potential for the effects on more sensitive unreinforced masonry buildings located at the outer edges of the settlement trough to likely fall into the Moderate category. The historic bluestone retaining wall located between Wyndham Street and Victoria Street West could be subject to settlements that fall into the Slight to Moderate Category. Use of stiffer diaphragm wall or secant pile retention walls may assist to reduce the potential effects of settlement to the Slight category.

Extension of the CRL tracks under the former Central Post Office building will require removal of several piles and use of temporary supports. The effects on the CPO building are expected to be Slight.

The alignment passes immediately adjacent to the corner of 21 Queen Street with minimal clearance. Whilst the building incorporates piled foundations, some minor damage could be expected with the expected effects falling in the Slight category.

Buildings immediately adjacent to the Aotea Station excavation are piled framed structures, some with deep basements. Hence effects in the Slight to Very Slight category are expected.

b. Mayoral Drive and Vincent Street

Between the stations along Mayoral Drive and Vincent Street the TBM tunnel runs generally beneath the road reserve limiting the level of surface settlement predicted outside the road reserve. Adjacent buildings are typically of more modern construction with the occasional building that has been listed in the BH Report. The effects on the buildings in this zone are expected to mostly fall in the Negligible to Very Slight category.

The eastern tunnel of the CRL passes within 4 to 5 metres of the outer basement wall of the Aotea Centre building at the North West corner. The effect of construction of the eastern tunnel on the Aotea Centre is not expected to exceed the Slight category.

The eastern tunnel of the CRL is expected to transverse directly beneath the zone of influence of the piled foundations to the Eclipse Apartment building, at 156 Vincent Street. The depth of the tunnel is such that it passes below the piled foundations of the building. The piles appear to be friction type piles and typically derived ground support over their length through the more competent subgrade layers of the East Coast Bay Formations. Settlement effects on the building could fall into the Slight to Moderate category. A detailed assessment of the expected level and effects of settlement will be required at a later stage once the design and construction aspects of the CRL have been finalised. If necessary suitable mitigation measures will need to be implemented to manage the effects of settlement, which could include ground improvements to the upper subgrade levels of the supporting ground to the Eclipse Apartment Building.

c. Karangahape Road Station and Newton Station

Between Pitt Street and Newton Station the TBM and mined stations are expected to transverse directly beneath or close to the building footprints. The majority of these buildings are listed in the BH Report so are considered sensitive to settlement. They are typically shallow founded. The tunnel runs at considerable depth below the existing ground level, with reduced coverage under the Central Motorway Junction.

Based on the damage criterion, the effects on these buildings are expected to generally fall in the Negligible to Very Slight category. The potential effects on several of the shallow founded masonry buildings could fall into the Slight category.

The construction of Karangahape road station and Newton Station also incorporates cut and cover shafts from the surface to the station platform as outlined in the Concept Design Report. Based on the damage criterion the settlement effects on the buildings immediately adjacent to the shafts, most notably the older unreinforced masonry shallow founded structures, are expected to fall in the Slight to Moderate category. These include the Mercury Theatre, Beresford Street and Pitt Street Buildings and Symonds Street Buildings.

A detailed evaluation will be required for the more sensitive buildings, namely unreinforced masonry and those listed in the BH Report. The evaluation will need to account for the local soil conditions, the structural stiffness and the construction type and layout of the building. This will be undertaken as the detailed design is being developed after additional geotechnical information has been gathered through further site investigation work.

d. Newton Station to NAL

Between Newton Station and the connection with NAL the depth to the alignment reduces considerably. The majority of buildings in this area are shallow founded and of generic building type. It is therefore expected that the effects on these buildings will fall into the Negligible to Slight category. However detailed evaluation may be required for the more sensitive buildings where the tunnel depth is significantly reduced; this includes the TV3 building (3 Flower Street) which sits directly over the mined length of the eastern tunnel beyond the Newton Station.

In the proximate area of the open cut and cover section of the tunnel, building properties are expected to be acquired so further investigation of settlement has not been undertaken at this point. Where this is not the case a detailed evaluation of settlement issues will also need to be undertaken. It is noted that the buildings in this area are a combination of unreinforced masonry and reinforced concrete and steel framed structures. The expected damage, therefore, ranges from Negligible to Slight.

e. Damage Risks

In general the level of damage associated with the Negligible to Slight categories is aesthetic or cosmetic in nature and non-structural. Likely forms of damage are outlined in Table 7.2.1 and are detailed further below. Visible effects are likely but are generally easily repairable with some form of mitigation required. The key damage risks are:

- Cracking of a superficial nature in the facades and walls of more sensitive buildings in close vicinity of the alignment.
- Cracking or a superficial nature in rigid infill facades to multilevel framed structures.
- Cracking of superficial nature at joints in plasterboard linings to the interior of lightweight residential houses.
- Superficial cracking in ground supported floor slabs in piled buildings immediately adjacent and above the alignment.
- Roof drainage effected where current levels are flat or nominally flat due to nominal movement in building.
- Minor grade effects at building entrances may require levelling as part of road and footpath re-instatement.
- The occasional window may stick and a minor level of redecoration may be required.

8.5 Conclusions

Unreinforced masonry buildings that are within the zone of influence of the alignment require special consideration as they are commonly of a brittle form of construction that is sensitive to ground movement. Numerous buildings of this type, including those identified in the BH Report, are situated in the vicinity of the alignment and most of these are likely to be subject to effects no greater than Very Slight to Slight category. The effect on some of these buildings has been identified as potentially falling into the Moderate category where significant hogging curvature or tensile strains occur in the settlement profile.

More flexible multi-level framed buildings of both modern and older examples are more tolerant of differential settlement and resulting ground curvatures, with effects expected to fall into the Negligible to Slight categories.

The assessments to date are preliminary in nature and provide a high level evaluation of the expected degree of building damage resulting from tunnelling and cut and cover excavation induced settlements. Further detailed evaluations will be required at a later stage once the design and construction aspects of project have been finalised, particularly of the more sensitive older buildings, including those identified in the BH Report. These will need to more accurately account for the local soil conditions, configuration, construction type and details of the individual buildings, existing condition and inherent structural stiffness.

8.6 Mitigation Options

Options for avoiding, remediating or mitigating the adverse effects of excavation induced settlements on buildings have not been described in this report although further discussion is presented in the Settlement and Movement Factual Report (refer Appendix E), the N & V Report and BH Report. The methods may comprise reducing the ground deformations associated with a particular construction method or design, changing the characteristics of the ground around the excavation or by compensating for ground movement around a particular structure by injecting the surrounding ground with grout. Local strengthening of existing building structures may also prove to be an appropriate approach. This could include, for example, underpinning to foundations, use of micropiles to strengthen the foundations, temporary strengthening and securing of facades.

For many buildings simple remediation of cracks and redecoration following the construction work may prove the most viable option for addressing damage.