Technical Note 05 – Response of Buried Assets other than Water Pipelines

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1 Background

Most of the studies on damage caused by earthquakes to buried assets relate to water assets, and especially to water supply systems in which damage is more readily observed and identified, and where loss of supply has an important and fast-acting effect.

This report reviews the key features of other buried utility services and summarises the kind of damage observed.

2 Similarities and Differences between Services

2.1 Materials of Construction

While there are differences in the materials of construction used for the different services, there also are many similarities. For example, water and gas distribution both use PE pipes and fittings made to AS/NZS 4130 [1] and AS/NZS 4129 [2] respectively, while steel or ductile iron may be used for larger transmission mains or where higher strength is required.

Modern electrical cables have copper or aluminium cores, often with lead or aluminium sheathing and are usually encased in PE [5], although this tends to be cross linked PE (XLPE) rather than the PE80 or PE100 used in water and gas pipelines. Older cables are more likely to have copper cores and to be Paper Insulated Lead Covered Armoured (PILCA) [6]. Ducting is essentially made of PVC or PE pipes that are similar to pipelines used in water applications – and just as with three waters systems, older ducts can be made of galvanized steel or asbestos cement [7] and, again, were similar to pipelines used in water applications.

Telecommunications cables include copper cables with lead or plastic sheathing and fibre optic cabling [18]. Ducts include similar materials to those used in electrical systems.

2.2 Installation

The major differences include the service-specific performance requirements, the impact of failure and breakage on service, the ease of location and repair and (perhaps most notably), the depth of installation. A water supply system has to be installed below expected freezing depths, which means it is usually deeper than other pipelines, cables and ducted services, while there is preference to install gas and electrical services above water pipelines so that they are more readily identified and repaired when needed.

Wastewater systems are installed below water ones to minimise risk of cross contamination in the event of a break or leak. Wastewater and stormwater systems typically flow under gravity. The slope of the pipelines required to allow gravity flow requires that each succeeding section is buried deeper than the next, until a pumping station and rising main are installed to lift the flows. The relatively shallow burial depth of some cabled and ducted services increases the risk of bending compared with deeper ones because shallower cover provides less resistance to vertical movement than deeper cover.

Bedding and support are typically similar for buried services of similar size and location, since the loads acting on the buried systems because the appropriate embedment and surround are largely influenced by what external loads can apply – for example whether in the road or in an untrafficked area – rather than by the service provided.

Because of the relatively similar materials used and the similar installed environments the response of buried services to a seismic event is largely determined by the response of the surrounding soil. In short, greater damage can be expected where there is liquefaction of soil and more still where there is permanent ground deformation or fault movement.

The depth of installation has relatively little impact since in seismic terms shallow soil extends 10 to 30 m beneath the surface, which is considerably greater than typical burial depth of utility services. However, services installed nearer the surface are potentially more likely to experience compressive bending instead of compressive buckling because of the reduced support above the service. The likelihood of bending is further increased since the services and ducts are relatively slender compared with water and gas systems.

2.3 Nature of Services

Water is an essential service and a reliable clean supply underpins modern public health expectations. Wastewater services are also important for public health, while stormwater services are important for minimising damage after an event.

While electricity, gas and telecommunications services are important, they are less critical than water supply to public health. Temporary electrical supplies can also be located above ground rather than buried, which means that restoration of electrical services, can be relatively quick. In Christchurch electrical supply was largely restored outside of the severely damaged red zone within 16 days (Figure 1 and Figure 2).

Similarly the widespread use of mobile phones meant that some communications capacity could be maintained through above-ground links provided people could recharge their phones. Many handsets for conventional landlines draw power through the phone line and can remain functional even where power supplies were limited.

3 Observed Behaviour

Different systems are considered in turn below. It was noted during this review and by other authors [6] that good quality information is less widely available than for water systems.

