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RESILIENCE AND FRAGILITY OF THE TELECOMMUNICATION NETWORK TO SEISMIC EVENTS: EVIDENCE AFTER THE KAIKŌURA (NEW ZEALAND) EARTHQUAKE

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ABSTRACT

This paper provides an overview on the physical and functional performance of the New Zealand telecommunication network following the 14 November 2016 Kaikōura earthquake (Mw 7.8). Firstly, the paper provides an overview of the New Zealand telecommunications infrastructure. Secondly, the paper presents preliminary information on the impacts of the Kaikōura earthquake on the telecommunication network following the format proposed by [1] for post-earthquake assessment and resilience analysis of infrastructure systems, namely: extent of earthquake-induced physical impacts on the components of the telecommunication networks, identified according to a proposed taxonomy; main observed dependency issues; identification of resilience attributes and strategies that allowed an effective and rapid reinstatement of the telecommunication service. Finally lessons learned and research needs are discussed.

INTRODUCTION

The New Zealand telecommunication infrastructure comprises two main networks, the landline and the wireless service network. These are linked together by means of data interoperability and transmission exchanges, with each comprised of further components, including among others: exchange facilities; overhead lines and poles; underground cables; access pits; roadside cabinets; cellular towers.

The operation of telecommunication networks is critical during business-as-usual times, and becomes most vital in post-disaster scenarios, where the services are needed to carry out emergency and relief management tasks, and for restoring other critical lifelines, due to inherent dependencies. In spite of the importance of telecommunication networks, the assessment of its seismic performance appears to be underrepresented in the literature.

New Zealand is contributing to bridge this gap. After the 2010–2011 Canterbury (New Zealand) earthquake sequence national and international researchers and highly experienced asset managers from Chorus collaboratively worked to enhance the understanding of the earthquake performance of telecommunication systems [2-6] In the same context, this paper aims to collect and collate some preliminary information on the physical and functional performance of the telecommunication network following the complex sequence of ruptures that started at 00:02:56 NZDT on 14 November 2016 in the South Island of New Zealand, referred hereafter as the Kaikōura earthquake.

Firstly, the paper provides an overview of the New Zealand telecommunications infrastructure. Secondly, the paper presents preliminary information on the impacts of the Kaikōura earthquake on the telecommunication network following the format proposed by [1] for post-earthquake assessment and resilience analysis of infrastructure systems.: The extent of earthquake-induced physical impacts on components of the telecommunication networks, identified according to a proposed taxonomy is first presented. Main observed dependency issues are then presented, followed by identification of the resilience attributes and strategies that allowed an effective and rapid reinstatement of the telecommunication service. Finally lessons learned, research needs and on-going researches are discussed.

NEW ZEALAND TELECOMMUNICATION INFRASTRUCTURE

The New Zealand telecommunications infrastructure is largely based on a series of *interconnected fibre-optic networks*, as depicted in Figures 1 and 2. The up- and down-stream traffic from each of the 1.22 million connections is transported around the country by a *core network of fixed lines and exchanges* (Figure 1) before being handed over to retailer service providers – such as Spark, Vodafone, Orcon, 2degrees and many others – at different locations around the country [7]. Specifically, the *National Backhaul* links the Gateways, which provide international connectivity via undersea cables, to the *Major Exchanges* located in large cities throughout the country. *Regional Backhaul* networks connect these *Major Exchanges* to smaller *Local Exchanges* in the surrounding region. Most homes and businesses connect either directly to a local exchange or via a roadside cabinet (Figure 2). This "last mile" connection has traditionally been copper. The local copper networks are all still in place throughout New Zealand, however they are increasingly being replaced with fibre in the

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most populated centres through the New Zealand government "ultrafast broadband" (UFB) initiative[1].

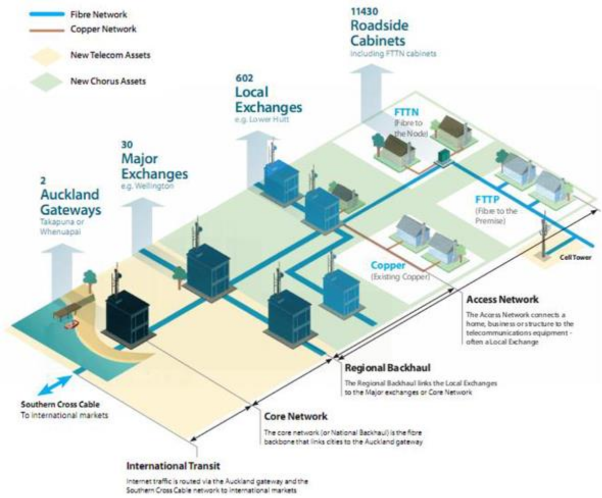

Figure 1: Schematic structure of telecommunication transport network in New Zealand (courtesy of Chorus).

