

Appendix N: LSN Examples

ENVIRONMENTAL AND ENGINEERING CONSULTANTS



KEY

LEGEND

Liquefaction and Lateral Spreading Observation Category

	1	No observed ground cracking or ejected liquefied material
	2	Minor ground cracking but no observed ejected liquefied material
	3	No lateral spreading but minor to moderate quantities of ejected material
	4	No lateral spreading but large quantities of ejected material
	5	Moderate to major lateral spreading; ejected material often observed
	6	Severe lateral spreading; ejected material often observed

Dwelling Damage Category

	None		Refer to Figure A9 for diagrams and a full description.
	Minor		
	Moderate		
	Major		
			To avoid plotting seven sets of results for the different mechanisms of foundation damage, the worst foundation damage severity is taken for each LDAT inspection and is referred to as a 'Dwelling Damage Category'.

N1 Introduction

This appendix presents a summary of typical land and dwelling performance with respect to calculated Liquefaction Severity Number (LSN). The performance of land at various LSN is presented. The LSN is discussed, followed by a summary of typical land and dwelling performance under seismic loading. The relationship between LSN and dwelling foundation damage is presented, followed by a discussion of possible foundation damage mitigation options.

N2 Liquefaction Severity Number (LSN)

LSN is a probabilistic parameter, and so a given LSN describes a range of probable behaviours, which can vary from no observed land damage to severe land damage with extensive ejection of liquefied material. LSN should be considered as an indicator of the risk of adverse liquefaction related effects occurring to the land. Higher LSN values mean that the land is at greater risk of adverse behaviour, while lower LSN values indicate lower levels of risk.

To understand the probabilistic nature of the parameter, it is analogous to another probabilistic function, the Body Mass Index or BMI. The BMI relates height to weight and is used in healthcare as a proxy to estimate the level of fat in individuals. The BMI was developed on the basis of population data, but is applied at an individual level. For instance, a high BMI is considered obese, but bodybuilders with extremely low fat contents and high levels of muscle can have BMI of 30 or more without being obese. The population of people with a BMI of 30 typically contains individuals who are overweight. Therefore, if you have a BMI of 30 you could be extremely muscular, but it is far more likely that you are overweight.

In a similar manner, some sites with an LSN of 40 experienced low levels of adverse liquefaction related effects. However, most sites with an LSN of 40 experienced moderate to severe liquefaction related adverse effects.

When applying the LSN in practice, it is important to understand the aspects of liquefaction that are not represented by LSN. This has been discussed in more detail in the main report body text.

N3 Liquefaction and lateral spread observations and dwelling foundation damage

N3.1 General

This section presents typical liquefaction, lateral spread and dwelling foundation damage observations for various LSN bands. The observations are described in more detail in Section 3.2 of the main report text.

N3.2 LSN - Population

This section presents the relationship between land damage of properties around Canterbury and the calculated LSN using UoC and Cornell peak ground acceleration distributions discussed in Section 3.4 of the main report. Note that the datasets considered have inherent scatter, the source of which has been discussed in more detail in the main body of the report.

The analyses presented in Appendix G plot all land and dwelling foundation damage observations that have parameters associated with them. Where data is being plotted within a category (such as the box and whisker plots and cumulative frequency graphs) there is an effective normalisation presented. However, once data is grouped by calculated LSN bands, the number of data in each observed damage category can skew the dataset. To mitigate this effect, the number of observations in each category has been normalised to provide equal weighting.

The graphs presented in this appendix therefore represent a normalised distribution of damage where equal weighting is given to each of the categories. Figures N1 to N4 present the land related observations. The land damage categories are defined in the key.