3.1 Gas Reticulation System

In Kobe in 1995, the gas system had a lower incidence of breaks than the water system. This was largely attributed to the widespread use of fused PE for the distribution network. The relatively good performance of the gas system resulted in Japanese engineers visiting the UK over the course of three years to discuss the UK experience of introducing PE80 pipelines to the UK water industry in the 1980s and the ongoing support programme for introducing PE100 in the 1990s [8]

Only 27 repairs were reported in 24,000 km of PE distribution piping following the Northridge Earthquake in 1995 [9].

In Christchurch, only one break was reported in 170 km of buried gas distribution system.
A representative from Gasco said in a phone discussion [10] that based on experience, the gas system held up well and said that the gas system had a high standard of construction. There was one physical failure in the ground where a steel transition sleeve guillotined a PE pipe. There was no evidence of stretching of PE pipes in the gas system.

There were, however, at least some failures in galvanized steel pipes exiting the ground where buildings were severely damaged (including by building collapse). There was also a report of a loosened flange connection in one pumping station and one LPG filling station had to be temporarily closed because loss of the water supply had shut down the fire suppression system.

Discussions at a meeting on 11 April 2013 [11] also indicated that the Rockgas system had virtually no damage. We were also advised that the OnGas system was installed in Northwood and Shirley.

The gas reticulation system in Christchurch was largely made of fusion welded PE and despite a substantial part of the system being exposed to shaking intensities in excess of 0.4g PGA, and some in excess of 0.8 PGA, it remained substantially undamaged (Figure 3). Since Shirley experienced widespread liquefaction, lateral spreading on the streams leading to later flooding, and significant property damage, low damage rates experienced cannot be attributed to the system being located away from areas of potentially damaging ground response.

Testing of fusion jointed PE systems [12] indicates that fusion jointed PE is very durable in tension, compression and bending. The type of damage that could render a fusion joint vulnerable to seismic failure would normally prevent passing of the site commissioning test, or would result in leakage within the first year or so of service. This behaviour is consistent with there being no records of failure in fusion joints in the PE pipeline system for either water or gas.

PE is capable of sustaining sub-critical damage, such as over-extension and deformation that could increase likelihood of future failure or degrade operability [13], Figure 4. Because sub-critical damage does not require immediate repair it may not be recorded as earthquake damage when the problem is eventually detected. This means that reported repair rates for PE are likely to underestimate the true damage rates. As sub-critical damage is usually a response to Permanent Ground Displacement, most sub-critical damage in PE pipelines will mainly be confined to areas subjected to lateral spreading.

Even allowing for some underestimation of actual damage rates in the reported figures, it is clear that PE gas systems have experienced relatively low damage rates in general and that modern systems in particular had very low rates of damage.

The current gas distribution standard NZS 5258:2003 [14] provides guidance on minimising seismic risks in gas distribution systems, as does the previous 1995 version. While the 1995 version provides less comprehensive seismic guidance, it appears reasonable to conclude that gas industry practices on design, construction and materials selection have together contributed to low damage rates even in ground subjected to substantial shaking and to liquefaction and to lateral displacement.

The gas system in Christchurch is composed of modern PE pipelines that have a history of performing well in earthquakes. The performance of steel gas lines is also of interest.

TCLEE Monograph 8, 1995 Northridge Earthquake Lifeline performance and post-earthquake response [9] reported that there were 35 non-corrosion related repairs in the 6,100 km steel gas system, of which 25 were cracked or ruptured gas welded joints made before 1932.

154 other instances of damage to metallic distribution and service pipes where there was no construction or corrosion damage or where the origin of the damage was unknown. Damage included pipeline breaks, leaking flanges and a fractured flange.

Steel liquid fuel lines showed distinct differences with method of construction. Eight failures were reported in a steel line constructed in 1925 using gas welded joints, but none in lines built in 1950 and 1993 using modern electric arc welding. It was not clear in the TCLEE report if liquid fuel included liquefied gas, but construction standards for flammable fuels will be broadly similar because of the potentially explosive nature of the contents.