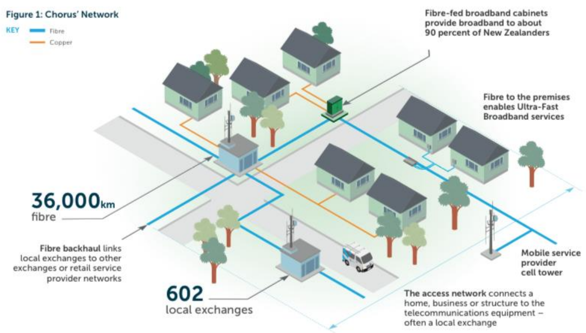

Figure 2: Schematic structure of telecommunication access network in New Zealand (courtesy of Chorus).

The *mobile network infrastructure* runs over a combination of 2G, 3G and 4G technologies operated by different mobile retail providers – such as Spark, Vodafone and 2degrees. It should be noted that wireless coverage is limited by the terrain conditions and typically does not exceed 5-10 km from a *cell-site*. Accordingly, the fibre backbone is used to connect *cell-site* to the *main fixed data transport networks* (in some remote areas, point-to-point microwave backhaul is also used). Further retail network providers, such as Skinny, Slingshot and Warehouse Mobile, among others, resell mobile network services.

Investment in Telecommunication Infrastructure

The telecommunications industry in New Zealand is investing at one of the highest rates in the Organisation for Economic Co-operation and Development, OECD. It is one of New Zealand's most innovative sectors, and provides a range of services that are increasingly competitive on both price and quality compared to other countries. The sector is helping to lift living standards, drive technological change, and enhance the economy's underlying productivity capacity.

Such progress is the result of unprecedented levels of investment by industry participants, innovation, industry collaboration as well as improving competition in a number of areas in the market. The roll out of the UFB initiative and of the Rural Broadband Initiative[2] along with the exceptionally quick deployment of three separate 4G mobile networks has underpinned this progress. Connecting learning centres, healthcare providers, emergency services and other community services to high speed broadband are delivering life-changing benefits for individuals and groups in New Zealand [7].

New Zealand Telecommunications Service Providers

Following a demerger from Telecom (now Spark) in 2011, Chorus Ltd is New Zealand's largest fixed line communications infrastructure services provider, and supplies more than 90% of all fixed network connections to retail service providers. The core of Chorus' business is the nationwide network of fibre optic cables (36,000km) and copper cables (130,000km) that connect homes and businesses to each other. These cables typically connect back to local telephone exchanges, of which Chorus has about 600 nationwide [8]. Chorus fibre also connects many cellular towers owned by mobile service providers. Approximately 7,000 cabinets provide inter-connection points for 50% of the lines in the Chorus network. A large number of these cabinets are active, containing the electronics to deliver the full range of services including Plain Old Telephone Service, POTS, (also referred to as Public Switched Telephone Network, PSTN) and Broadband services. Chorus' existing business fibre and fibre-to-the-node (copper/fibre) networks compete with a range of other network operators across different areas around New Zealand, including:

• Local fibre companies (LFCs), Northpower, Ultrafast Fibre and Enable Networks, have built portions of the UFB network beside approximately 365,000 premises in 9 UFB regions;

• Vodafone has a cable network in Wellington, Kapiti and Christchurch connecting about 60,000 broadband end-users. It also has business-fibre networks in all major central business areas and a national transport and backhaul network;

• Vector, FX Networks (subject to a purchase offer by telecommunications company Vocus), Citylink and Unison operate fibre networks of varying sizes, typically focused on the backhaul and business markets.

• Some retail service providers have chosen to 'unbundle', by installing their own broadband equipment in exchanges and just renting access to the local lines from Chorus;

• Vodafone, Woosh, CallPlus and Now are among a range of "fixed wireless" network providers;

• Spark, Vodafone and 2degrees operate mobile phone networks that are currently based on 3G technology and they are implementing, or planning, upgrades to 4G technology.

14 NOVEMBER 2016 KAIKŌURA EARTHQUAKE

A complex sequence of ruptures with a combined moment magnitude of M_w7.8 started at 00:02:56 NZDT on 14 November 2016. The hypocenter was at a depth of 15 km. The epicentre was 15 km north-east of Culverden and 95 km from Christchurch [9] and ruptures occurred on multiple fault lines in a complex sequence that lasted for about two minutes [10]. The east coast of the South Island was the worst affected area.