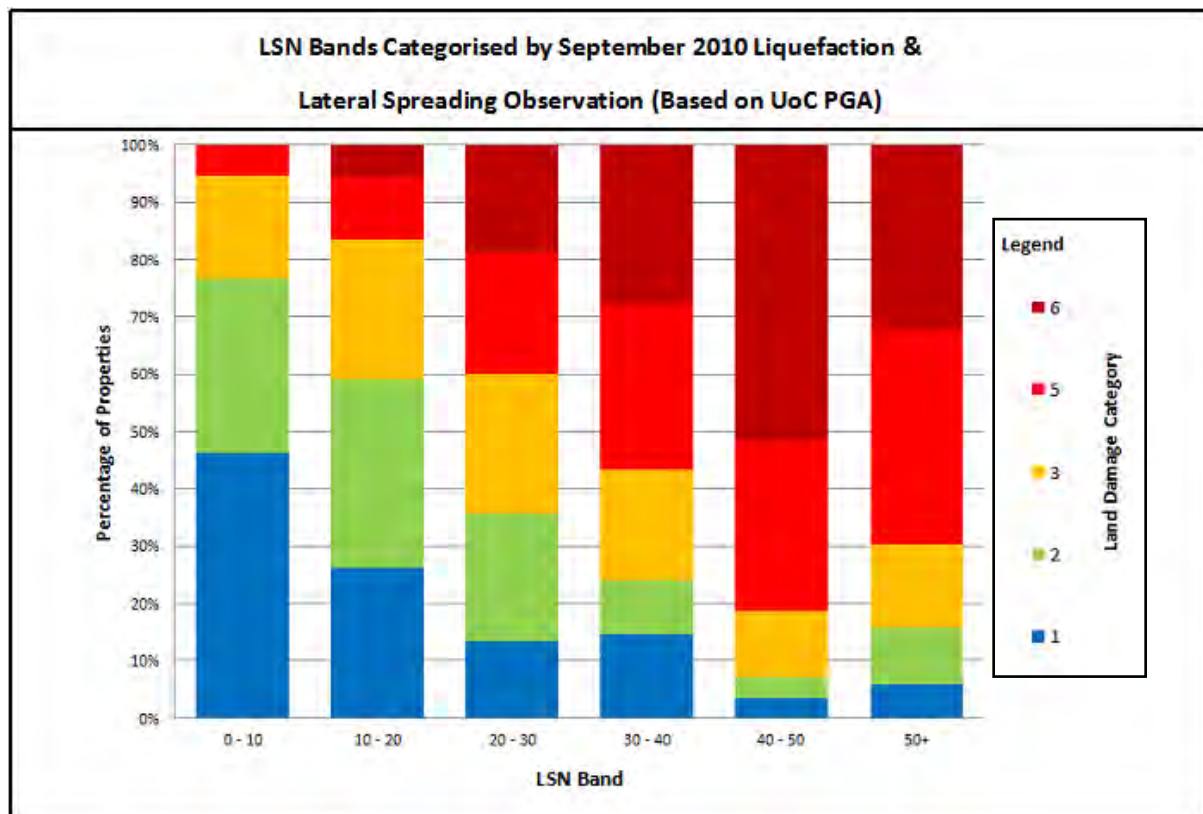


Figure N1 – September 2010 land observations

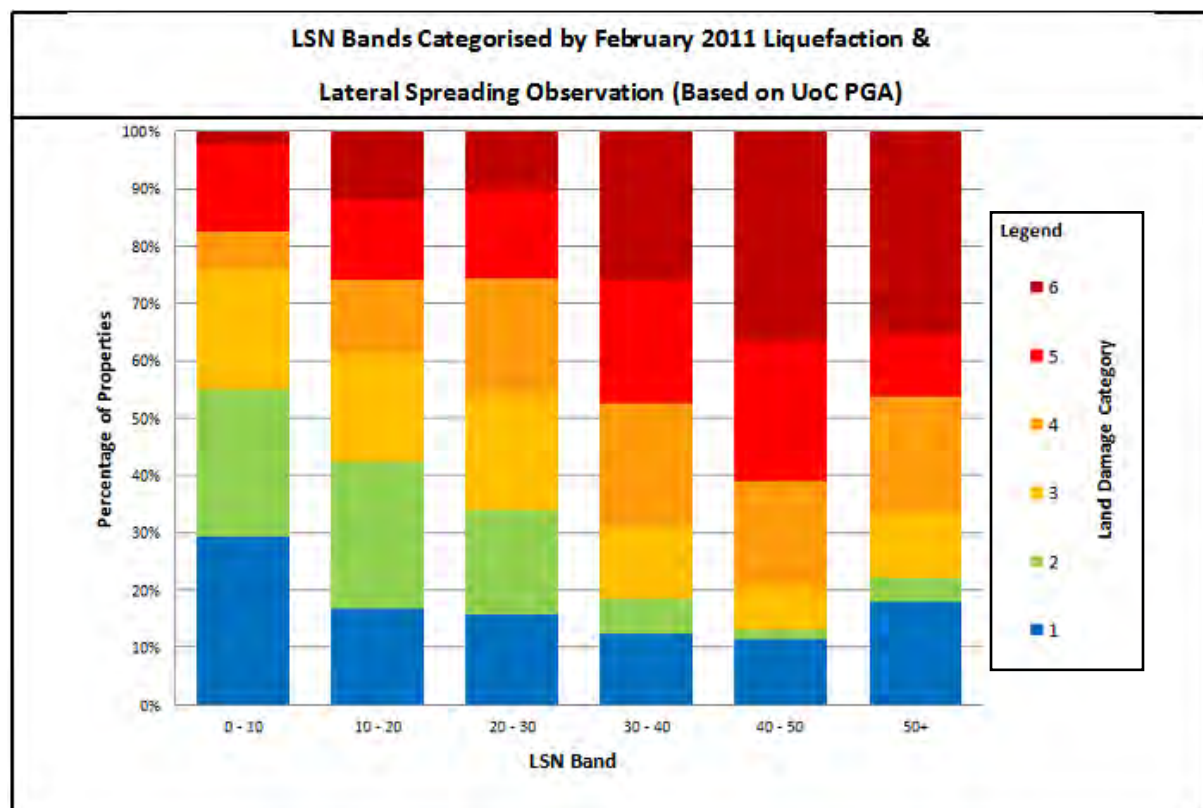


Figure N2 – February 2011 land observations

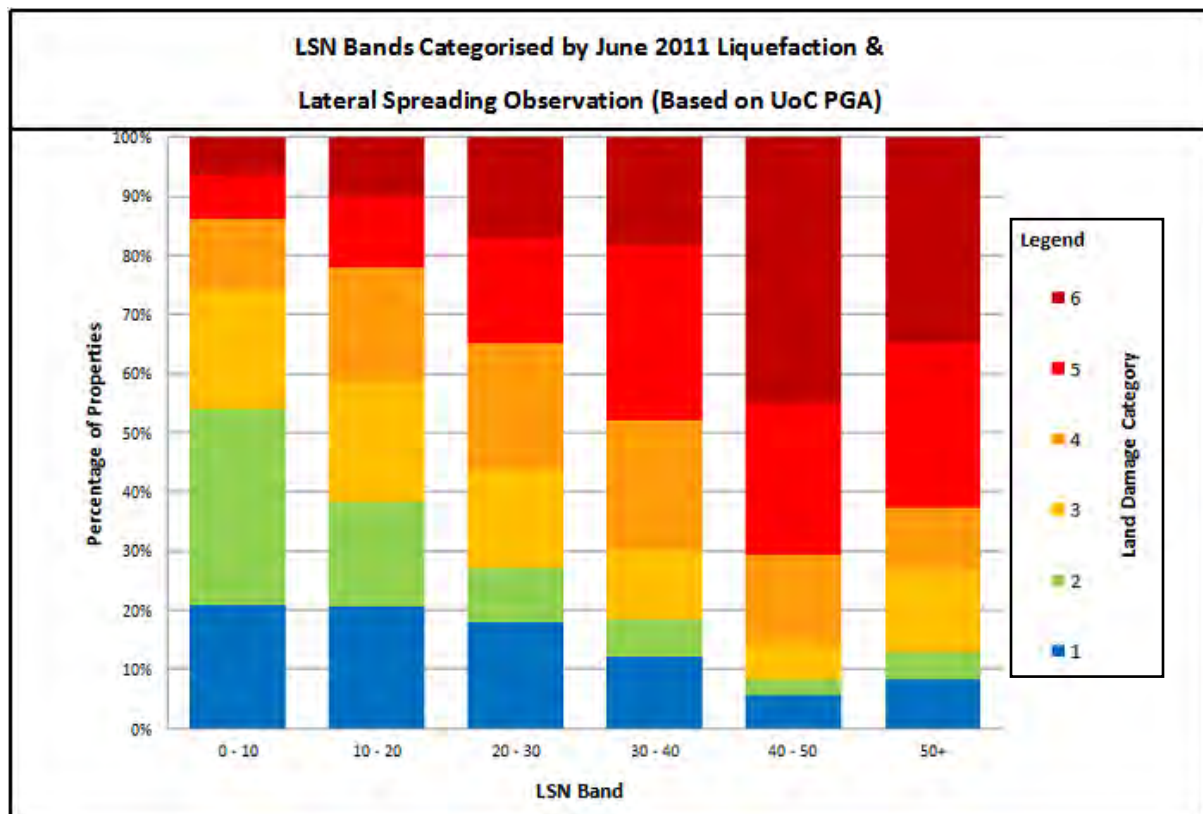


Figure N3 – June 2011 land observations

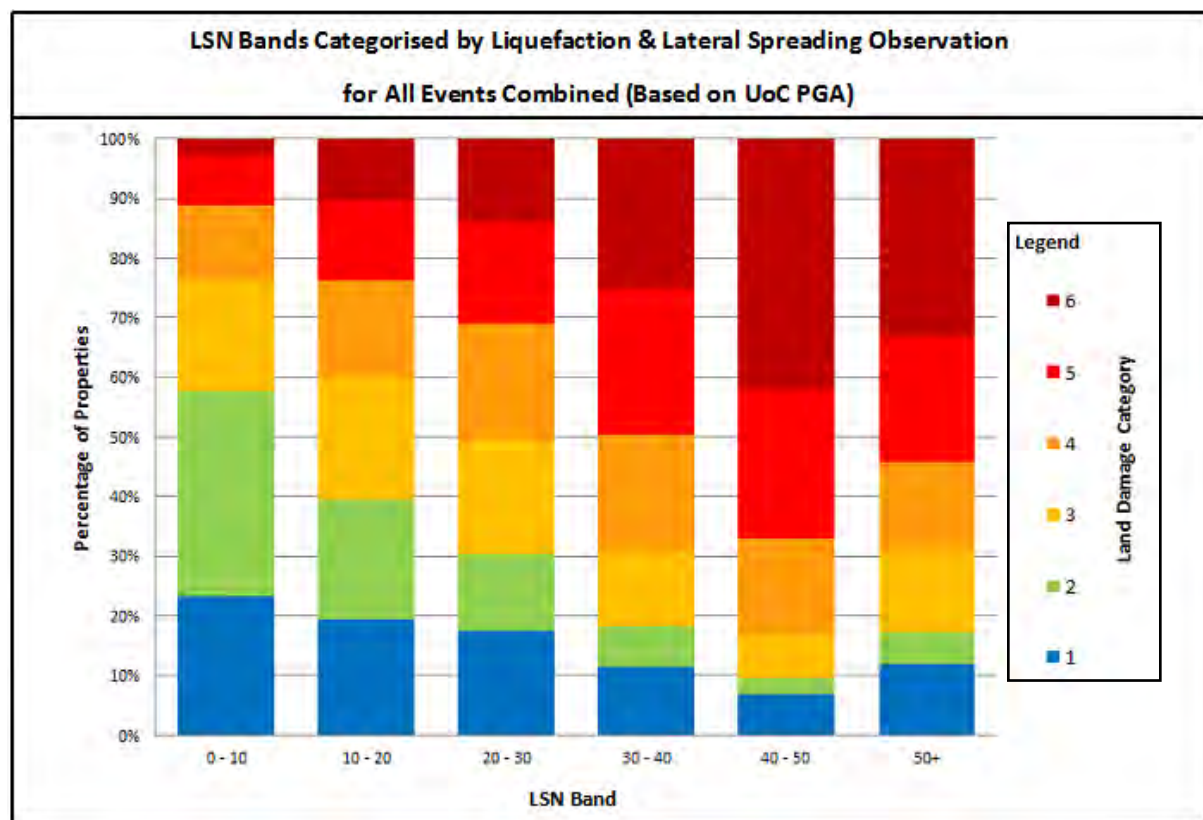


Figure N4 – All events land observations

The figures show consistent trends for the earthquakes of an increasing severity of liquefaction and lateral spreading observations with increasing LSN. The shape of the trends with the normalised data is consistent, with very low levels of severe liquefaction induced damage at low LSN. By comparison, at high LSN there are very few sites with no to minor liquefaction induced damage. The September 2010 data has a very high proportion of no to minor liquefaction induced damage at low LSN, which is consistent with the low levels of liquefaction related damage around Canterbury.

These figures are based on the same datasets as those discussed in the primary analyses (Appendix F and G), but show the clear relationship between LSN and the severity of the liquefaction observations.

N3.3 LSN - Individual sites

