Tsunami Impacts to Lifelines:

Review of Current Knowledge and Post-Event Survey of the 16 September 2015 M8.3 Illapel, Chile Tsunami

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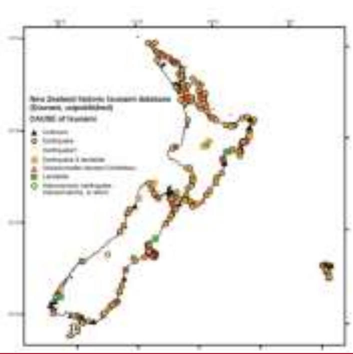
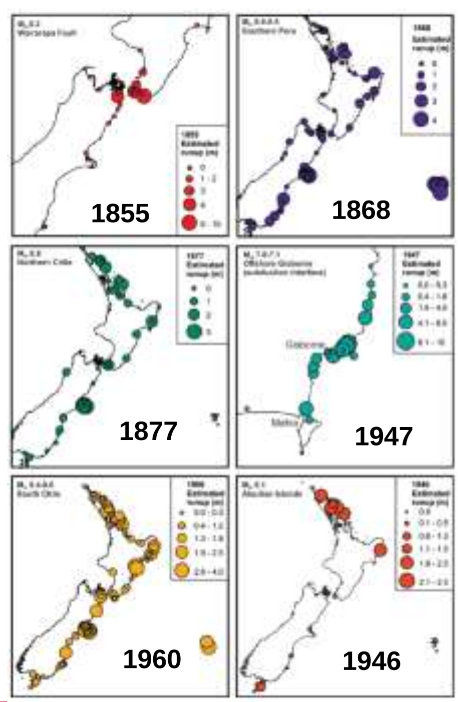
New Zealand's Tsunami Hazard

- 10 tsunami with coastal heights over 5m since 1840
- Most prior to significant coastal development





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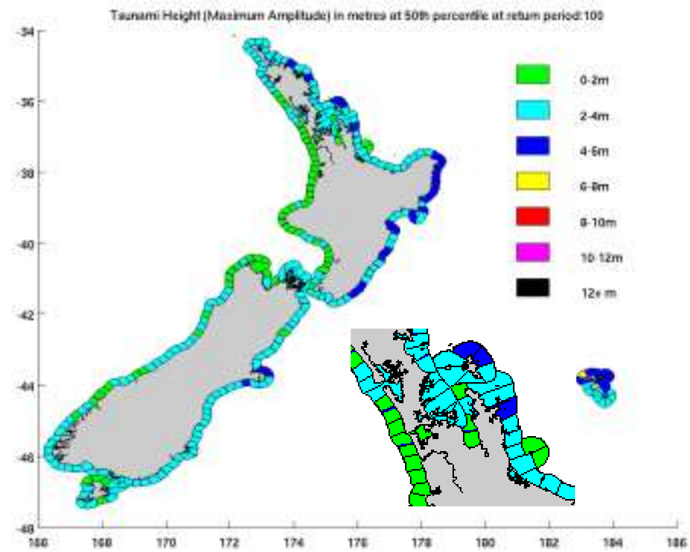
100 Year Return Period Tsunami Heights



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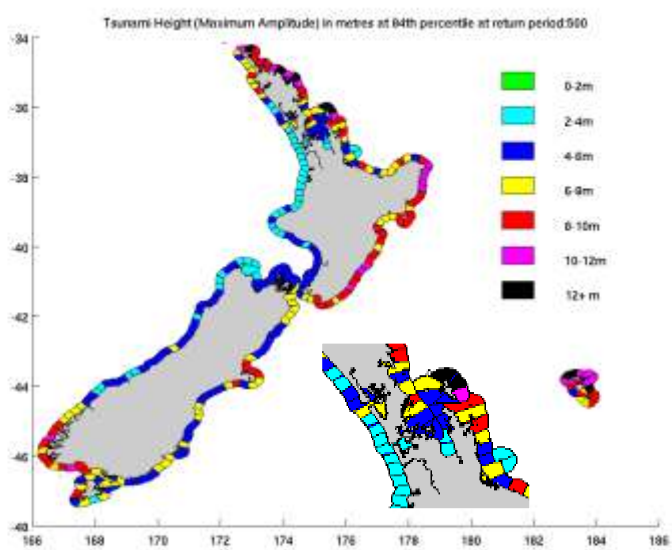
500 Year Return Period Tsunami Heights



