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Managing risk for workers on slopes following the 2016 Kaikōura Earthquakes

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ABSTRACT

Disaster recovery takes place in an abnormal environment. A defining tension exists between the need to rebuild quickly, but with careful deliberation. This tension poses risks for the health and safety of workers involved, at a time when risk levels are higher than normally encountered in the workplace. A key question is how to implement "best practice" health and safety procedures to protect workers in condensed timeframes that are distinctive post-disaster. This case study on the Kaikōura Earthquake will specifically address the demands placed on rope access workers involved in the reconstruction of the distributed transport network, the hazards encountered and how risk was managed.

Key findings are that the transition from disaster response to recovery is a crucial phase of reconstruction, during which clarification of expectations and information sharing benefit workers. Quantification of risk, including a consideration of societal risk, should be a process that is both transparent and inclusive of workers, according to the law and to "best practice". Preparation activities, such as pre-disaster training, planning and testing of emergency procedures can reduce risk.

Future research is recommended into reconstruction following the Kaikōura Earthquake to evaluate emergent safety culture and develop a model to improve risk communication through a multi-level organization to workers at field level. Improvements in the management of safety for reconstruction workers will allow for more effective and efficient recovery in future natural hazard events

affecting critical lifelines and infrastructure, improving the resilience of transportation networks and communities in New Zealand.

1 INTRODUCTION

1.1 The Kaikōura Earthquake

The M_w 7.8 Kaikōura Earthquake on 14th November 2016 caused severe social, economic and environmental impacts in New Zealand. Ground shaking, surface rupture and thousands of co-seismic landslides damaged infrastructure on a regional scale, across the north east of the South Island and in Wellington. The township of Kaikōura was severely affected, suffering acute isolation during the peak tourist season. State Highway One (SH1) and the Main North Rail Line (MNL) are critically important strategic assets for New Zealand. Both were severely impacted by the earthquake, requiring closure for urgent repairs, lasting for 13 months.

Mitigation of the landslide hazard above the road and rail is ongoing; operational restrictions, such as single lane access and reduced speed limits still apply in places. The economic recovery of the Kaikōura and Hurunui Districts, the Canterbury and Marlborough Regions and the nationally important tourism and freight industries is directly reliant on a fully functioning and resilient transportation network. Prolonged closure and restrictions to normal functionality have incurred a high economic and social cost for the nation (Davies et al. 2017; Mason & Brabhaharan 2017; Ministry of Transport 2017; NZ Govt. 2016).

1.2 NCTIR Alliance

Large-scale natural disasters require multi-agency responses. In December 2016, the New Zealand government passed the Kaikōura/Hurunui Earthquakes Recovery Act and agreed to fund the repair of SH1 and the MNL, north and south of Kaikōura. The North Canterbury Transport Infrastructure Recovery Alliance (NCTIR) was established as the lead delivery agency for repair and opening of the road and rail by the end of 2017. NCTIR is an alliance partnership between the New Zealand Transport Agency (NZTA) and KiwiRail (the asset owners) and four large civil construction companies (NZ Govt. 2016). As large numbers of rope access personnel were needed on the slopes in Kaikōura to complete the scope of works in a timely manner, all the major rope access contractor companies operating in New Zealand and one Canadian company became involved in the reconstruction, as subcontractors to the NCTIR Alliance.

1.3 Risk Levels for Workers During Disaster Reconstruction

Reconstruction following a natural disaster is often large in scale, long in duration and complex in terms of the range of hazards, to which workers are exposed. An over-arching characteristic of disaster recovery is compression of infrastructure repairs in time and in a limited space. Both time and space compression have critical implications for protecting the health and safety of workers during the immediate and sustained phases of the response and recovery (Jackson et al. 2002; Johnson & Olshansky 2016; Olshansky et al. 2012). During disaster reconstruction, workers are required to carry out critically important, urgent and dangerous work, at some personal risk. Even trained and highly skilled individuals increasingly have to cope with events of a scale larger than they would normally encounter. Inadequate training of some workers, due to the numbers required, results in situations and responsibilities being encountered which fall outside their accustomed roles. There is often a more prolonged exposure to high-risk situations than they are equipped to deal with (APHA 2008; GAO 2007; Jackson et al. 2002; Olshansky et al. 2012; Sim 2011).