This section presents the performance of individual sites with different LSN. Representative individual sites have been selected that show the change in liquefaction effects as the LSN changes. The following effects are observed and examples of typical behaviour in Table N1 below. It is important to reiterate that the LSN describes a range of possible damage and the information below represents only a typical behaviour. The actual site performance may vary from this. Photographs have been selected that are considered to represent the typical land performance described below and are presented at the end of this Appendix.

Each LSN range contains a range of photographs within that show the variation of typical response.

Table N1 LSN ranges and observed land effects

LSN Range	Typical effects	Photographs in Appendix N
0 – 10	Little to no expression of liquefaction, minor effects	Figure N7a-y
10 – 20	Minor liquefaction expression, some sand boils	Figure N8a-y
20 – 30	Moderate expression of liquefaction, with sand boils and some structural damage	Figure N9a-t
30 – 40	Moderate to severe expression of liquefaction, structural settlement and damage	Figure N10a-v
40 – 50	Major expression of liquefaction, undulations and damage to ground surface, severe total and differential settlement of structures	Figure N11a-p
>50	Severe damage, extensive evidence of liquefaction at surface, severe total and differential settlements affecting structures, damage to services.	Figure N12a-x

N4 Effects of liquefaction on dwelling foundations and mitigation options

N4.1 General

This section presents information relating to the effects of liquefaction on residential dwellings and mitigation options available to mitigate these effects for new construction. Commonly constructed foundation types are summarised in Section N4.2 while options for new construction are discussed in Section N4.3. Note that these assessments are limited to conventional residential dwellings affected by liquefaction. Other structures should be considered on a case by case basis.

N4.2 Existing residential foundations

The nature of the dwelling and foundation affects the level of damage that a structure experiences due to liquefaction effects. The LSN only assesses the vulnerability of the land and does not directly consider the susceptibility of structures and foundations to liquefaction. However, analyses of the performance of various foundations have been carried out and are discussed below. Residential dwellings in Canterbury were divided into three broad foundation construction types which are summarised in Table N2 below.