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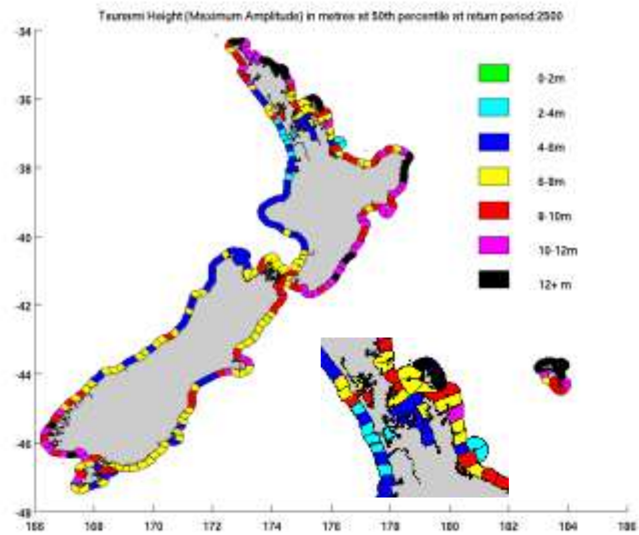
2500 Year Return Period Tsunami Heights



Key Tsunami Characteristics Related To Damage

- Can affect large areas of coast
- High flow velocities (30 cm can knock over an adult)
- Large amount of debris (vegetation, vehicles, buildings)
- Sediment deposition
- Salt water contamination and corrosion
- Multiple waves with inward and outward flows
- Wave period can be 10-20 minutes between peaks
- Significant scouring
- Large forces in both directions:
  - lateral hydrodynamic forces (seismic design)
  - vertical buoyancy forces (not designed for)

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The ALG/WeLG Tsunami Impacts Project

- WeLG/ALG commissioned GNSby to:
  - Summarise literature on tsunami impacts to lifelines into a format suitable for NZ lifelines
- Project oversight by ALG/WeLG Steering Committee
- Aim to include information from major events:
  - Indian Ocean Tsunami (2004)
  - Chile (2010)
  - **Japan (2011)**
- Draft reports April 2015/July 2015
- Impact tables developed in August 2015 (replacing posters)
- Incorporate new findings from 2015 Chile Survey

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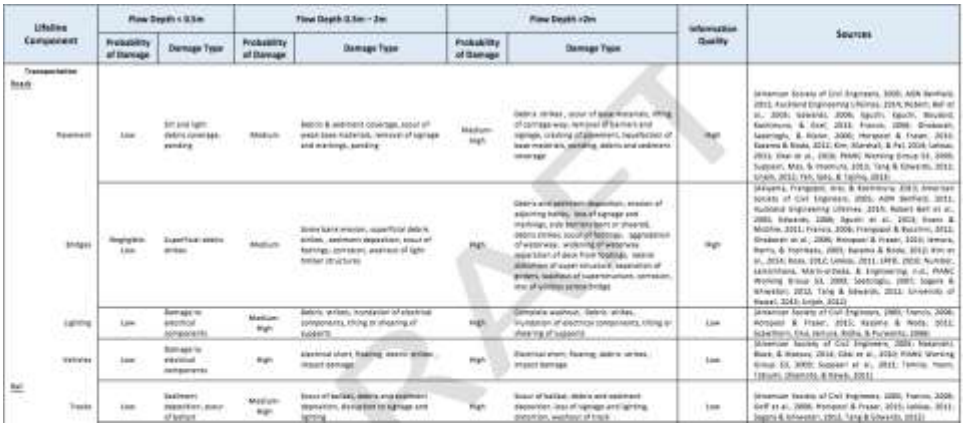
Impacts Table

- Based on that developed by VISG for ALG



Lifeline Component	Flow Depth < 0.5m		Flow Depth 0.5m – 2m		Flow Depth >2m		Information Quality	Sources
	Probability of Damage	Damage Type	Probability of Damage	Damage Type	Probability of Damage	Damage Type		
Transportation Roads								
Pavement	Low	Silt and light debris coverage, ponding	Medium	Debris & sediment coverage, scour of weak base materials, removal of signage and markings, ponding	Medium-High	[illegible]	High	[illegible]
Bridges	Negligible-Low	Superficial debris strikes	Medium	[illegible]	High	[illegible]	High	[illegible]
Lighting	Low	Damage to electrical components	Medium-High	Debris strikes, inundation of electrical components, tilting or shearing of supports	High	[illegible]	Low	[illegible]
Vehicles	Low	Damage to electrical components	High	Electrical short, floating, debris strikes, impact damage	High	Electrical short, floating, debris strikes, impact damage	Low	[illegible]
Rail Tracks	Low	Sediment deposition, scour of ballast	Medium-High	[illegible]	High	[illegible]	Low	[illegible]