Intense pressure to open the transport network in the shortest possible time contributed to the Kaikōura reconstruction becoming a high-hazard industry sector, with an elevated risk profile for workers on slopes. This paper identifies some approaches used by rope access workers within the NCTIR Alliance to implement "best practice" in health and safety standards and outlines risk management strategies used to manage the elevated risk levels, at a time where urgency to rebuild quickly was an overriding factor. Our recommendations for improvements form part of a long-term strategy to reduce risk for emergency response and recovery workers following future large earthquakes in New Zealand, where slope instability impacts critical infrastructure and conventional means of access are not available.

2 THE REGULATORY ENVIRONMENT

The Kaikōura Earthquake occurred in the year following a significant reform of New Zealand's Health and Safety at Work legislation, brought about by the Pike River Mine tragedy in 2010 and the subsequent findings of a Royal Commission of Enquiry. Post-disaster reconstruction in New Zealand is governed by two parallel pieces of legislation (and by risk management and "working at height" guidelines and qualifications).

The Health and Safety at Work (HSW) Act 2015 governs health and safety at work, but recognizes that other New Zealand legislation may affect workers. The Act addresses such overlaps by providing that other legislation can be considered when deciding whether health and safety duties are being met. Where two pieces of legislation apply, *the duty holder must follow both* (WorkSafe 2017). There is no distinction in the HSW Act 2015 between post-disaster times and "normal" times, yet an important distinguishing characteristic of disaster recovery is that it takes place in an abnormal environment (Johnson & Olshansky 2016). Under the Act, there is no provision for special circumstances during a disaster response or recovery such that workplace health and safety regulations may be circumvented. Standard operating procedures and "best practice" must be adhered to in all workplaces. There should be processes in place for workers to contribute to decisions which affect their health and safety, and that workers should be provided with all the necessary information and support to perform their jobs safely. A framework for continual improvement includes appropriate scrutiny and review of actions taken by persons performing actions or exercising powers (HSW Act 2015).

The Civil Defence and Emergency Management (CDEM) Act 2002 creates a framework within which New Zealand can prepare for, cope with and recover from local, regional and national emergencies. The CDEM Act requires communities to achieve acceptable levels of risk by correctly identifying risks, adopting risk reduction management practices and provide for planning and preparation for emergencies, and for response and recovery (CDEM Act, 2002). The CDEM Act (2002) does not specify particular health and safety environments for workers during or after emergencies, but does recognize that the safety, health and well-being of a "community" is an integral part of the generic recovery structure after a natural disaster. The "community" is not specified by the Act, but must surely include the workers who have been involved in reconstruction?

The AS/NZS ISO 31000:2009 Risk Management Principles and Guidelines outline best practice processes and is the accepted standard for managing risk in New Zealand. According to the guidelines, every aspect of the risk management process needs to be systematic, transparent and inclusive, and facilitate continual improvement of an organization and a dynamic response to change. In the case of risk management for workers the priority should be protecting life and safety from harm. Agencies responsible for the safety of workers have an overarching responsibility to make good decisions about exposure of workers to known risks (ACC & WorkSafe 2013; Jolly et al. 2014; WorkSafe 2017).

"Working at height" is the term used to denote a preventative safety measure where work positioning is achieved using Personal Protective Equipment (PPE) to prevent a person from falling. "Working at height" methods allow the worker to access the place of work and perform tasks while suspended, in areas where conventional means of access are not possible (IRATA 2014). Workers must have either International Rope

Access Trade Association (IRATA) or Industrial Rope Access Association of NZ (IRAANZ) qualifications (or both) to utilize "working at height" methods in the workplace in New Zealand.

Figure 1: Rope access technicians (circled) scaling head scarp, Slip 7 north of Ohau Point, Kaikōura, Feb. 2017. Photo: R.Musgrave

Some occupations are unavoidably exposed to hazards that are in the nature of their jobs. The requirements of the role played by rope access workers involved in the Kaikōura reconstruction are such that it could not be performed without exposure to some risk (Fig. 1). A lack of New Zealand-based rope access technicians with the relevant experience meant that many in the workforce were contractors from overseas, or were newly qualified technicians with no prior geotechnical experience.

3 HAZARDS

Working at heights is intrinsically hazardous; workplace accidents can have severe consequences. Worldwide, falls from height remain the most common cause of serious and fatal injuries in the workplace (Fleming 2001; IRATA 2014). Additional hazards to personnel are encountered in the geotechnical field. Environments can include falling rocks, toxic dust and unstable surfaces, as well as the frequent use of heavy machinery, drills and compressed air, which require intensive management processes. High levels of experience and supervision are needed to ensure that safe working methods are maintained (IRAANZ 2012).