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[1] Ultra-Fast Broadband is a generic term used to describe the transmission medium (such as fibre, copper or wireless) capable of delivering high-speed internet access. In New Zealand, the government's UFB initiative aims to provide faster, better internet to at least 99 per cent of the population by 2025 [7].

[2] The Rural Broadband Initiative is designed to help rural communities to benefit from high class internet connectivity. The combination of wireless towers, rural cabinets and fibre will enable more than 90 per cent of users outside UFB areas to enjoy broadband internet [7].

The geometric mean peak ground accelerations (PGAs) from strong motion stations in the area where telecommunications infrastructure was most affected are summarised in Figure 3 [11], along with the epicenter of the earthquake. A more comprehensive summary of the ground motion characteristics across the region can be seen in [12].

Several roads in the South Island were closed as a result of the landslides and earthquake-induce damage to road pavement and structure, including a significant number of routes connecting the west and east coasts [13]. Widespread damage was reported to bridges, infrastructure and buildings in the northern South island [14], [15]. Power was lost in many small South Island towns and parts of Wellington [16].

As far as telecommunication is concerned, further to some damage induced by the ground shaking, fault ruptures, that crossed State Highway 1 at multiple locations, resulted in damage to the buried fibre cables that ran alongside the roadway (Figure 4). Further co-seismic impacts to the telecommunications network were a result of landslides [17] and liquefaction/lateral spreading-induced damage. Cables crossing bridges, which were damaged due to differential movements between the superstructure and the approaches, sustained damage because of spreading and slumping. Poles close to riverbanks affected by lateral spreading, moved or tilted, stretching overhead cables. Further details are provided in the subsequent section.

Figure 3: Map of part of New Zealand South Island, location of the epicentre of the events and of the main town/locations mentioned in the paper with recorded PGA (g). The approximate region that was impacted by landslides and fault rupture is summarized in this figure. Yellow lines indicate the main road links, with red shields representing the State Highway numbers.

Figure 4: Example of a fault rupture on State Highway 1 that severed the East Coast fibre-optic cable. Photo: Dizhur & Giaretton.

IMPACTS ON THE TELECOMUNICATION NETWORKS

The Kaikōura earthquake impacted both mobile and fixed line services in the lower North Island and upper South Island. The areas of Kaikōura, Ward, Hundalee, Clarence and Waiau sustained significant damage and customers in these areas experienced a loss of telecommunication services. Around 2500 customers were without fixed line service on 14 November. Kaikōura was completely isolated from the national network as the major fibre optic cable supplying the region, known as the *East Coast Link*, was severely damaged. Most residents of Kaikōura and other affected areas could call each other on fixed copper lines locally, but no calls could be made into or out of the affected areas. Text service within Kaikōura was restored within five days from the event. Emergency calls were relayed on satellite phone.

Delimitation and Description of the Network Affected by the Event

The telecommunications infrastructure in the areas affected by the Kaikōura earthquake is similar to other rural centres in New Zealand. Among others, two exchanges operate in the affected areas, namely the *Kaikōura exchange*, a Major Exchange located in Kaikōura town (operated by Chorus) and the *Waiau exchange, a Local Exchange,* located in Waiau, a small in-land town (Figure 3). The Kaikōura exchange and its distribution area are connected to the *National Backhaul* network via the *East Coast link. The East Coast links* runs from the top of the South Island to Christchurch along State Highway 1 through Clarence and Kaikōura, and supports both fixed line and mobile networks for minor and major town centres, including Christchurch and Dunedin (the largest and the second-largest cities in the South Island of New Zealand, respectively), though these two cities are also connected through the *West Coast fibre link*. Cell sites in the Kaikōura region, operated by all the major service providers, are also connected to the national network via the *East Coast link*. Houses and businesses in Kaikōura and the surrounding regions are mostly connected to the *local exchanges* via *copper lines*, though *roadside cabinets* are connected to the exchanges by underground or overhead fibre links. The way the local network is structured means that local traffic, i.e. calls within the region served by a single exchange, can continue to be routed without needing a connection to the national core network.

A coincidental feature is that an undersea fiber cable, known as *Aqualink Cable*, connecting Wellington and Christchurch (owned and operated by Vodafone NZ Ltd) comes ashore in Kaikōura for signal amplification only and it is normally not connected to the local network at that point.

Damage Assessment

After the Kaikōura earthquake, aiming to locate any likely faults, Chorus and Vodafone tested the main cables from Blenheim South to Christchurch North. An aerial inspection was also undertaken from a helicopter by flying over the main cable lines from Blenheim South to find out the cables cross areas that were affected by land movements or landslides. The inspections helped to quickly identify major faults.