Information and Data Gaps

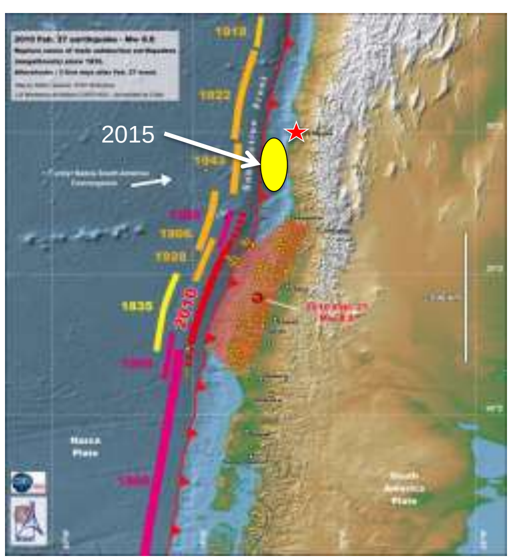
- Significant gaps in information/data for some sectors
  - Little contextual information (e.g. a substation was damaged)
  - Lack of differentiation between earthquake and tsunami damage
  - Variability in publication of information between lifeline companies

Lifeline Sector	Damage and Failure Models	Recovery Actions	Increasing Resilience
Water			
Telecommunications			
Transport			
Energy			

16 September 2015 M8.3 Illapel, Chile Earthquake and Tsunami

- Survey: Sat 26th Sept – Mon 5th Oct (10 days after event)
- Included: GNS, NIWA and Auckland Council staff, one consultant and one University of Canterbury Masters student
- Funding: GNS/NIWA RiskScape, EQC, NZSEE, AC, UC
- Local support from CIGIDEN
- Main investigations carried out in Coquimbo
- Lifelines assets reviewed:
  - Electrical
  - Roads, footpaths, rail
  - Port and wharves
  - Water(s)
  - Seawalls

16 September M_W8.3 Illapel, Chile Earthquake



ShakeMap

Population per ~1 sq. km. from LandScan

Coquimbo – Port Town of 200k people

600m inundation extent, 6m run up, 5m flow depth

Survey Method

- Lifeline damage survey
  - 2 x 2 person teams (one lifeline per team)
  - Used Real-Time Asset Capture Tool (RiACT) tablets
  - Census style data collection (all assets in inundation zone were surveyed)
  - Tsunami water marks recorded
  - Meetings with electricity and water companies
  - Aim to develop tsunami vulnerability models

- Summary statistics:
  - ~600 high quality water marks
  - > 3,000 assets surveyed

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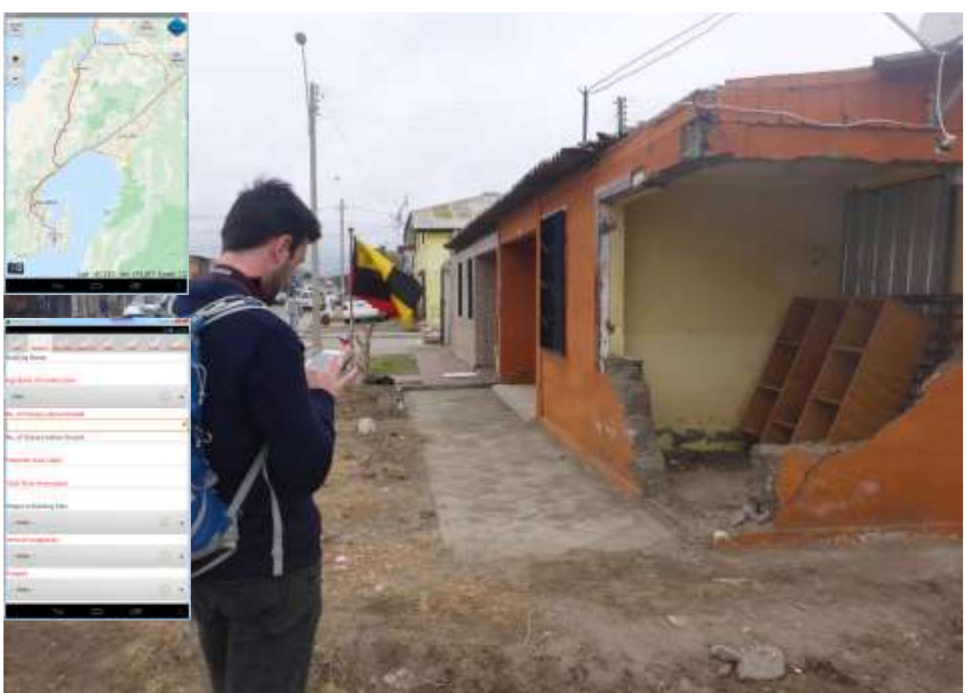