Failure rates in modern steel gas systems also appear to be low although older systems constructed before more reliable electric welding was available present a higher risk. The type of joint also has an impact and Eidinger [15] reports that by upgrading a single lap welded joint to a double lap weld (welded both internally and externally) or a butt weld the pipeline can withstand additional ground movement.

Installation practices that minimise seismic risk and improve system resilience are largely transferrable directly to water supply applications, and some can be applied in other piped or ducted systems.

The pattern of behaviour is consistent with that observed elsewhere, in which modern systems performed well while older systems made using inferior construction practices showed more evidence of failure.

3.2 Electrical Cables

Orion had more than 2,000 km of 11 kV cables in Christchurch that were affected by the September 2010 and February 2011 events [6]. Breaks in cables included failure of couplings in tension, failure of cables in compression (Figure 6) and damage resulting from failure of concrete slabs used to support cables [16]. Damage included critical 66 kV cables. While many failures occurred in areas that experienced liquefaction and lateral spread, failure also occurred in areas that were only affected by shaking [19].

Eidinger's work [16] showed that liquefaction-induced bending failure of concrete slabs used in the trench construction first resulted in the cables acting as reinforcement, and then caused local crushing of the metal cable sheath leading to shorts.

Eidinger also reported that initial test results showed that ducted cables survived these conditions better than exposed cables because while the duct deformed, the cross section remained sufficiently circular to allow the cable to remain undamaged, although it probably would have needed repair to allow new cables to be installed in the duct.

Installation and jointing faults tend to dominate in buried electrical cables in normal service [5]. In common with water pipeline systems, the concept of pseudo-static loading indicates that poor installation practices also reduce the effective factor of safety against seismic loading [17].

The break rate in buried electrical cables could be reduced by eliminating the use of concrete beams and by encouraging the use of good installation practice. Use of post-installation testing will help improve or maintain good jointing practice [5] and is likely to also encourage good installation practice where the installation and jointing teams use the same people.

In the 11 kV system, break rates in the September 2010 and February 2011 events were approximately 4 times the typical annual break rate [6]. Despite some limitations in the data and further restrictions imposed by commercial sensitivities, it was clear that break rates increased where there was liquefaction and permanent ground deformation. Modern cables with PE sheathing had lower break rates than older cables with PILCA sheathing. Higher break rates in copper conductors were believed to reflect the greater historic use of copper when PILCA cables were being installed, rather than any weakness in copper itself.

This indicates that over time there will be benefits from replacing older cables with newer more resilient systems in combination with use of improved installation practices. There were relatively few reports of failure in ducted services.

3.3 Telecommunications Cables

Chorus reported localised cable damage and water intrusion, along with sub-critical damage and delayed failures that had not caused immediate outages but which were expected to result in increased future cable faults [18]. There were also some issues where soil settlement or flotation of connection boxes required re-levelling of the covers.

During a SCIRT meeting on 11 April 2013, we were advised:

> *Enable Broadband, a new and relatively limited system experienced little or no damage, and that the Telstra network suffered very little damage, although liquefaction entered ducts.*

While telecoms systems had experienced low rates of damage during the earthquakes, there were some concerns about third-party contractor damage during repairs on other systems. It appears that the incidence of third-party damage was increased because as-built drawings that referenced features such as trees and buildings were of limited help if the trees had fallen during an event or if the reference building had collapsed. Chorus considered that they could improve overall system resilience by improving as-built specifications (citing Enable's as-built specifications as a good example), including by taking reference benchmarks from points more likely to survive an earthquake.

In part the low damage rates were because the clearance between the bore of the duct and the service inside allows space for differential movement the ducts can accommodate some measure of temporary or permanent deformation without impinging on the cable. This is illustrated by preliminary test results reported by Eidinger [16] in respect of electrical cables.

4 Summary

The overall behaviour of ducted cable systems can largely be explained by reference to observed behaviour of other services and systems.

PE ducts can experienced over extension (Figure 7). PVC ducts generally do not have end-load resistant joints and can be expected to pull apart when subjected to tension, as with PVC pipelines. Similarly compression will tend to result in buckling, bending or over-insertion of the pipe into the socket of the joint.