In business as usual times, Chorus has responsibility for the maintenance of cables from the North down to Parikawa (a small village North of Clarence) while Vodafone has the responsibility for the cable maintenance from Parikawa to South. However, after the Kaikōura earthquake there was high-level cooperation between Chorus and Vodafone to undertake the damage assessment of the cables and to plan for subsequent repair activities.

Qualitative Description of the Damage to the Network Components

The damage observed in different components of the telecommunication network, after the Kaikōura earthquake, is herein reported according to the taxonomy proposed by Giovinazzi et al. (2015) for landline and wireless telecommunication networks (Table 1).

(a) *(b)* *(c)* *(d)*

Figure 5: Damage of cables after the Kaikōura earthquake: a), b) Instances of permanent ground deformation and fault ruptures at cable locations; c) example of stretched cable; d) example of broken cable (Photos courtesy Rob Ruiter, Chorus).

Table 1: Components of the landline and wireless network.

Landline Network	Wireless network
Exchanges (Major and Local)	Mobile Switching Centres (MSC)
Remotes	
Buried cables (copper and fiber)	
Access pits (vaults /manholes)	
Roadside cabinets	Cell sites (and roadside cabinet)
Aerial cables (copper and fiber) and poles	Cellular towers
Cross connect pedestals	-
Micro-wave system	

Landline Network

Exchanges:

- *Kaikōura Exchange:* the structural elements of the building were undamaged but the exchange sustained minor damage internally, limited to a rack that had broken mounting causing some electronic boards to rattle. Some of these electronics just had to be reset and in some cases reprogrammed, but others had to be replaced with new boards that were flown in to Kaikōura. However, the exchange was not connected to the national network due to damage to the fixed network.
- *Waiau Exchange:* the exchange itself was not damaged but the fibre connectivity to the exchange was. As a result the exchange was isolated. Restoration of the connectivity to the Waiau exchange was completed on 16th November after the replacement of 1km of fibre cable that was helicoptered in.

Buried cables (copper and fibre):

- *The East Coast Link*, a major fibre optic cable, was severely damaged. Six breaks were identified along the East Coast Link cable [18].
- *Cables* many (mainly copper) were severely damaged. Overall, most of the damage identified on the network was on cables and it was due to cables being stretched and broken as a result of both transient ground motion, permanent ground movements and fault rupture at cable locations (Figure 5). Where cables were stretched, faults were identified not only in the immediate vicinity of ground cracking, but also in some cases 100 m plus along the cable length away from the main source of the displacement. This was due to the internal wires being stretched. In some instances, the extent of stretching was to a degree that changed the cable characteristics quite markedly.
- *Cables at bridge crossings* were severely damaged. Cables, attached to the side of bridges, sustained damaged because of ground motions and/or differential movement between the bridge superstructure and the approaches. This resulted in twisting and stretching of cables that therefore had to be replaced.

Access pits (vaults /manholes):

No damage was observed to access pits that are normally very small in the rural areas; there was no damage to manholes located in Kaikōura town, where little liquefaction induced was observed [19]. After the Canterbury earthquake sequence 2010-2011, key damage to manholes and access pits was generally due to permanent ground movements and liquefaction, causing manholes to floating or be filled with ejected material [5].

Roadside cabinets:

One roadside cabinet was damaged with a power pole falling on to it (Figure 6a); others had instances of electronic card dislodgement (rattled) while the cabinet itself remained undamaged.

Aerial cables (copper and fibre) and poles:

Ground shaking and permanent ground deformation caused poles to move, stretching the overhead cables on them. Where the poles were at river crossings where the banks were affected by lateral movements towards the creek, the poles went along with the ride and tilted.

Cross-connect pedestals:

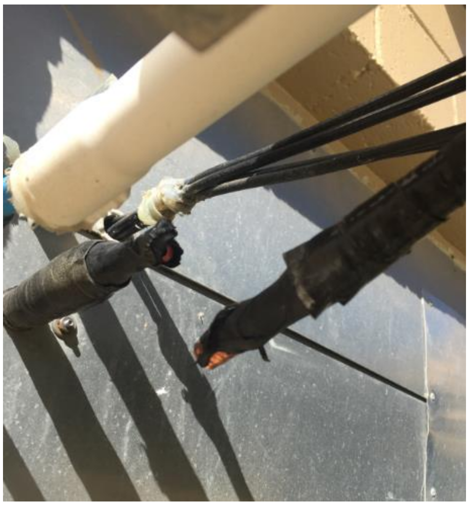
No damage was observed at cross-connect pedestals that are small and robust above ground structures.