Table N2 Foundation construction types

Foundation type	Description
A	Timber floor on piles
B	Timber floor on internal piles with perimeter concrete footing
C	Concrete slab on grade

The performance of foundations in response to the 04 September 2010 and 22 February 2011 earthquakes has been analysed and are presented in Figures N5 and N6. Unlike land damage, the effect of liquefaction on foundations was not typically repaired between earthquakes. Foundation damage is therefore more likely to carry over from one earthquake to the next. The quality of the correlations that can be drawn from foundation damage datasets therefore drops through the earthquake series (discussed further in Section 9 of the main text). Consequently, only damage data due to the September 2010 and February 2011 earthquakes are presented as these are more reliable. The correlations for the 13 June 2011 earthquake have therefore not been presented.

The data presented in these tables has been normalised as discussed in Section N3.

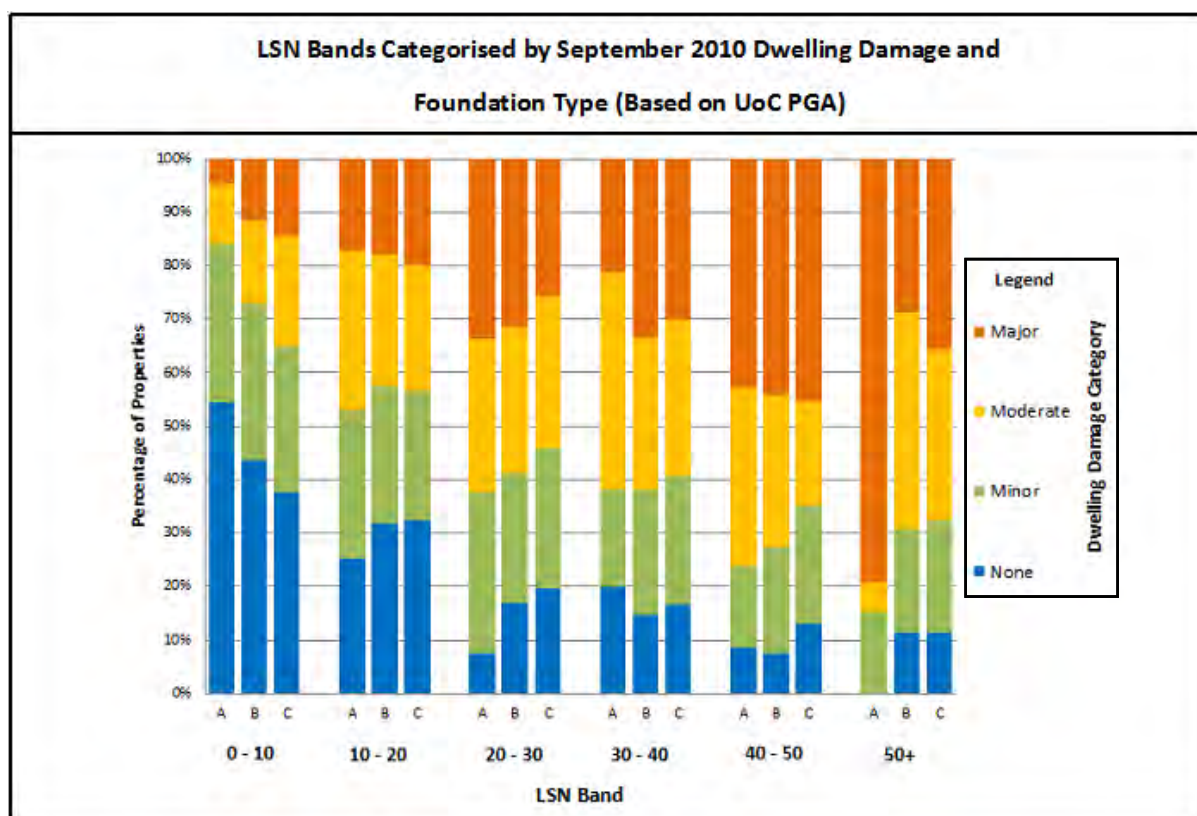


Figure N5 – September 2010 dwelling foundation damage observations

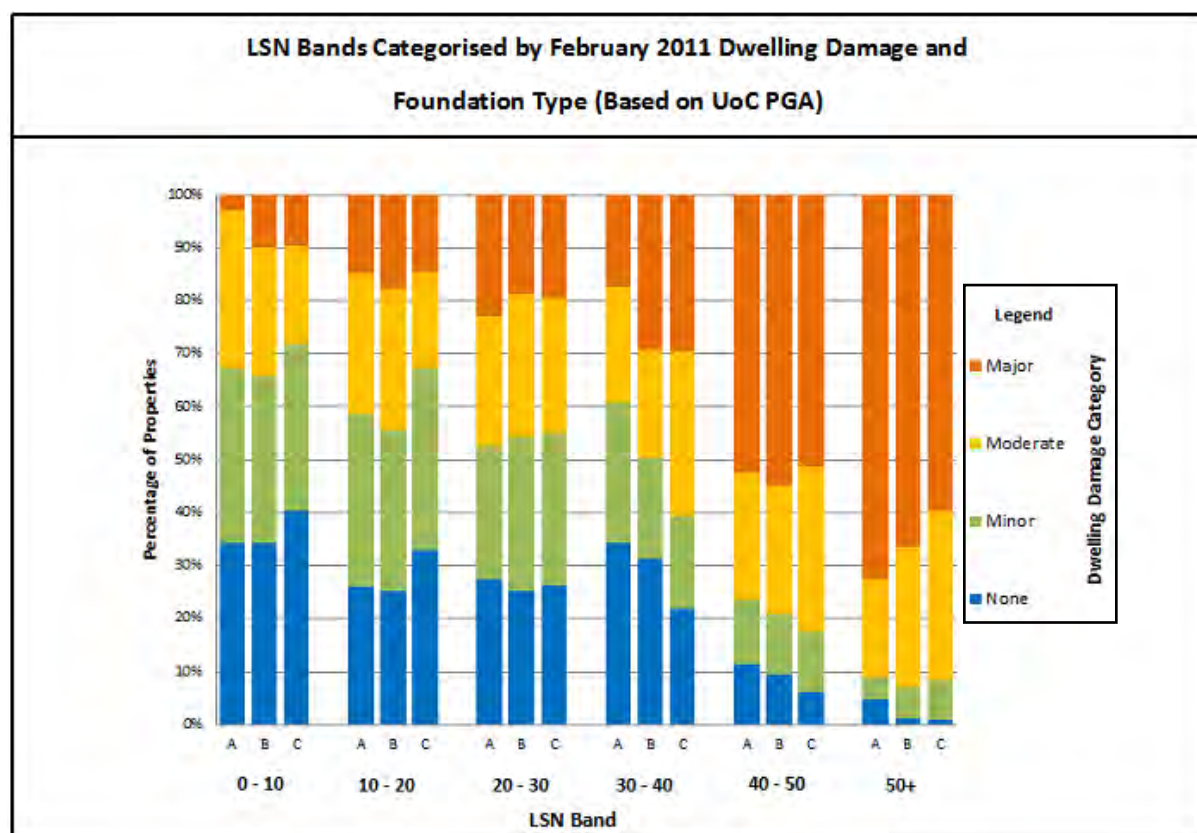


Figure N6 – February 2011 dwelling foundation damage observations

The figures show that there is a weak to moderate correlation between LSN and dwelling foundation damage. The correlation is not as strong as that between LSN and land observations.

While there are differences between the different foundation types, Figures N5 and N6 show that no foundation type performs significantly and consistently better than others.

N4.3 New construction - mitigation options