Provided the service inside the duct has some slack, it has some ability to accommodate tension by straightening out before substantial strain is applied. Similarly, a cable inside an over-inserted duct could remain undamaged if the reduction in overall length could be accommodated by curvature of the service.

Compressive buckling may reduce the local bore, but is typically a localised phenomenon, so provided the cable does not get damaged at that point, the line may well remain serviceable. Similarly, separation of the cable or re-insertion failure will not cause immediate failure or loss of service if the cable inside remains undamaged. Loss of duct integrity is, however, likely to result in an increased risk of failure or deterioration due to local loss of protection.

Bending of ducts may cause damage if the bending is sufficient to reduce the free bore below the diameter of the conveyed services or if the bending radius is too tight for the conveyed systems to accommodate. As with electrical services, damage to the duct can prevent extraction of an existing service or installation of a new service even if the existing service remains functional.

Silt intrusion is likely to hinder future repair and maintenance activities by blocking ducts and hindering the ability to extract and install cables. Reduced ability to accommodate thermal expansion and greater time of wetness could potentially compromise durability of cables in silt-affected ducts, but these longer-term effects may not become apparent for some time.

5 Estimated Break Rates

As with water pipeline systems, break rates in other buried services can be predicted as follows:

- Shaking intensity is determined in the form of pga using standard procedures for earthquake hazard assessment such as NZS 1170.5;
- Soil hazard maps and can be used to identify whether liquefaction or lateral displacement also need to be considered;
- A breakdown of different materials types used within the community is obtained from the asset register provide. Even a crude percentage breakdown for different materials types is useful;
- Fragility functions are then applied to determine how many breaks can be expected in each system.

While reasonable break rates can be determined, good quality information is less widely available than for water pipeline systems [6] and that sub-critical failures or deferred failures can occur in buried systems other than water pipeline ones.

6 Conclusions

Break rates for utilities other than three waters systems can be determined using a similar approach to that used for three waters systems;

Good quality information is less widely available than for three waters systems;

Sub-critical failures and deferred failures can occur in all buried systems, not just in three-waters systems. Because of this, estimated short–term break rates are likely to under-estimate the total amount of damage caused by seismic events, especially in areas subjected to lateral spreading.

7 References

1 AS/NZS 4130: 2008 Polyethylene (PE) pipes for pressure applications

2 AS/NZS 4129:2008 Fittings for polyethylene (PE) pipes for pressure applications

3 http://www.nexans.co.nz/eservice/NewZealand-en_NZ/navigate_304855/Nexans_Cables_electrical_cables_manufacturer_fibre_optic_cables_accessories_LAN.html, accessed August 2016.

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5 T Lord, "Power Industry Update – Identification of the major issues determining cable life and reliability", 2005.

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7 "Fibrolite pipes catalogue", James Hardie and coy pty Ltd, 1972

8 J Morris, personal experience while in the UK, 1996 to 1999.

9 TCLEE Monograph 8, 1995 Northridge Earthquake Lifeline performance and post-earthquake response.

10 J Morris, on 21 February 2013 phone conversation with Gasco and subsequent conversations with AltasGas, OnGas and Contact, 2013 and 2014.

11 SCIRT meeting, Christchurch, 11 April 2013

12 J Morris, personal experience, 1991 to 1999 and physical testing 2016.

13 Technical Note 3 Sub critical seismic damage and hidden failures, 2016.

14 NZS 5258:2003 "Gas distribution networks".

15 J Eidinger, in "Optimizing post-earthquake lifeline system reliability" edited by WM Elliot and P McDonough, TCLEE Proceedings of 5th US Conference on Lifelines Earthquake Engineering, August 12 to 14, 1999, Seattle Washington, USA.