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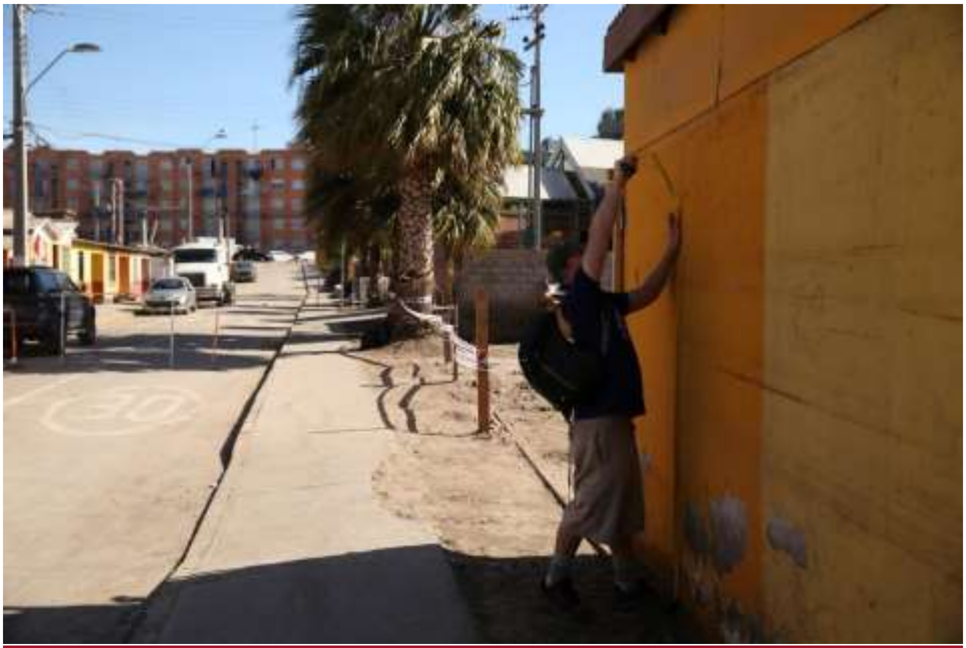

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Coquimbo

Electrical – ALG/WeLG report findings

- This sector is under-represented in literature on damage to lifelines in tsunami
- Little information on underground services
- Generic information on tsunami effects on poles exists
- Little information on effects to substations and transformers
- No fragility curves could be derived from the information

Electrical – Coquimbo findings

- There were no transmission assets in the tsunami zone
- There were minimal buried cables in the tsunami zone
- The distribution network was largely overhead
- Data was captured for:
  - Power poles
  - Street lights
  - Substation(?)
- Information gathered from Conafe (local lines company)
- Overhead lines/pole mounted transformers were washed away if tsunami reached them
- Pole failure from shearing at base, debris strike, scouring at foundations

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Electrical – Coquimbo findings

- Aspects from Conafe (local lines company):
  - Distribution lines were heavily impacted in tsunami zone
  - Increased staff from 50 (BAU) to use 550 staff over the six days following the tsunami
  - 40 HV crews and 140 LV crews worked
  - Their key was to have a logistics plan in place to support the inflow of staff
  - Planners worked nights and provided crews plans/tasks for the days. Handovers were at 7am/7pm
  - All distribution lines assets were recovered within 6 days
  - Conafe staff had no 'Lost Time Injuries'
  - Conafe extended their mandate to install two working lights within each household