Structures constructed or repaired in New Zealand must meet building code requirements. The Ministry of Building, Innovation and Employment (MBIE) administer the building code and compliance documents and have published guidance relating to the design of residential foundations in land susceptible to liquefaction hazards. Guidance was published by MBIE (2012) relating to general foundation designs in the various technical categories. The guidance identifies Type A foundations (suspended timber floor on piles) as the foundation type that can most easily be repaired. In addition, the mitigation methods summarised in Table N3 were presented in the MBIE guidelines (2012). Table N3 also shows the effect that the various foundation mitigation options have on the LSN parameter and the vulnerability to the liquefaction hazard. Note that LSN only captures certain aspects of liquefaction vulnerability as discussed in the main body of the report.

Table N3 Summary of MBIE mitigation measures

Mitigation measure	Effect on the vulnerability of the structure to the liquefaction hazard	Effect of the mitigation measure on the LSN
Type A construction (fully piled, lightweight timber framed structures)	Reduces differential and total settlements compared to heavier build, often allows economical repair of structure	No change to LSN as no effect on ground
Construction using raft foundation	Slightly reduces differential settlements	May slightly reduce LSN depending on depth of raft
Structure founded on deep piles	Significantly reduces differential and total settlement of structure. No significant effect on ground settlements.	No change to LSN as no effect on ground
Ground improvement	Reduces differential and total settlements of both ground and structure.	Lowers LSN on the footprint wherever the ground treatment is undertaken

Typical Photographs of LSN Ranges

LSN 0 - 10



a) Even lawns and undamaged pavers



b) Undamaged asphalt driveway



c) Undamaged concrete driveway and kerbing



d) Aerial shot of Broomfield area showing no liquefaction ejecta on the roads or Broomfield Common