16 J Eidinger "Performance of buried high voltage power cables due to liquefaction", 2012

17 Technical Note, Effect of Installation on seismic performance.

18 C Foster et al, "The performance of the Telecommunications Network in the Darfield Earthquake: a success story", Proceedings of the ninth Pacific Conference on Earthquake Engineering, 14 to 16 April 2011, Auckland, New Zealand.

19 L Sheng-Lin et al, "Seismic Performance of Buried Electricity Cables during the Canterbury Earthquake Sequence", Australian Earthquake Engineering Society 2016 Conference, Nov 25 to 27, Melbourne, Victoria, Australia

Figures

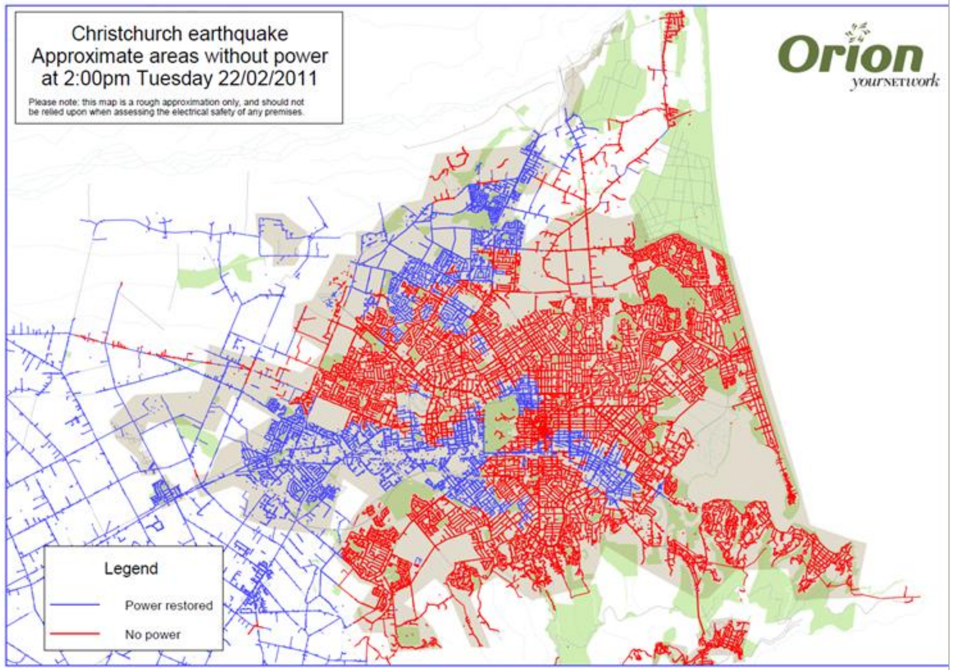

Figure 1: Orion Faults 22 February 2011

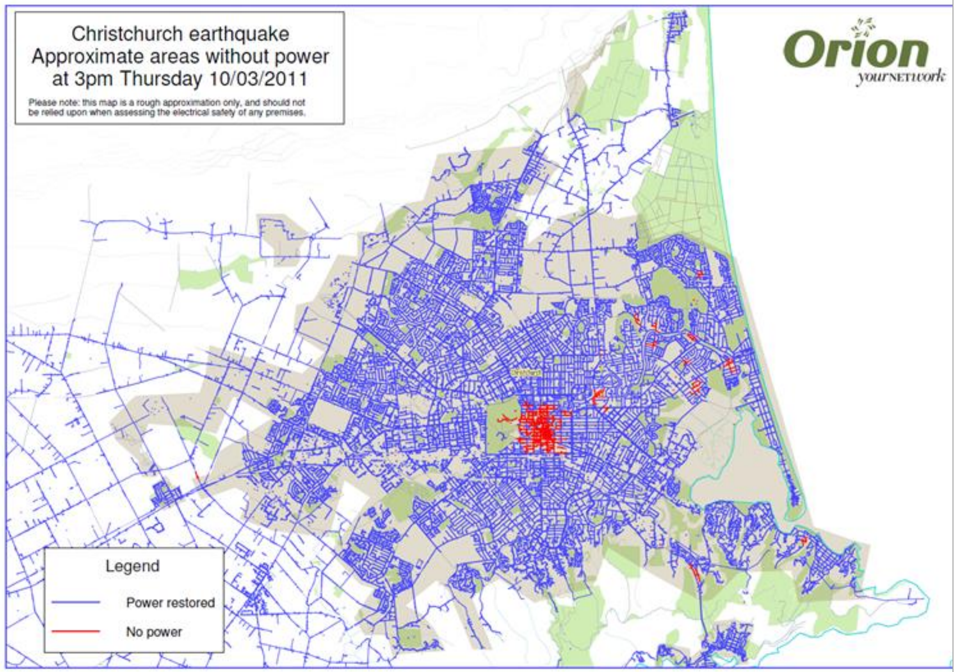

Figure 2: Orion faults 10 March 2011

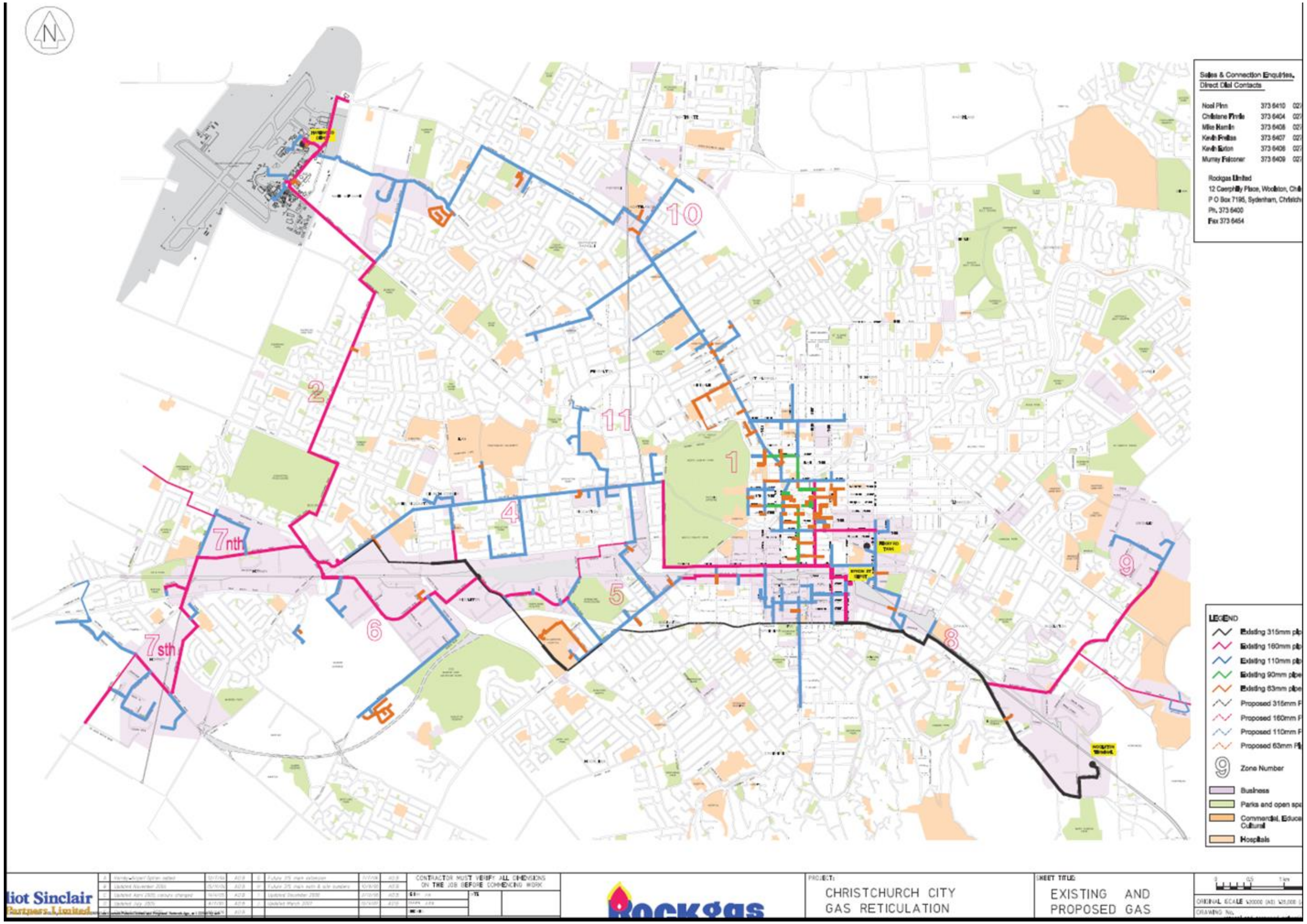

Figure 3: The RockGas Christchurch gas pipeline network from http://resources.ccc.govt.nz/files/customercentre/gasreticulationnetwork.pdf, August 2016. Most of the lower right quarter of this map experienced PGA in excess of 0.4g, and PGA exceeded 0.8g at the Woolston Terminal in the lower right hand corner.