Increasing Resilience

- Buried lines are less vulnerable than overhead lines unless cable housing damaged by earthquake
- Locate substations outside of tsunami inundation zones
- Outside substations are more vulnerable than internal ones, particularly for washout
- Stockpile spares (electrical components, poles etc) for rapid repairs
- Have a plan for response – larger than BAU

Roads – ALG/WeLG report findings

Damage and failure modes:

- Debris, sediment deposits and flooding are common throughout inundation zone after tsunami withdraw
- Debris size is related to flow depth and available debris (vegetation, vessels, vehicles, buildings)
- Scouring, often on roads near coast, on raised embankments or changes in slope (focussed flow)

Roads – Coquimbo findings

- Most observations (below) from a 0-5m flow depth
- Debris and flooding present after tsunami
- Most roads in the inundation zone were founded on sandy material, with a granular base and a thin asphalt surface
- There were very few ‘both-lane’ wash-outs (by the sea)
- There were many minor / single lane wash-outs (by the sea)
- All wash outs were where culverts ran under road to sea
- Most roads away from the sea/drainage features were relatively unaffected

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Increasing Resilience

- Introduce redundancy in network
- Strengthen and protect coastal roads at sites of culverts or outflows with rip rap
- Develop arrangements with contractors to clear debris repair scoured sections
- Use well engineered road bases

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Ports and Wharves – ALG/WeLG Report

Can be affected by very small tsunami and strong flow velocities (marine threat events)

Damage and failure modes:

- Damage to wharf decks and piers (buoyancy forces and lateral loads)
- Scour of piers and seawalls/breakwaters
- Damage to wharf buildings
- Damage to vessels from entrainment in flow
- Significant source of debris – vessels, containers etc

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Port and wharves – Coquimbo findings

- Wharves relatively unaffected by tsunami (higher levels of earthquake damage likely)
- Operations heavily affected by floating debris

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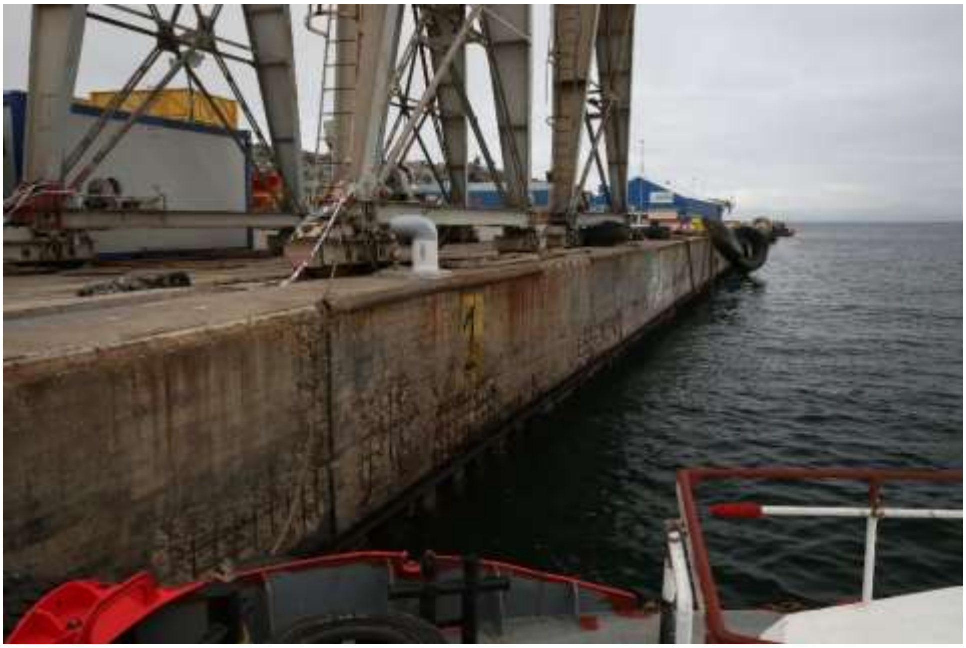