e) View of Aston Drive with little damage



f) View of Centaurus Road with little damage

Figure N7.A - F



g) Flat lawn



h) Slightly undulating lawn and driveway



i) Slightly undulating lawn



j) Liquefaction ejecta on lawn



k) Undulating lawn



l) Liquefaction ejecta pile on road

Figure N7.G - L



m) Foundation damage

n) Foundation damage



o) Foundation damage

p) Foundation damage



q) Undulating lawns and liquefaction ejecta

r) Liquefaction ejecta on lawn

Figure N7.M - R



s) Liquefaction ejecta on driveway



t) Damage to brickwork



u) Foundation damage



v) Undulating paving slabs



w) Foundation damage



x) Piles of sand along the footpath

Figure N7.S - X



y) Undulations on road with ponding water

Typical Photographs of LSN Ranges

LSN 10 - 20



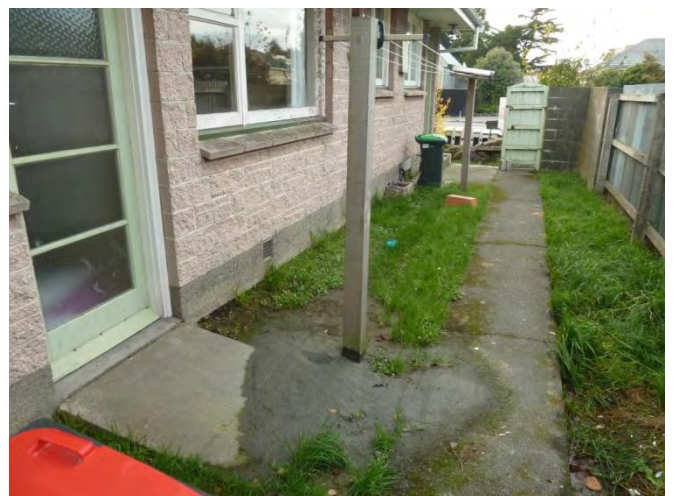
a) Undulating lawn

b) Aerial photo of North New Brighton showing little damage



c) Isolated area of liquefaction ejecta on lawn

d) Isolated area of liquefaction ejecta on lawn



e) Isolated area of liquefaction ejecta on lawn

f) Liquefaction ejecta around washing line pole

Figure N8.A - F



g) Liquefaction ejecta on lawn

h) Foundation damage



i) Undulating paving slabs

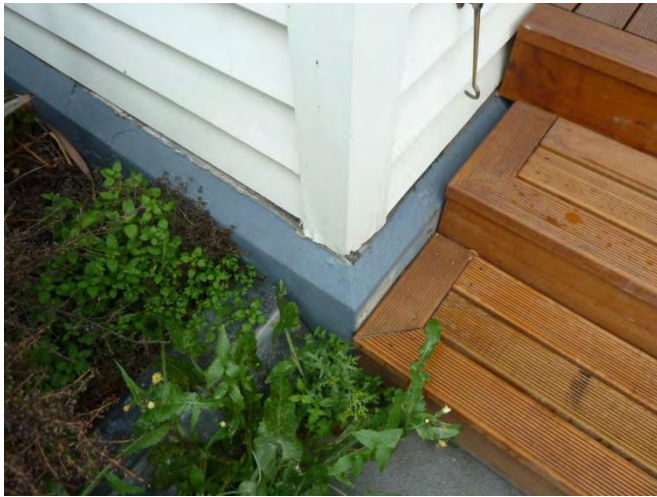
j) Liquefaction ejecta on lawn



k) Foundation damage

l) Foundation damage

Figure N8.G - L



m) Foundation damage

n) Liquefaction ejecta on lawn



o) Liquefaction ejecta on lawn

p) Liquefaction ejecta trapped under lawn



q) Liquefaction ejecta in planter

r) Liquefaction ejecta in planter with undulating pavers



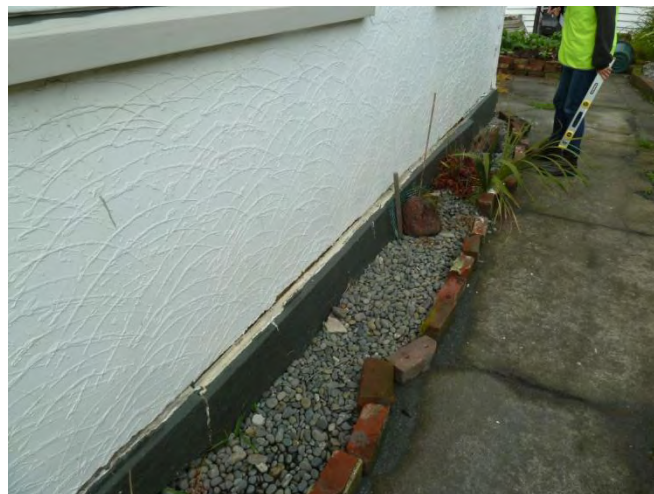
s) Undulating brick paving



t) Foundation damage



u) Foundation damage



v) Foundation damage



w) Liquefaction ejecta at a New Brighton Road junction



x) Liquefaction ejecta on Shirley Boys High School lawns

Figure N8.S - X



y) Sinking electricity box with liquefaction ejecta and ponding water

Figure N8.Y

Typical Photographs of LSN Ranges

LSN 20 - 30



a) Aerial photo of liquefaction ejecta at Cashmere High School



b) Liquefaction ejecta on lawn



c) Liquefaction ejecta on lawn



d) Liquefaction ejecta on lawn



e) Liquefaction ejecta alongside culvert



f) Isolated area of liquefaction ejecta

Figure N9.A - F



g) Damage to asphalt

h) Liquefaction ejecta trapped below asphalt



i) Aerial shot of Redcliffs with liquefaction ejecta

j) Foundation damage



k) Liquefaction ejecta on lawn

l) Liquefaction ejecta in piles on road

Figure N9.G - L



m) Foundation damage

n) Liquefaction ejecta piled on Cashmere High School lawns



o) Road damage on Orontes Street with ponding water

p) Liquefaction ejecta covering turning circle in Chale Lane



q) Liquefaction ejecta on driveway

r) Liquefaction ejecta and ponding water

Figure N9.M - R



s) Foundation damage, tilting dwelling

t) Liquefaction ejecta on driveway with water ponding