(a) *(b)*

Figure 6: Damage of above-ground components after the Kaikōura earthquake: a) power pole falling on a roadside cabinets; b) effect of the ground-shaking on one of the remote radio terminals where the radio transceiver card has dislodged from its rear connector causing service loss (Photos courtesy Rob Ruiter, Chorus).

(a)

(b)



(c)

(d)

Figure 7: Microwave Station building at Weld Cone, damage: a) building, tower and waveguide bridge between the two; b) permanent ground movement at the tower base; c) broken original coax cable; d) temporary fix for the coax cable (the thin grey cable splicing between the ends of the failed coax cable) and extent of the separation between the building wall and the waveguide bridge caused by earthquake (Photos courtesy of Brent Jones, Chorus).

Microwave:

There was one instance of failure at Weld Cone near the town of Ward (Figures 7) due to ground displacement between the microwave tower and the equipment building. A coaxial cable was broken with associated loss of service. As shown in Figures 7c and d, the coaxial cable between the DMR (Digital Microwave Radio) indoor unit in the Microwave Station building at Weld Cone and the DMR outdoor unit (attached to the rear of the parabolic antenna) up the lattice microwave tower stretched and failed near the "waveguide window". Lateral movement between the building and the tower had been so significant that there was insufficient slack in the coaxial cable between its captive point at the waveguide window and where the coax was clamped via "hangers" on the waveguide bridge out to the tower. There were no problems with antenna alignment [20]. An instance of tower misalignment was observed in one small station called Mt Lyford (north of Waiau) where land slumping occurred at the radio site, causing the tower misalignment and some deterioration but no actual loss of service (Figure 8).

Mobile Network

Cell sites (and roadside cabinet):

Instances of toppled cell sites were observed (Figure 6b). Also multiple cell sites were immediately impacted by power outages in a number of regions on both the North and South islands of New Zealand.

Cellular towers:

In remote areas, the radio sites on high ground, towers and mast were all generally in good condition with no damage. However there was damage to their access tracks that had to be repaired.

Performance of Independent or Specially Contracted Communication Networks

The New Zealand Police Service operates a national land-mobile VHF/UHF wireless network for dispatch radio and to co-ordinate search and rescue. A fixed repeater for this network is located north of Kaikōura at Weld Cone. While the earthquake did not disrupt the police wireless network, further land movement threatens the Weld Cone repeater site [21].

Power distribution companies also run their independent or specially contracted communication networks to monitor and control equipment in the electricity network. The performance of these communication networks during and immediately following the Kaikōura earthquake is not currently known. However from the outage recovery statistics of electricity power it appears that they did not experience particular issues [16].

(a) (b) (c)

Figure 8. Mt Lyford Microwave tower: a) Mt Lyford microwave tower and portacom hut; b) c) ground slump at the southern edge of the microwave tower base and edge of the concrete base of the portacom hut.

DEPENDENCIES

Maintaining and servicing faults on the telecommunications network following an earthquake relies heavily on other infrastructure lifelines, such as electric power, and transportation access to equipment sites and buried lines. Similarly, the telecommunications network, particularly wireless services, is often required to organise and carry out the repairs on other infrastructure.

Telecommunication and electric power dependency issues

After the Kaikōura earthquake power was lost in many small South Island towns and parts of Wellington [16]. The power outages impacted a number of sites and components of the telecommunication network.

Power was cut from the *Kaikōura exchange* immediately after the event but the exchange equipment continued to operate on the backup generator and batteries until the power was restored. The generator on site had fuel for around five days and there were arrangements in place for refueling should it be needed. In the Kaikōura area, the *Kaikōura exchange* was the only component of the telecommunications network that had an “Auto-Start” generator. For the other components, including, in many cases the roadside cabinets, the back-up generation needed to be portable and it was progressively brought to priority sites as required.

Maintaining a power supply to the roadside cabinets was of particular importance following the Kaikōura earthquake. A lot of the service within the Chorus network, especially to remote customers, is, in fact, through roadside cabinets. Even in Kaikōura, ‘local’ calls within the otherwise cut-off phone network could still be routed, thanks to roadside cabinets. Roadside cabinets are normally equipped with on-site backup batteries to provide an electricity supply to the equipment during a power outage. However, the battery capacity is limited and typically lasts for up to around 8 hours (with some up to 24 hours), which is sufficient for ‘typical’ outage events. If the power is not restored (or the batteries are not replaced or the cabinets are not connected to temporary generators) before the backup batteries run out, the services will be lost. After the Kaikōura event, generators were deployed to cabinets that had vehicle access and in most cases the service was restored even to remote areas. Despite these efforts, several houses in those remote areas did not have power to enable the residents to use their normally AC-powered devices such as modems, cordless phones etc.