Figure 4: PE pipes deformed in laboratory tensile testing.

Figure 5: Damaged aluminium sheath on electrical cable damaged in Christchurch, and recovered December 2012.

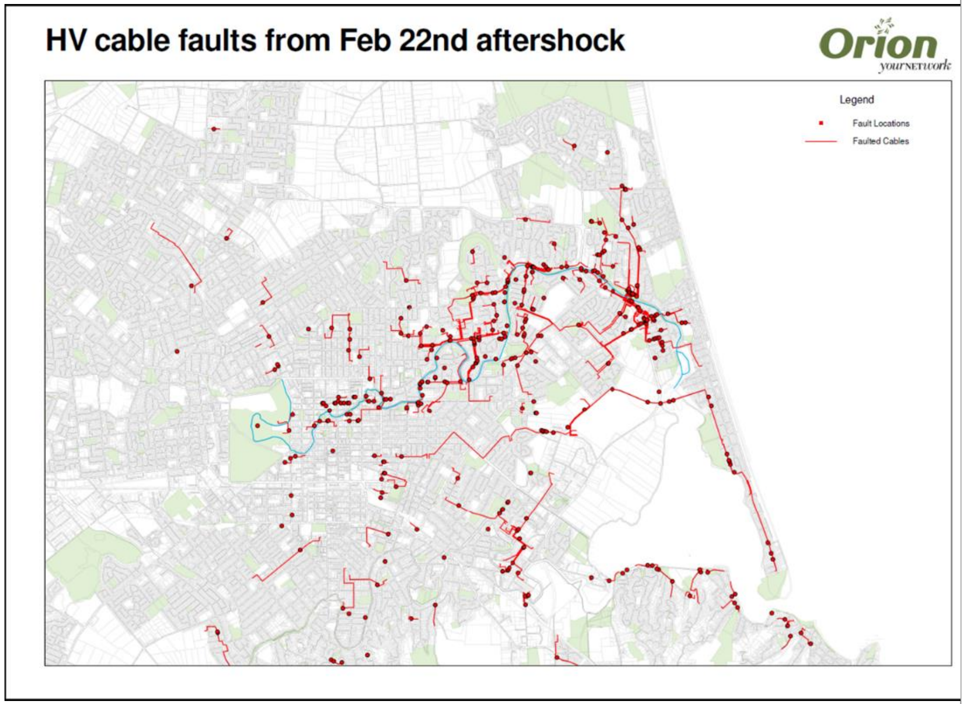	
Figure 6: HV Cable faults identified in Orion High Voltage Cables after 22 February 2011.	Figure 7: Telecommunications cable duct damaged in one of the Christchurch earthquakes. It is believed to be PE100 DN 25. Yielded and hyper-extended to fracture at RHS. It is unclear if the feature at the LHS is due to compressive buckling or bending. Image provided by Frank O'Callaghan.