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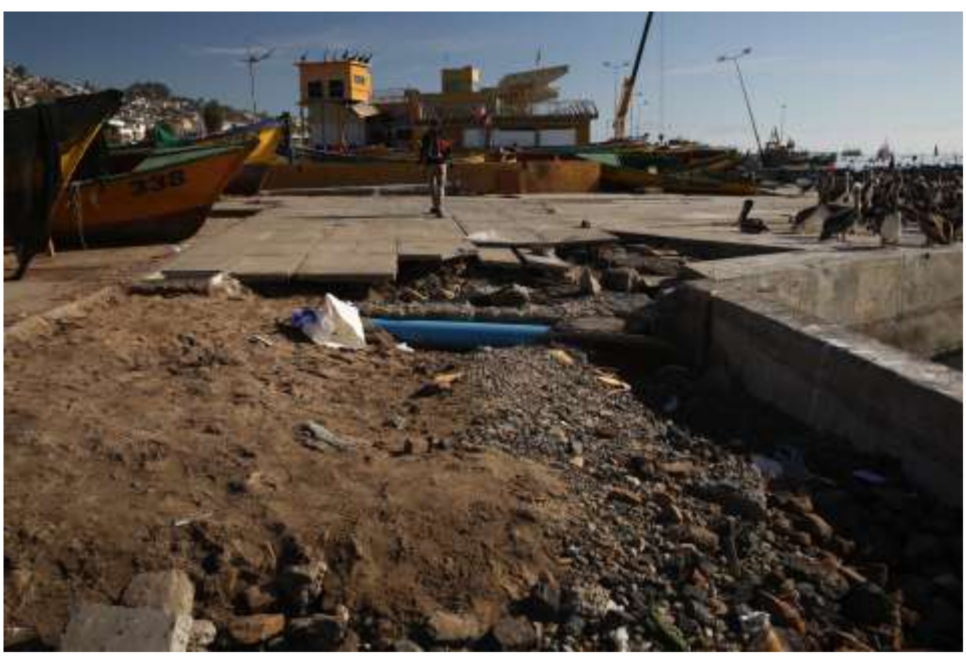

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Increasing Resilience

- Strengthen ties between piers and decks to resist buoyancy forces
- Develop response plan for large vessels to exit to deep water (~150m depth)
- Some evidence ‘bumpers’ can reduce impact forces from debris/vessel strikes
- Evacuation plan for port/wharf personnel

Fuel Tanks/Depots

Damage and failure modes:

- Damage to pipe connections (> 2 m)
- Scour of tank foundation
- Buckling of base of tank
- Floatation and entrainment (> 2m) dependent on capacity and fullness
- Fire following

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Increasing Reslience

- Large capacity tanks are less likely to slide and float
- Relocate tanks outside of tsunami inundation zone
- Construct scour resistant foundations
- Construct tanks to seismic design standards to resist lateral loads
- Locate tanks away from sources of debris
- Minimize low levels of fuel in tank

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Bridges - ALG/WeLG report findings

- Bridges are often vulnerable hot spots in transport and other lifelines networks

Damage and failure modes:

- Most bridges will experience scouring around wing walls, usually more severe on landward side from tsunami withdraw (higher velocities) and at base of piers
- Debris deposition on deck
- Debris strikes cause damage to superstructure
- Earthquake engineered bridges perform well under lateral tsunami loads but not designed for buoyancy forces on superstructure from tsunami which leads to washout (> 2m above deck)

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Bridges - Coquimbo findings

- RC four-lane multi-span bridge
- Bridge was overtopped by 1m flow depths
- Superstructure undamaged
- Minor-moderate scour of unprotected wing-walls on all four sides. More severe on landward side.
- Failure of services on landward side of bridge from scour

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Increasing Resilience

- Design longer wingwalls to reduce scour
- Use deeper pier foundations to reduce effect of scour
- Design with lower profile to reduce hydrodynamic drag and chance of debris strike
- Strengthen connections between piers and superstructure to resist buoyancy forces
- RC/PC perform better than steel or steel truss
- Bury services instead of attaching to bridge

Rail - ALG/WeLG report findings

Damage and failure modes:

- Ballast and rail embankments are sites of scour
- Rail tracks can be shifted laterally in < 1 m of water
- Train carriages were observed to float in as little as 1.7 m of flowing water
- Overhead lines and ground based switches can be shorted upon contact with tsunami flow and are often washed away
- Overhead line poles can be damaged from strong flows or debris strikes

Rail – Coquimbo Survey

- Single track in inundation area
- On wooden sleepers
- Shifted laterally in <1 m flow depths
  - 200 m length
- Washed away in > 2 m flow depths
  - 800 m length
- Minor scouring of ballast

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Increasing Resilience

- Develop contingency plan to clear debris from line, repair overhead lines, repair scour or washouts
- Stock pile of spares of electrical equipment
- Develop tsunami evacuation response plan for passengers on coastal lines
- Strengthen steel rail bridges in tsunami inundation zones