FibreX Hybrid fibre-coaxial, HFC nodes operated by Vodafone in Wellington were, as well, impacted by the power outage; a small number of Fixed Broadband customers in Wellington, experienced service interruptions because of that.

The restoration of mains power to the exchanges caused some secondary damage to the telecommunications network. In particular, transient ‘spikes’ in the reconnected electricity supply were observed to damage sensitive electronic equipment. However this phenomenon was quite limited.

Telecommunication, electric power and transport networks dependency issues

Following the Kaikōura earthquake it was found that the core fibre had been broken in a number of locations. However, with access roads also blocked, the initial repairs were only possible by flying in technicians and lengths of replacement cable with helicopters. Also, the numerous slips and road blockages made it quite difficult to test the underground damaged cables or to repair them. In most cases new cables had to be run on the ground surface over the slips and through trees to bypass the damaged cable sections. More permanent repairs were made when the ground movement had stabilised and road access was possible.

Similarly, while the telecommunication exchanges in the Kaikōura region were equipped with backup generators, only 5-7 days reserve fuel was stored on-site. However, the electric power supply to the exchanges was re-established within 2 days, so transportation links to refuel the generators was not a major issue. Otherwise, in order to keep the generators running after this time, it would have been necessary to establish suitable transportation access.

Another example of combined electric power and transport network dependency issues is the possible delay in deployment of generators to roadside cabinets in the event of power outages longer than 8 hours and disrupted road access.

This could possibly result in the backup batteries to fully drain, needing therefore full replacement[3].

MANAGEMENT OF THE EMERGENCY AND RESPONSE PHASES

The Kaikōura events isolated the town of Kaikōura and its immediate surroundings with numerous landslides blocking the roads and creating a unique and challenging situation in terms of mobilizing repair or restoration equipment and staff. The repair technicians and replacement cables had to be flown in using helicopters. Staff safety was always regarded as a priority. The continuous aftershocks and many unstable slopes, where landslides could have been triggered by aftershocks, required coordination with the Civil Defence and Emergency Management (CDEM) groups to avoid sending staff into areas at risk.

The continuous aftershocks also hindered the restoration process as new damage was discovered during the repair and restoration operations and in some cases only temporary repairs were undertaken because of the risk of damage from subsequent aftershocks. It turned out to be a "progressive" repair process, as it was not possible to get a full view of all the fibre failures, but only to test fault by fault progressively.

In terms of deployment of human resources, in the first days following the 14^{th} November, a team of 5 technicians operated in the affected areas. After about four days, 12 additional technicians were on the ground helping with the repairs. Further staff was involved in coordinating the repair actions both locally and from the national office. The repair crews stayed in Kaikōura for four to five weeks and then gradually were reduced in number as the repairs were completed.

As for the time required to repair/replace cables, spot repairs in damaged cables usually took around half a day and included digging, putting a joint in and filling. For cables that were stretched or damaged at multiple locations and had, therefore, to be replaced, the temporary replacement cables were run on the ground and each replacement could take a full day of work even for a relatively short cable length (e.g. 200-metre cable). The timeline was similar for repair/replacement activities related to fibre optic cables.

Medium/long-term impacts were observed. After the repairs of the earthquake-induced faults to cables were completed, a greater number of faults seemed to affect the network compared to the number of faults normally observed during 'business as usual' times. These faults might have been related, for example, to cables with minor faults being worsened during aftershocks or to cables connected to bridges, that suffered minor damage due to earthquake-induced displacement of the bridge components, further deteriorating in the medium-long term by heavy trucks passing over.

In term of establishing priorities, during the emergency phase, every effort was made to assist a number of customers who provide critical services to New Zealand (e.g. banking, emergency services, and health services for example) to remain connected. However, the relatively low number of customers in the Kaikōura region meant that little or no congestion/traffic issues were experienced when the fibre link was re-established to the core network. In the event of congestion, service providers such as Spark, Vodafone, 2 Degrees, would have been required to actively manage *service providers equipment (switching and call handling equipment*) either *POTS (Plain Old Telephone Service) or Cellular*, to guarantee, as a priority, the telecommunication service to critical service. Chorus would have been required to provide to the service providers network capacity, i.e. the conduit for backhauling both POST and Cellular services.

