Performance of Underground Electricity Cables during the 2010-2011 Canterbury Earthquake Sequence: Insights for assessing Criticality and Resilience

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Motivation

The reliability of an electrical network is a key feature in Power System's network operation which ensures a continuous power quality and minimum interruption. However, during a low-probability high-impact event like earthquakes the disruption on the network can be long- term depending on the damage to the network assets.

For network restoration, the overhead equipment can be more easily monitored and accessed for repairs, while underground cables which are distributed through a wide area are difficult to monitor in order to identify fault locations and target repairs. The aim of this project is to study the effect of earthquakes on underground cables using case history data from the Canterbury earthquake sequence, identify the critical assets in the network and develop metrics to improve the assessment of the resilience of the network.

Impact	Darfield Earthquake	Christchurch Earthquake
Date & Time	04 Sep 2010 4:36AM	22 Feb 2010 12:51PM
Magnitude & Depth	Mw7.1, 10 km	Mw6.2, 5 km
Location	40 km west	10 km south-east
Damage (%)	1-3	7-10
Restoration Time (90%)	1 day	10 days
Customer Minutes Lost	88 Million	630 Million

Table 1: Effect of Darfield and Christchurch earthquakes Ref. [1]

Impact of Earthquake on Orion Electrical Network

Orion operates the third largest electricity distribution network in New Zealand which covers 8,000 square kilometres across central Canterbury and delivers electricity to more than 201,000 homes and businesses. A schematic overview of the Orion network and the upstream transmission and generation is presented in Figure 1.

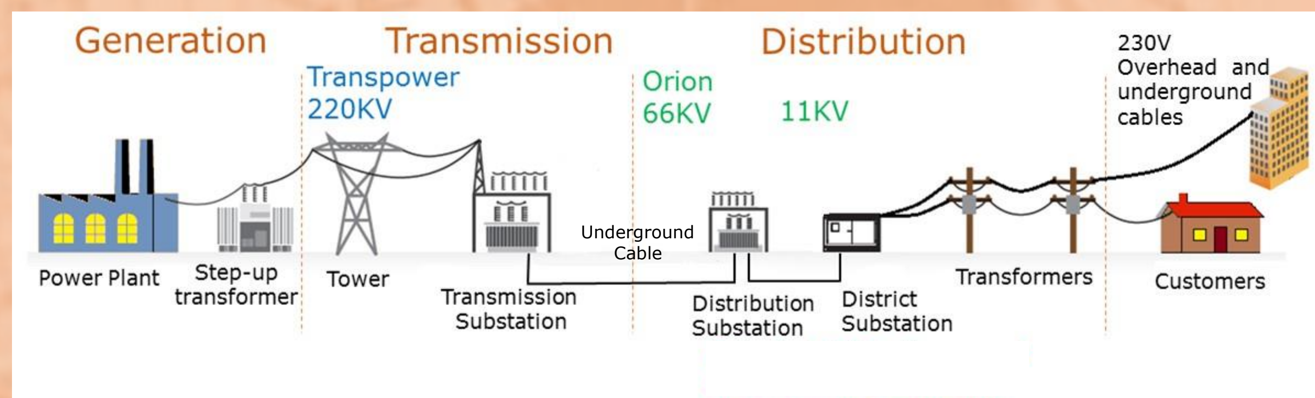

Fig. 1: Schematic of the Orion network

The characteristics of the 2010 Darfield and 2011 Canterbury earthquakes and the impact on the Orion network are summarised in Table 1. The majority of the city of Christchurch resides upon alluvial sediments, with the south of the city situated on the Port Hills [Ref. 2]. As such, during these earthquakes the network was exposed to a range of hazards. The potential effects of these hazards on the overhead and underground electricity assets are summarised in Table 2.

Hazard	Overhead Asset	Underground Asset
Liquefaction	Minor/Moderate	Major
Lateral Spreading	Minor/Moderate	Major
Ground Deformation	Minor	Major
Tectonic Uplift	Minor	Major

Table 2: Effect of earthquake hazards on electricity assets

Cable Damage

This project focussed on the faults that occurred on 11kV underground cable during the earthquake events of 2010 to 2011. The cable characteristics in the 11kV network are summarised below, and examples of the types of cable damage are summarised in Figure 2 and below.

Type of Underground Cables

Metal core
- Copper
- Aluminum

Insulating Material
- Paper-Insulated Lead Covered Armored (PILCA)
- Cross-Linked Polyethylene (XPLE)
- High-Density Polyethylene PILCA (PILCA HDPE)

Damage to Underground Cables

1. Bending
2. Stretching
3. Insulation damage
4. Joint Breaks
5. Connections pulled-off equipment

Fig. 2: Examples of damage to the Orion network in 2010 and 2011

Framework

Process

- The initial focus was the identification of the fault locations of 11kV underground cables.
- Using repair job data and through discussion with network engineers, identify all repair jobs across the network during in 2010 and 2011 related to the earthquake damage.
- Collate data in a geospatial database with the associated metadata: cable type, date of repair, type of joint and job number.
- Map the geo-spatial data with the ground shake intensity map to observe the damage.

Dataset

- Following the 2010 and 2011 earthquakes, 1066 repairs jobs were carried out on the 11kV network. The temporal repair characteristics are summarised in Figure 3 and the geospatial characteristics of the repairs during 2010 and 2011 are summarised in Figure 4.