Airports – ALG/WeLG Report

Damage and failure modes:

- Damage and flooding of terminal buildings
- Damage to low lying electrical equipment
- Floatation of vehicles and machinery
- Floatation of aircraft (no planes in Sendai airport)
- Scour of embankments (not runway tarmac)
- Debris deposition on runway
- Ponding of water on runway

Increasing Resilience

- Primarily through recovery planning
- Develop plans for removing debris and pumping ponded water from runway
- Stockpile critical spare parts
- Plans for moving aircraft that have been floated
- Develop evacuation plan for passengers in terminal and onboard aircraft on tarmac based on maximum expected tsunami heights

Water - ALG/WeLG report findings

Damage and failure modes:

- Treatment ponds can be contaminated if inundated
- Pump station electrical equipment and mechanical equipment vulnerable to flooding and sediment contamination or washout (>3m flow depth)
- Pipes are often scoured but undamaged
- Frequent weak points in pipe networks are where they cross bridges
- Wells and bores are easily contaminated if in inundation zone
- Outflows and drains are often clogged with debris and sediment and require significant cleaning

Water – Coquimbo Survey

- Surveyed:
  - Manholes
  - Drains
  - Pump station (1)
  - Pipes (where visible)
- Potable water pipe broken at bridge from embankment scour. Rest of pipe scoured but not damaged.
- Main sewerage pump stations severely damaged. Back to 70% load in 2 weeks.
- Most drains blocked, but cleaned out 10 days later
- Culverts were points of weakness and most heavily damaged from scouring

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Increasing Resilience

- Locate water supply and treatment facilities outside of tsunami inundation zones;
- Construct facility buildings using reinforced concrete and ensure areas containing power systems are watertight, or locate electrical equipment at height to minimise damage to key electrical components;
- Install sealed lids on pumps and tanks to stop contamination by saltwater, sediment, and debris;
- Bury pipes across water crossings or attach to earthquake strengthened reinforced concrete bridges, preferably with protection buffers to reduce damage from debris impacts;
- Use watertight caps on wells

Seawalls / washouts

Damage and failure modes:

- Significant sea wall washout can occur in flow depths >2 m
  - ~1 km in length
- Seawalls suffered minor damage in flow depths < 1m
  - > 3 km in length
- No damage < 0.5 m flow depth
- Sea wall failure often exposed road/footpath behind seawall for scour
- Significant scour of seawall occurred at sites of storm water outflows or culverts

SeaWall Construction

- Large stone riprap
- Concrete conglomerate sloping and vertical wall
- Loose sand fill beneath

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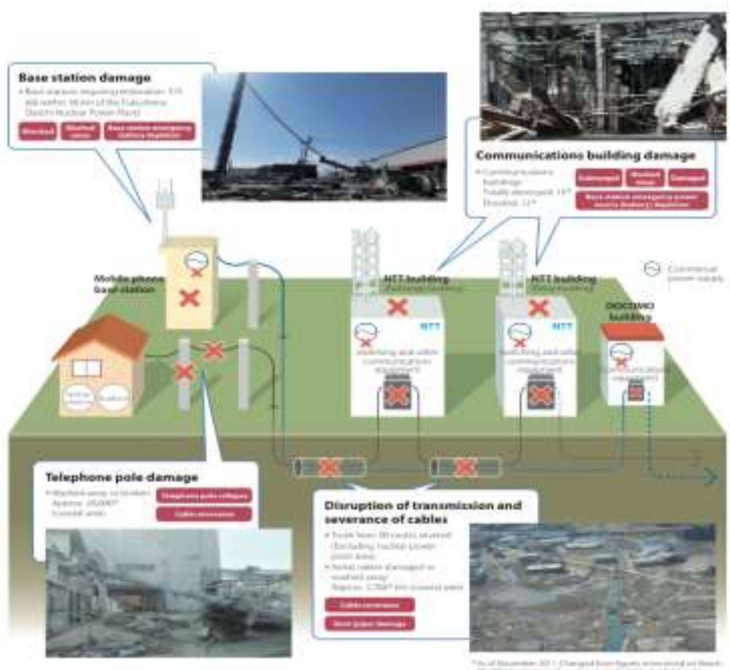
Telecommunications – ALG/WeLG Report