RESILIENCE STRATEGIES AND SOLUTIONS TO REINSTATE THE TELECOMMUNICATION SERVICE

Crowdsourcing the Location of Outages and Damage

Within Kaikōura, the biggest challenge was locating service outages and damage. Civil Defence and Red Cross staff undertook a door-to-door survey in the impacted region, including Kaikōura, to check on houses' safety. As part of that process information was collected, at property level, on the availability of essential services, but limited to water and electricity. Communications was, unfortunately, not initially part of the Civil Defence checklist during these initial visits.

The locating of specific outages was, therefore, somewhat dependent on customer reporting. Chorus has, normally, systems in place that alarm when there is a fault and help to an extent with localizing the fault. However, there is still a high level of reliance on customer reports to identify and resolve connection issues. Unfortunately, in the absence of customers reporting on the availability of communication or data services, it was much more difficult to identify service outages and to identify likely damage locations within the first week after the earthquake.

Therefore, not long after the earthquake, a message was sent out by Chorus to the public asking the Kaikōura residents to report any outages to their service provider or to the staff on the ground to help with the identification of any issues in the network. As a lesson learnt from this experience, the functionality of the telecommunication will be likely added to the post-disaster CDEM safety checklist as discussions are on-going between the telecommunications sector and the Ministry of Business Innovation and Employment (MBIE) in New Zealand, to raise the "Status" of the telecommunication service (see Conclusions section in this paper).

Strategic Repair and Restoration Solutions

The Aqualink cable as a temporary back-up to the East Coast Link

Due to the conditions and nature of the damage to the *East Coast Link* fibre optic cable and to the damage sustained by the roads adjacent to State Highway 1, repairs could have taken weeks or possibly months to be completed. A strategic solution was therefore discussed and put in place by Spark, Chorus and Vodafone to repurpose a Vodafone-owned undersea cable, known as *Aqualink cable*, passing by the coast of Kaikōura to provide temporary connectivity (both broadband and mobile services) for customers in Kaikōura and some surrounding areas. The *Aqualink cable* links the North and South Islands, from Wellington to Christchurch, and comes ashore in Kaikōura for signal amplification only.

To repurpose the cable for proving temporary connectivity, approximately 50m of fibre optic cable had to be laid to connect Chorus and Spark to Vodafone's *Aqualink cable*. The work to repurpose the *Aqualink cable* commenced on 15^{th} November with the aim to complete it in 24 hours. The potential solution had a range of challenges and was not certain to be successful. Equipment had to be reconfigured in Wellington and Christchurch to free up extra capacity on

[3] Chorus is now in the process of putting low-voltage disconnectors on new cabinets to disconnect the cabinet backup batteries when they are used extensively in a post-event situation and their voltage drops below a certain level. This helps to save the batteries from draining and avoids the need to replace them. However, for most existing cabinets retrofitting to add this feature is not feasible and this is only done for new cabinets.

Vodafone's Aqualink cable in order to provide access to Chorus and Spark.

However the solution proved to be successful and highly instrumental to rapidly and effectively reconnect the affected communities.

Sharing capacity on the Western Link Cable

The loss of the major fibre optic cable, namely the *East Coast Link* meant that the three main providers (i.e. Chorus, Spark and Vodafone), faced challenges as back up connectivity options were reduced. Multiple service providers of the South Island were, in fact, reliant, for both the landline and broadband services, on the integrity of the *Western Link cable*, (owned and operated by Chorus/Spark) which runs from Blenheim and Nelson down to Christchurch via Greymouth. Therefore, further to the collaboration to share the *Aqualink Cable*, work started in parallel to share capacity in the cables on the west side of the South Island, aiming to improve the telecommunications network resiliency in all the South Island. To achieve this solution, patching connections had to be put in place between the providers' respective sites in Wellington, Christchurch and Kaikōura.

Safeguarding South Island connectivity by protecting the integrity of both the East and Western Link cables

Protecting the integrity of both the eastern and western cables remained of paramount importance. With the *East Coast link* damaged, damage to the *Western Link Cable* would have seriously degraded the connectivity for the majority of the South Island. Therefore, to increase protection of the *Western Link cable*, Spark and Chorus cancelled permits for any earth works or maintenance along the length of the cable and asked assistance of New Zealanders living or working along the length of the Western Cable to protect the cable against any risk of damage. In parallel, Vodafone worked with the New Zealand Government to protect the *Aqua Link cable*, from any possible risk of damage from incoming vessels.

Installation of microwave backhaul links

In the afternoon 14th November a microwave backhaul link, was successfully installed to provide voice and text connectivity for some of the people in the affected areas of Kaikōura, Huandalee, Clarence, and Waiau.