3.1 Aftershocks

A particular issue for workers in the Kaikōura reconstruction is the dynamic nature of the risk, which remains elevated due to the increased likelihood of aftershocks following a significant earthquake. Although the risk is expected to decline with time (as the aftershock sequence decays) the recovery effort may well be over by the time the probability of seismic events returns to background levels (GNS 2016). In the year following the earthquake (during the most intense phase of reconstruction activities) the probability of one or more M_w 6.0-6.9 aftershocks in the Kaikōura area was estimated at 98% (extremely likely); although only three aftershocks of this magnitude occurred (Geonet 2016). A large aftershock, if centred close to an occupied worksite on or below an unstable slope is likely to have had severe consequences.

3.2 Tsunami

A locally generated tsunami is characterized by a short time interval between initiation and run up. Multiple tsunamis generated by either a fault rupture offshore, or by underwater landslides into the Kaikōura Canyon (or both) are possible following an aftershock near the Kaikōura coast. These types of tsunami have arrival times of between 10 minutes and 1.5 hours following an earthquake (Walters et al. 2006). Many occupied worksites on the coastal transport route are situated close to sea level.

3.3 Post Seismic Rainfall-induced Landslides

A large earthquake can not only trigger severe co-seismic landsliding but can also reduce the stability of slopes for a long period of time post-earthquake. The probability of recurrence of large-scale landslides is very high, as slopes have been weakened and fractured by recent seismic shaking (Huang & Li 2014; Qiu et al. 2017; Tang et al. 2011). In addition, critical rainfall thresholds for triggering landslides and debris flows decrease significantly (compared to the pre-earthquake thresholds), subsequently increasing the frequency of rainfall-induced landslides in regions affected by strong ground shaking (Lin et al. 2006; Zhang et al. 2014). The seismically damaged slopes north and south of Kaikōura are now more susceptible to rapid failure in high-intensity rainfall events. Secondary effects such as rock falls, landslides and debris flows after heavy rain have potential to cause significant problems for people working in the immediate areas where slopes have been seismically weakened.

4 THE ROLE OF ROPE ACCESS IN EMERGENCY RESPONSE AND RECOVERY

Rope access technicians were positioned on sites above the Inland Kaikōura Road (Inland Route 70) within days of the Kaikōura Earthquake. The value of rope access techniques to facilitate safer access for the opening of this critical lifeline was evident early on in the emergency response, as the slopes above the road were unable to be accessed by traditional means. Rope access workers were engaged in removing the critical hazards at the source by "scaling" (removal of loose rocks with crow bars) and were also used as "spotters" positioned on the landslides to observe initiation of movement and provide early warning. These actions were implemented to reduce the risk for other workers at road level who were clearing debris for emergency access, and with minimum disruption to New Zealand Defence Force convoys travelling the route daily to take essential supplies into Kaikōura.

On November 30th 2016, the Inland Kaikōura Road was provisionally opened to civilian convoys. Work then began on SH1 and the MNL, first south and then north of Kaikōura. Construction workers began to remove debris from the toe of the landslides, in order to gain access for repairs to the road and rail. Initially, rope access technicians provided a support role, reducing risk for other workers, thus enabling important and urgent work below the earthquake-damaged slopes to proceed. Later, the construction of temporary and permanent engineered rock-fall and landslide risk mitigation structures began on the slopes. This specialist activity requires a high degree of skill and experience (Figs. 2-3).

5 RISK MITIGATION FOR EMERGENCY RESPONSE

Aftershocks were occurring frequently during the response phase, creating a culture of extreme caution amongst abseil workers, who needed to descend into the zones of rock-fall hazard on slopes to perform tasks.

Figure 2 (left): Construction of shallow landslide barrier, Slip 18 south of Kaikōura, Nov. 2017. Figure 3 (right): Installing mesh by helicopter sling load, a high-risk activity, Slip 18. Heli-operations were often conducted over an open highway during short road closures to minimize disruption to the travelling public. Compression of these types of construction activites in time and space increased the risk for workers.

Safety concerns had to be balanced with a commitment to assist in the emergency response and play what was a critically important role. Key safety considerations included:

- Limiting time spent and number of people in high risk zones, minimizing exposure to individuals.
- The abseil teams employed a "top down philosophy" which dictates removal of rock fall hazard before descending below, and avoidance of areas with high hazard lower on slopes (where possible).
- Rescue systems were rigged prior to descent, with standby rescuers remaining at the top of slopes, to facilitate very rapid extraction of operators from the rockfall hazard zone if required.
- Only the most experienced and highly qualified rope access team was engaged in the response phase.
- The team included two rope-access qualified engineering geologists who were able to report site observations to the ground-based geotechnical team at the time.