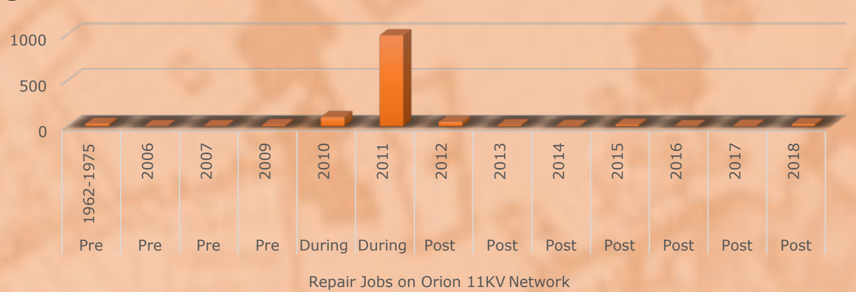

Fig. 3: Temporal distribution of repairs on the 11kV network

- Due to the nature of the response, the nature of the damage was not always recorded, as priority was given to repairing the network. As such the damage dataset is not 100% complete.

Outcome

- The repair jobs were greater around Avon River due to severe liquefaction manifestation and lateral spreading.
- The majority of these repair jobs were due to the failure of existing joints across the network.
- The cables passing through bridge abutments were damaged due to differential movement between the bridge and the approach.

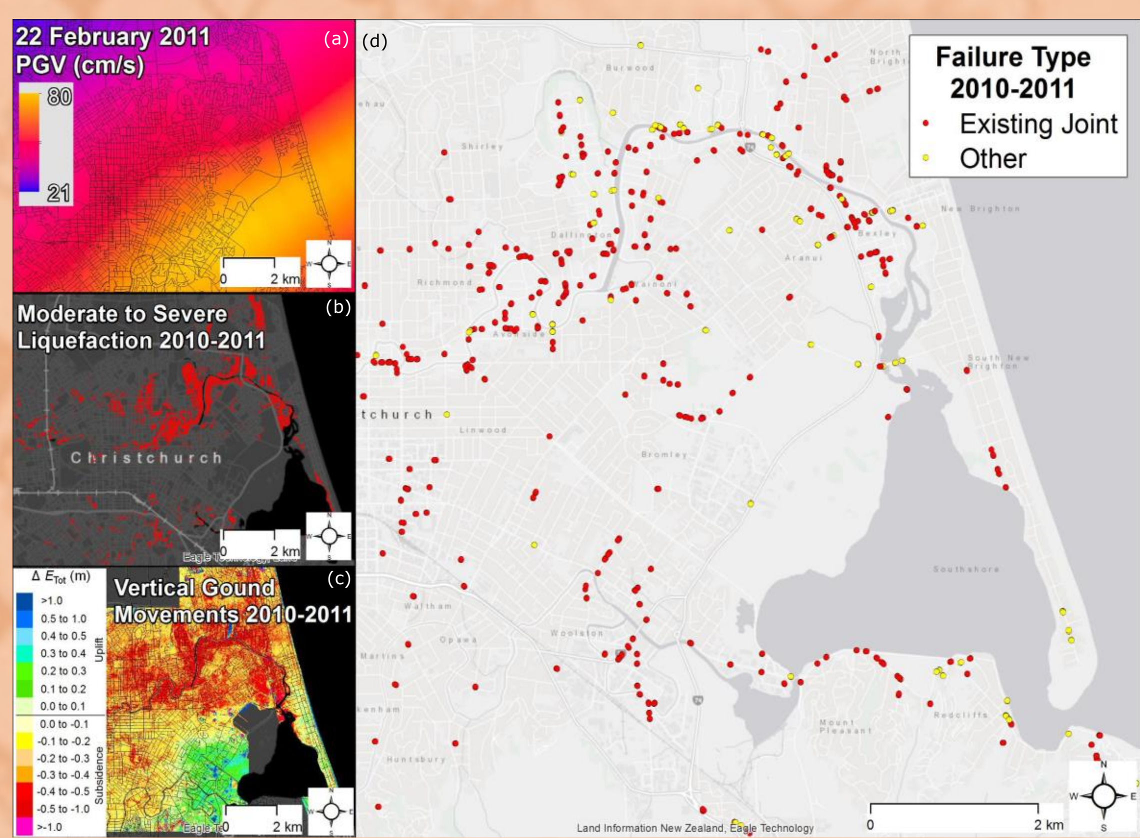

Fig. 4: (a). Peak ground velocity, (b). Liquefaction, (c). Vertical ground movement, (d). Repair jobs in 2010-2011 on the 11kV network (combined)

Future Work

- Complete the case history database for the entire underground network consisting of HV and LV cables following the 2010 and 2011 earthquakes.
- Collate pre and post earthquake data to assess the rates of repair during these periods.
- Assess the data for cables not damaged during the earthquakes.
- Combine the datasets outlined in Figure 4 to develop fragility curves for these assets.

References

1 K. Group, "Resilience Lessons: Orion's 2010 and 2011 Earthquake Experience - Independent Report," 2011, Available: http://www.oriongroup.co.nz/assets/Customers/Kestrel-report-resilience-lessons.pdf.
2 M. Hughes et al., The sinking city: Earthquakes increase flood hazard in Christchurch, New Zealand. 2015, pp. 3-4.

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