Typical Photographs of LSN Ranges

LSN 30 - 40



a) Undulating paving bricks



b) Isolated area of liquefaction ejecta



c) Foundation damage



d) Foundation damage



e) Liquefaction ejecta



f) Foundation damage

Figure N10.A - F



g) Liquefaction ejecta on lawn

h) Liquefaction ejecta in many places on lawn



i) Large area of liquefaction ejecta on lawn

j) Foundation and brickwork damage



k) Large area of liquefaction ejecta on lawn

l) Brickwork damage

Figure N10.G - L



m) Liquefaction ejecta and brickwork damage



n) Foundation damage



o) Foundation damage



p) Liquefaction ejecta in many areas on lawn



q) Aerial photo of Woolston showing road damage and liquefaction ejecta



r) Close up photo of road damage seen in aerial photo of Woolston



s) Undulating paving slabs



t) Foundation damage



u) Undulating paving slabs



v) Foundation damage

Figure N10.S - V

Typical Photographs of LSN Ranges

LSN 40 - 50



a) Undulations in lawn



b) Liquefaction ejecta covering driveway



c) Foundation damage



d) Undulations in paving area



e) Foundation damage



f) Foundation damage

Figure N11.A - F



g) Liquefaction ejecta on lawn



h) Undulations in lawn, liquefaction ejecta removed



i) Foundation damage



j) Liquefaction ejecta alongside culvert



k) Liquefaction ejecta on lawn



l) Liquefaction ejecta on lawn

Figure N11.G - L



m) Foundation damage

n) Liquefaction ejecta on New Brighton Road



o) Liquefaction ejecta, dwelling tilting

p) Liquefaction ejecta, dwelling tilting

Typical Photographs of LSN Ranges

LSN 50+



a) Isolated patches of liquefaction ejecta



b) Large patch of liquefaction ejecta



c) Numerous patches of liquefaction ejecta



d) Numerous patches of liquefaction ejecta



e) Undulating paving slabs with liquefaction ejecta



f) Foundation damage

Figure N12.A - F



g) Tilting paving slabs as dwelling settled

h) Aerial view of Bexley with flooded roads and large amounts of liquefaction ejecta



i) Liquefaction ejecta piles along Androssan Street

j) Liquefaction ejecta piles along Avonside Drive



k) Liquefaction ejecta around property

l) Foundation damage

Figure N12.G - L



m) Aerial photo showing liquefaction ejecta on Seabreeze Close

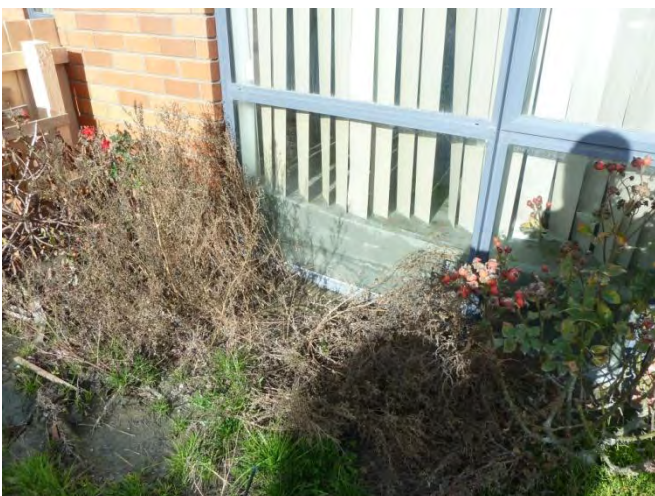
n) Liquefaction ejecta in turning circle of Seabreeze Close



o) Foundation damage, dwelling tilting



p) Outside of dwelling showing level liquefaction ejecta reached on brickwork and windows



q) Liquefaction ejecta inside dwelling



r) Large amounts of liquefaction ejecta



s) Large amounts of liquefaction ejecta and tilting dwelling

t) Large amounts of liquefaction ejecta around property



u) Large amounts of liquefaction ejecta

v) Large amounts of liquefaction ejecta



w) Large amounts of liquefaction ejecta

x) Large amounts of liquefaction ejecta inside dwelling

Figure N12.S - X