6 RISK MITIGATION FOR RECOVERY/RECONSTRUCTION

6.1 Avoid or Substitute

Where possible, operators avoided accessing the hazardous lower slopes of the landslides, by substituting alternative methods for removal of hazards (Figs. 4-5).

Figure 4 (left): Air bags used to remove an unstable column of rock while operators retreat to a safer location, Slip 10, south of Kaikōura. Photo R. Musgrave. Figure 5 (right): Sluicing to remove loose debris below abseiler, Slip 7, north of Ohau Point, Kaikōura. Photo R. Musgrave

6.2 Temporary (non-engineered) Risk Mitigation Structures

To begin the construction of engineered risk-mitigation design structures, it was necessary in some cases to first install temporary structures for the protection of workers required to spend long periods of time below significant rock fall hazard on the lower slopes of landslides (Figs. 6-7).

6.3 Additional Training

During the Kaikōura reconstruction, due to the difficulties around access and safety, geotechnical professionals relied heavily on observing slopes from a distance (by helicopter) and using information relayed by other contractors about ground conditions. This is not best practice. Up-close inspection of slopes is necessary to make informed judgments about stability and engineering solutions and allows for greater confidence and fewer assumptions about the nature of the hazards and failure probabilities (AGS 2000; Hunter & Hendrickx 2009). Over the course of the reconstruction, some members of the geotechnical team became qualified for rope access, allowing them to observe slope conditions more closely (under the supervision of more experienced rope access operators).

Additional training was also provided for technicians by some contractor companies about risk awareness, hazard identification and basic structural geology with factors affecting stability on the earthquake-damaged slopes. This enabled operators to better understand significant factors that lead to slope failure, identify and report unsafe conditions and take appropriate action. Observing, monitoring and reporting slope conditions by all on site proved an effective way of managing risk in the work environment.


Figure 6 (left): Example of temporary rockfall mesh installed above an occupied worksite, Slips 18 &19, south of Kaikōura. This structure contained a ~100 m^3 failure which occurred during rainfall, June 2017. Figure 7 (right): Temporary rockfall catch fence above worksite, Slip 18. This structure was impacted 4 times by rocks ~1m^3 during the course of construction of a shallow landslide barrier directly below. Photos: R. Musgrave.

6.4 The NCTIR Rainfall Trigger Action Response Plan (TARP)

To manage the elevated risk to workers during rainfall, telemetered slope monitoring instruments and rain gauges were installed at numerous locations along the coastal transport route, on sites most affected by slope instability. The NCTIR Rainfall Trigger Action Response Plan (TARP) was implemented as a predictive risk management tool in March 2017, to reduce risk for the travelling public and recovery workers. Decisions are made using real-time monitoring of rainfall to close worksites (and the road and rail), based on forecasted rainfall in relation to antecedent rainfall conditions, using a model developed by Glade et al. 2000 for determining rainfall-triggering thresholds for landslides in Wellington. Rope Access supervisors and the goe-technical team then used the model thresholds as a guide (along with observations and slope monitoring) for dictating avoidance of the slopes, during or immediately after significant rainfall events.

6.5 Emergency Procedures

All qualified rope access teams have the training and capability to perform a rescue of an injured worker on ropes (IRATA 2014). However, in January 2017, senior rope access contractors became concerned that the particular hazards encountered in the work environment on the slopes in Kaikōura, combined with the possibility of a large aftershock occurring, required specialist rescue-training over and above “normal” requirements. The possibility of multiple rock falls and slope failures in an aftershock could mean that many severely injured casualties would require rescuing simultaneously from different sites. It was felt that the capability to perform rescues in this scenario did not exist. The abseil teams requested that senior members received "long line" rescue training where rescues are performed from underneath a helicopter, giving the option to perform rapid extraction of many injured persons from slopes if necessary.

6.6 Evacuation Planning

All rope access teams had their own evacuation plans in case of emergency and had identified safe places relevant to every worksite. Often, the safest means of egress from a worksite on a slope was up to a muster point on a ridge, rather than down to road level. During a review early in 2017 of the tsunami evacuation plan for worksites along the coastal route, it was pointed out by many abseil workers that the tsunami "safe" places and muster points identified in the NCTIR plan were at sea level, in the tsunami evacuation red and orange (must evacuate) zones (ECAN [MAP] nd).