Installation of a signal booster to the mobile cell site on the Kaikōura peninsula

Spark installed a signal booster to the mobile cell site on the Kaikōura peninsula as an interim solution to allow customers to have limited access to the mobile network. Customers were encouraged to use available signal for calling and texting rather than data.

Establishment of a temporary Femtocell over satellite link

Vodafone's Instant Network (Femtocell over satellite) was deployed to the Waiau area afternoon 15th November, to provide critical voice and text connectivity for many people in Waiau area.

Deployment of power back-ups to roadside cabinets.

The backup power to roadside cabinets enabled some internal communication within the Kaikōura town during the power outage period.

Service back-ups

Home broadband customers were encouraged to investigate whether they were eligible to take advantage of Vodafone's 'Always Connected' promise, i.e. where possible, a free mobile data bundle was loaded onto customer's mobile phone so that they could remain connected via mobile hotspots, until the fixed broadband connection was re-established.

Communications to customers and relationship with the media

All the service providers kept communicating and collaborating through the Telecommunications Emergency Forum. Communications with customers was maintained at a high level. Media releases, from Chorus and different service providers and joint media releases were regularly provided and made available through the companies' websites and main media channels. Customers could check their fixed line service on a dedicated website updated every few minutes (https://outages.chorus.co.nz/).

CONCLUSIONS

Lessons learned and research needs highlighted by the performance of the telecommunication network and service after the Kaikōura earthquake are briefly summarized in this section.

A key message to pass: "Increase the awareness of the criticality of the telecommunication service after crisis events". Raising the profile of the telecommunications as a sector that is becoming increasing important to everyday life and essential to most businesses operations is necessary. At the moment, telecommunications is not seen by CDEM teams and lifelines groups as vital as other infrastructure such as electricity and water, and therefore is not given the priority that it deserves in terms of mobilizing their staff and resources to undertake the repairs on the telecommunications network after a crisis event. However, as said, telecommunication is most vital to keep up several essential service, and unfortunately, any delay in undertaking the necessary repairs after an event could cause more damage to the network. For example, leaving damaged cables exposed to water for a longer period allows more moisture to get into them. Another example is delay in deploying generators to roadside cabinets that could result in the backup batteries to fully drain, needing replacement as a consequence. The telecommunications sector is having discussions with MBIE at present over the overall "status" of telecommunications in a crisis event such as the Kaikōura earthquake. Telecommunication should be regarded as an "essential service" and should be therefore given higher priority, compared to current practices, also in term of facilitating the logistics to undertake repair activities into an affected region. This need is everyday more critical as the "Internet of things" (IoT), is becoming a reality. The inter-networking connectivity of smart connected physical devices, such as vehicles, buildings, and others (e.g. driverless cars, smart power grids, etc.), will rely on telecommunication network to enable these objects to collect and exchange data. Telecom network will therefore be the lifeline that runs the whole community

Collaboration as a key asset. One of the very important achievements in the aftermath of the Kaikōura earthquake that helped to a great degree with the rapid restoration of service was the fact that all the service providers involved worked collaboratively and shared their equipment and assets for a rapid restoration of service within a few days from the event. Without such collaboration, the service outage duration could have been much longer. A great example of such collaborations was repurposing Vodafone's Aqualink undersea cable by Chorus to restore service to Kaikōura and sharing capacity on the Western Link.

Identify and quantify the values of resilience strategies and solutions. Several effective resilience strategies were put in place, including technical and organizational resourcefulness to: detect damage; deploy resources for coping with damage and disruption; guaranty alternative means of providing the service to the affected community; etc. It would be critical to quantify the benefits provided by such interventions in terms of restored connectivity to customers (e.g. number of customers for which the service was restored) and organizations [22] to support business-cases for investing in resilience. Similarly it would be beneficial to quantify the effectiveness of enhancing the physical resilience of components of the telecommunication networks when applicable.

Sourcing extra-capacity from independent or specially contracted communication network. Can the extra capacity from dark fibre communication infrastructure of power companies to help support other life-line's communication needs also need proper research and understanding.

Planning for Cascading effects. Unfortunately challenging circumstances, including landslides, unstable land, lack of road access to sites and a range of terrible weather conditions along with continued aftershocks, (aftershocks greater than Mw 5.0 in certain areas trigger the requirement to inspect buildings and seek clearance before allowing access to staff and/or the public) presented additional challenges for the restoration of telecommunication service. There is a need to plan for cascading issues and circumstances.

Smoothing dependencies. Dependencies proved to be an issue. There is a need to plan and act further to promote mitigation solutions and strategies.

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