Damage and Failure Modes

- Cellular sites from debris strike or hydrodynamic forces on towers or collapse of buildings
- Exchanges from flooding or washout of building
- Buried cables entering buildings (scour around foundation)
- Buried cables from scour
- Power outages to cell sites/exchanges and depletion of backup batteries (2 hrs) and flooding of backup generators
- Washout and flooding of submarine cable landing sites



Damage to exchange buildings and PC poles

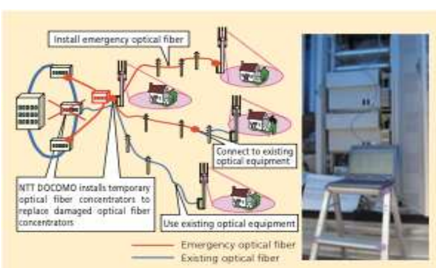


Figure 2 Facilities recovery using optical fiber/emergency optical fiber cable

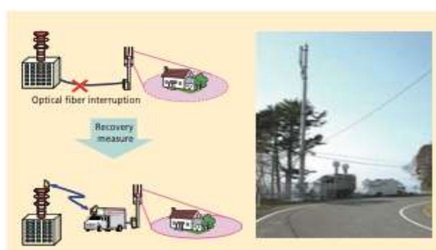


Figure 4 Facilities recovery using microwave-entrance

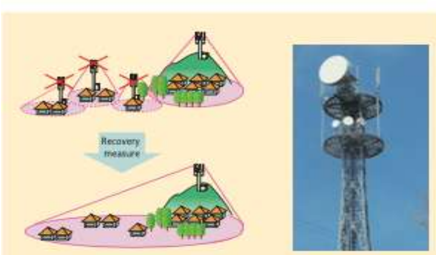


Figure 3 Facilities recovery by increasing zone size

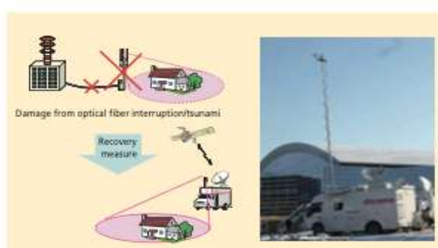


Figure 5 Facilities recovery using satellite entrance link

Increasing Resilience

- Relocate exchanges/cell towers out of tsunami inundation zones or on upper floors of multi-storey reinforced concrete buildings
- Raise electrical equipment, switches and back up generators
- Bury cables across waterways rather than across bridges
- Use buried cables rather than overhead lines
- Install large radio base stations to use as back up for exchanges Increase battery life on cell sites and exchanges, possibly setting up alternate power sources (e.g., solar, wind etc.)
- Continued…..

Increasing Resilience continued….

- Have a stockpile of mobile cell sites, generators and radio repeaters that can be deployed to areas with service outages
- Develop short voice messaging system
- Deploy mobile WIFI hotspots that use satellite links

Key Findings Across Lifeline Sectors

- Relocation of assets if possible is best mitigation option
- Electrical equipment is vulnerable and located near ground
- Back-up generators are often located on ground floors and also damaged
- Availability of spares critical to quick recovery
- Contingency plans for response
- Tsunami Hotspots for lifelines:
  - Coastal outflow sites and culverts → scour of coastal roads and loss of all below and above ground services
  - Bridges → scouring or washout causes loss of all services on bridge
  - Coastal sites with multiple lifelines (coastal road/rail/buried services or ports with fuel depots)

Coastal State Highways

- Multiple lifelines services run along route
- Potentially vulnerable to scour and washout

SH2 Wellington

SH1 Kaikoura

Seaview Fuel Terminal

- Significant source of debris from vessels
- Wellingtons main road fuel supply

Landing of Cook Strait HVDC/Fibre Optic Cable

Next Steps

- Update ALG/WeLG report and damage tables for with findings from Chile survey and release report
- Publish survey report for International Tsunami Information Centre (ITIC) and NZSEE
- Develop quantitative lifeline fragility models (probability of damage) to be used in tsunami impact/risk assessments using RiskScape

TsuRGe – Tsunami Impacts Research Group

- Collective of researchers and stakeholders
- Raise awareness of tsunami impacts
- Coordinate research on tsunami impacts driven by end users (e.g. lifelines)
- Coordinate post-tsunami surveys and reconnaissance trips
- Plan to hold initial scoping workshop and draft ToR

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