7 DISCUSSION

7.1 Assessing Risk

IRATA requirements specify that site-specific risk assessments be carried out, with input from all rope access team members, before work commences. These assessments are qualitative, and use a risk matrix to assess the potential likelihood and consequences of hazardous events. Before commencing work, all tasks should be organized, planned and managed so that there is an adequate margin of safety to reduce risk (IRATA 2014). Most experienced rope-access trained contractors are proficient in their work but lack formal training in geology or engineering geology (Hunter & Hendrickx 2009). It is important that persons with training and experience in rockfall and landsliding are involved in assessing risk on site, because under or over estimating risk can affect the outcomes of the risk analysis (AGS 2000).

The New Zealand Transport Agency (NZTA) have a process to assess risk for road users where slope instability exists, as part of their risk management strategy and commitment to building a safe State Highway network. This process follows the guidelines of the New South Wales Transport Authority in Australia (NSW RTA 2011). During the course of the Kaikōura reconstruction, qualified risk analysts completed risk assessments for sites affected by slope instability on the Kaikōura coast. The results of these risk assessments were not formally communicated to contractors working on (or below) slopes. This confidentiality breaches legislation, risk management standards and best practice.

7.2 Quantifying Risk

Quantifying risk is useful because it allows a comparison of hazards, and enables authorities and workers to prioritize risks in order to inform decision-making (AGS 2000; Massey et al. 2012; Rovins et al. 2015; Taig et al. 2012). In New Zealand, managing the risk from landslide hazards follows principles and guidance set in Australia by the Australian Geomechanics Society (AGS). The AGS recommends that some degree of quantification of risk is attempted in all cases, even if crude or preliminary, especially where loss of life is a possibility. This allows comparison with the acceptance criteria for loss of life, which is also quantified (AGS 2000).

Quantitative risk assessment is increasingly being used to inform government and private sector policy decisions in New Zealand. The Christchurch Earthquake Sequence set a precedent for its use. Individual annual fatality risk was the criterion for establishing upper limits of risk tolerability from rock fall and cliff collapse on the Port Hills. The Christchurch City Council then used this criterion to guide decision-making regarding the safe occupation of buildings below or on the edge of cliffs (Massey et al. 2012; Taig et al. 2012).

In 2012, two small eruptions from Mt. Tongariro produced multiple volcanic hazards in the Tongariro National Park, prompting closure of the popular Alpine Crossing track for 6 months. The key reasons for this extended closure were safety concerns for track users, however decisions had to made prior to the track opening, to determine whether the risk was tolerable, to allow Department of Conservation workers and GNS scientists access to the closed areas (Jolly et al. 2014). The period following the November 2012 eruption was a time of considerable uncertainty requiring a transparent decision-making process concerning access close to the active volcanic vent. Discussions with the New Zealand government agency responsible for health and safety in employment emphasized that there should be no compromise to staff safety standards by the Department of Conservation or GNS Science. Life safety risk mitigation was the paramount consideration, which had to be balanced against losses for the local, regional and national economy (Jolly et al., 2014). GNS scientists performed basic quantitative risk assessments within days of the eruption to analyze life safety risk from ballistic hazards. The risk assessments balanced the urgent need to collect scientific data and repair infrastructure with health and safety in employment regulations, in order to facilitate informed decision-making (Jolly et al. 2014).

In the Kaikōura situation, fatality risk for individuals is the primary consideration and should have been quantified in order to manage overall risk in the workplace on slopes (AGS 2000). The entire risk management process must be transparent and inclusive of stakeholders at all levels (ie. clients, regulators and persons affected) according to New Zealand law, to risk management standards and best practice (AS/NZS ISO 2009; HSW Act 2015).

7.3 Risk Evaluation, Establishing Criteria & Uncertainties

Risk evaluation assists with decision-making after risk has been assessed, to decide whether to accept or treat the risks and to set priorities for action. To make decisions, the level of risk is compared against criteria, to determine what is acceptable, tolerable or otherwise. The UK Health and Safety Executive (HSE) judges the tolerability of risk first in terms of the absolute levels of risk to individuals - only if individual risk is tolerable is it then reasonable to proceed. Individual risk is used as the primary measure of risk, but societal risk must also be considered (HSE 2008).

In general, higher risks are likely to be tolerated for workers in industries with hazardous slopes, than for society as a whole. Upper limits of tolerability of 10^{-4} per year individual fatality risk for members of the public and 10^{-3} per year for employees are suggested in the UK (AGS 2000; HSE 2008; Taig et al. 2012). In New Zealand, such criteria have not yet been firmly established at Government level and in the private policy sector with regard to the workforce.

A significant aftershock on a nearby fault, which ruptures at shallow depths has the potential to cause multiple rock falls, landslides and generate a tsunami on the coast near Kaikōura. In this scenario, significant hazards existed for people on worksites on and below steep slopes at sea level. Loss of lives was a real possibility during reconstruction. If the possibility of loss of lives exists, the probability that the incident might actually occur should be sufficiently low that relevant risk criteria are met (eg. probability x number of deaths $<10^{-3}$ for workers). This accounts for society's particular intolerance to events that cause many simultaneous casualties and is embodied in societal tolerable risk criteria (AGS 2000).

There will be an element of risk in all decisions that are made: zero risk is not achievable. Furthermore, it is not advisable to use quantitative risk estimates as the sole determinant for making decisions in light of the uncertainties in many estimates of risk. The assessed risk may span the acceptance criteria, requiring a high degree of confidence about what is tolerable when making decisions (AGS 2000; HSE 2001; HSE 2008; Taig et al. 2012).

7.4 Exposure

The reconstruction following the Kaikōura Earthquake was a large-scale civil construction project involving over 2000 people at one time (Brown, 2017). On Dec 15th 2017, State Highway 1 to Picton re-opened and the consequent traffic flow increased to approximately 5000 vehicles daily. This was a significant milestone for the Kaikōura community, the freight and tourism industries, the New Zealand government and the NCTIR alliance (NZTA 2018).

The benefits of opening the highway were clear to all working on the project. However, conducting the repair works above an open highway with traffic passing below work-sites caused concern for rope access contractors. Many consequential stoppages lengthened the duration of the project and affected productivity, adding to the frustration for workers, stakeholders and the public. More importantly, this decision changed the level of risk workers were exposed to, as they were required to spend a longer period of time in the hazard zone that would be normally be acceptable to them.

The result of re-opening the highway while rope access work was still ongoing was that the temporal probability (of an individual being at a given location, given the spatial impact of the hazard) increased significantly for workers, because the scope of the project was increased by an unspecified period of time. An increase in temporal probability (exposure) increases the fatality risk for people working on or below slopes (and for members of the public using the road).

7.5 Testing of Emergency Plans

Under the HSW Act 2015, emergency plans must be prepared for each workplace prior to work commencing. There must be provision for the testing of evacuation plans and training and instruction given to workers. This is also a key component of IRATA risk management procedures (HSW Act 2015; IRATA 2014). The CDEM Act 2002 specifies that scheduling of training and exercises to validate plans falls under "Readiness" activities (CDEM 2005).

Pre-disaster plans can improve the speed and quality of post-disaster decisions. Organizations involved in recovery should plan and act simultaneously (Johnson & Olshansky 2016). The fast pace of the Kaikōura reconstruction did not allow for a robust process through which emergency plans were formulated in an inclusive manner and were comprehensively tested at all levels. This was one of the key failings identified at the Pike River Mine (Royal Commission 2012).

7.6 Production Pressure

WorkSafe recognizes that both physical and psychological factors are at play in the work place: deadlines create stress and fatigue amongst workers and can compromise efforts to maintain a work environment with acceptable levels of health and safety (WorkSafe 2017). Since the Kaikōura Earthquake, a number of milestones have been heralded as major successes during the rebuild of the transport corridor. The scale of works completed or near completion would normally have taken many years during a time of standard operations. In the Kaikōura context, political decisions were made the national level imposing deadlines on the workers involved in the reconstruction. Those decisions had fundamentally economic drivers. High profitability and high health and safety standards can be complementary factors. At the same time, from a health and safety perspective, it is important to acknowledge that tension could arise between the different goals (profitability and safety) in specific decision-making processes.

7.7 Cost-Benefit Analysis vs the Cautionary Principle

Commonly, operating companies and regulators conceptualize risk as a product of frequencies and consequences, often by quantification. A cost-benefit analysis is a method for quantifying the advantages and disadvantages of different solutions and providing a basis for their prioritization, and is used as the justification for implementing (or not) risk-reduction measures. A cost-benefit analysis is a useful tool, giving insights into risk and the considerations involved. However, there are limitations on its use as the results are conditional, based on a variety of assumptions. In the context of high-risk industry sectors, such as reconstruction after a natural disaster, it must be recognized that some benefits and costs (loss of life or injury) are exceedingly difficult to quantify in monetary terms. Any attempt to provide a comparison of costs and benefits in the context of major accidents with low probabilities of occurrence is nearly impossible (Sorskar & Abrahamsen 2017).

The cautionary principle is a fundamental principle in safety management giving full weight to risk and uncertainty, thus representing an extreme safety perspective. According to this principle, in a context with uncertainty and risk, caution should be the ruling principle, by the implementation of risk-reducing measures, or by not starting an activity (Sorskar & Abrahamsen 2017).

8 RECOMMENDATIONS

Workers are an integral part of the disaster recovery community. The requirement to protect workers should be a primary consideration in a recovery done well in order to improve safety, capability and efficiency in processes and outcomes after future disasters. Future strategies for worker protection include:

- Establishment of a National register of trained and experienced rope access operators.
- Appropriate ratios of inexperienced to experienced operators maintained.
- Increased capacity for planning the transition between response and recovery and for testing of emergency plans.
- Workers and regulators require support mechanisms for decision-making during times of uncertainty.
- Assessing, quantifying and communicating risk through formal channels is critically important for the protection of workers.

8.1 Staff Training and Experience

Natural hazard events like the Kaikōura Earthquake will occur again in New Zealand, requiring input from contractors, consultants and stakeholders in a collaborative approach. Having a skilled New Zealand based workforce to call on in the event of a future emergency will increase the capability of regions to respond in a safe and effective manner. A register of all contractors and consultants, who have had experience with this type of geotechnical work in Kaikōura and following the Canterbury Earthquake Sequence (and have undergone additional training) would allow the experience gained during this reconstruction to benefit New Zealand in the future.

IRAANZ and IRATA qualifications are adequate for training people to work safely at heights. The training and certification are conducted in a controlled environment, which does not prepare technicians for the additional hazards encountered on unstable slopes in a seismically active area. Newly qualified rope access technicians require a high level of supervision by experienced operators. Appropriate ratios of inexperienced to experienced operators should be carefully maintained in hazardous work environments.

8.2 Planning the Transition from Response to Recovery

Disaster recovery starts while the response is still active. The transition is a process, which should be planned, documented and communicated (CDEM Act 2002). Increasing the capacity for planning the transition, by adding personnel and technical assistance is a solution to the tension between speed and deliberation that exists in disaster reconstruction (Johnson & Olshansky 2016).

Workers require information and support during the transition, as the priorities for action differ during these phases. What is considered to be a tolerable level of risk for workers may change after a disaster. In the early phases of a response it may be appropriate to take risks if there is a reasonable chance of saving lives At some point an incident must transition to recovery. At this point it is no longer considered appropriate to allow workers to expose themselves to significant risks to perform duties (Jackson et al. 2002). Where significant risks exist, adequate mitigation and protection must be in place according to law (HSW Act 2015).

8.3 Decision Making Support

Following disasters, decisions are made which may differ from those made during non-crisis (business as usual) situations. Crisis decisions are made in high-risk / low-operating time environment with large uncertainties. Decision support mechanisms for regulators and operators have been shown to contribute to the prevention of major accidents (Sorskar & Abrahamsen 2017).

A suggested approach to clarify decision-making at practitioner level is based on the Fire and Emergency NZ (FEMNZ) "safe person" concept where an emergency responder "will, may, or will not" take risks, depending on the context (Fig. 8). The regulatory decision-maker should be able to take a dynamic approach, i.e. be able to give weight to an extreme economic perspective, or an extreme safety perspective, or a perspective on a continuum in between (according to the adopted risk management approach and the context) (Sorskar & Abrahamsen 2017) (Fig. 9).

8.4 Communication Channels Between Scientists, Engineers & Contractors

Knowledge and information sharing are critically important for successful worker protection after a disaster (APHA 2008; GAO 2007; Jackson et al. 2002; Sim 2011). Assessing risk should be an inclusive process involving workers representatives, experts, stakeholders and technical partners. Experts involved in risk assessments will need to collaborate beyond professional boundaries during recovery (Rovins et al. 2015).

An organizational model where the fast pace of disaster reconstruction is matched by equally fast-paced development of safety culture in organizations involved, would ensure that health and safety "best practice" can be implemented at all times in future disasters in New Zealand. This may be achieved through a communication network that transfers risk information quickly through the different levels of a complex organization, providing communication channels between recovery actors to facilitate information transfer, inclusion and transparency about known risks.

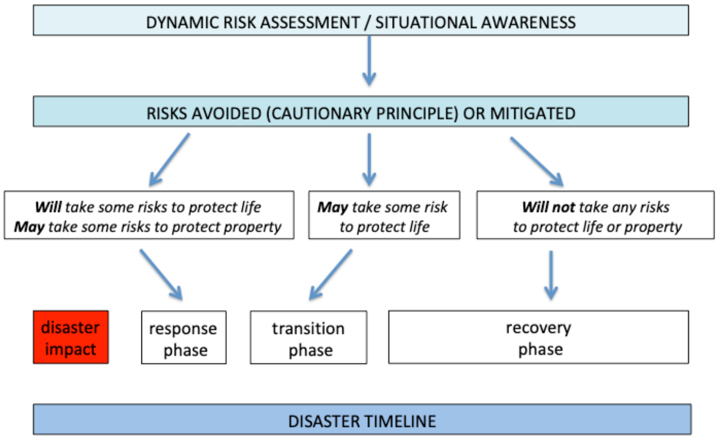

Figure 8: Suggested decision-making approach for operators during different phases of disaster Practitioners require communication and support from regulators during transition between the phases. Where clear boundaries do not exist, risk levels and accident rates should be trending down. Image adapted from (FEMNZ 2017).

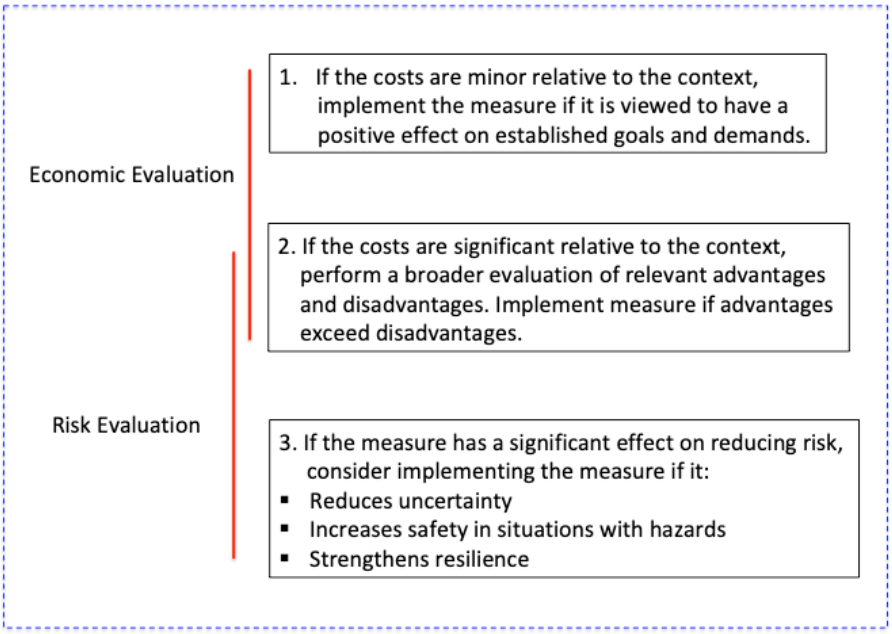

Figure 9: Suggested decision-making approach for regulators and stakeholders during times of uncertainty. A dynamic approach is recommended, giving weight to either an economic or safety perspective, depending on the context, Image adapted from (Sorskar & Abrahamsen 2017).

9 CONCLUSIONS

Following the Kaikōura Earthquake, the New Zealand Government, stakeholders, consultants and contractors faced considerable uncertainty and had to balance the tensions between urgency to rebuild and the need for due care with regard to health and safety concerns. Rope Access workers played an important role in the emergency response and recovery, reducing the long-term risk post-earthquake. The Kaikōura reconstruction has highlighted the difficulty in maintaining a balance between reducing the risk to workers to tolerable levels and allowing nationally important strategic recovery works to proceed rapidly. Mitigating the risk to life safety is of upmost importance, although this will be balanced with contextual factors such as economic losses, political priorities and the well being of affected communities.

Improvements in the management of safety for reconstruction workers will allow for more effective and efficient recovery in future natural hazard events affecting critical lifelines and infrastructure, thus improving the resilience of transportation networks and communities in New Zealand. This report distils lessons from the Kaikōura reconstruction, where significant disaster recovery challenges led to different management approaches being used to reduce risk.

The key findings of this study were:

- There was no formal process to adequately communicate risk from scientists to workers at field level.
- Emergency procedures were not in place prior to commencing work.
- Additional training and pre-disaster planning reduces risk for workers.
- Workers require support, communication and clarification of expectations from stakeholders and government during the transition from response to recovery.
- In Kaikōura the additional risks posed by ongoing seismicity and secondary natural hazards required additional input from experts with knowledge and experience in assessing, quantifying and managing these types of risks.

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