Lessons learned from one of New Zealand's most challenging civil engineering projects: rebuilding the earthquake damaged pipes, roads, bridges and retaining walls in the city of Christchurch 2011 - 2016.

Real asset in innovative damage assessment

Story: Asset Assessment

Theme: Programme Management

A document which outlines SCIRT's post-earthquake asset assessment process.

This document has been provided as an example of a tool that might be useful for other organisations undertaking complex disaster recovery or infrastructure rebuild programmes.

For more information about this document, visit www.scirtlearninglegacy.org.nz

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Real asset in innovative damage assessment

Tools of the trade were redesigned and redefined as SCIRT grappled with the massive task of post-earthquake asset assessment.

Sonic dig: A worker uses a sonic rig to cut boreholes to test ground conditions in Fitzgerald Avenue.

Broken pipes, slumps in the street, jagged edges and battered bridges were among the hazards splayed across the damaged landscape of the former "garden city".

The SCIRT investigations team faced a daunting – and often confronting – task to uncover the hidden depths and coarse layers of damage caused by multiple quakes rolling across Christchurch, leaving behind the shattered horizontal infrastructure and a vertical mass of teetering edifices.

In all, $140 million would be spent on assessing the damage.

Differential settlement and lateral spreading created a new cityscape, smothering drains and waterways. Repair and replacement work on wastewater and storm water pipes would take up much of the overall rebuild cost. Horizontal work would have to be completed before vertical projects could get under way. About 1600 kilometres of council-owned gravity pipelines made up the Christchurch wastewater network – with sections dating back to the 1880s – while about 900km of gravity pipelines united the storm water network.

A primary storm water system of kerb and channel, sumps, pipes, swales, open channels and pump stations, along with a secondary system of overland flow paths through roads and reserves, were contorted by the fury of the earthquakes.

Storm water catchments and wastewater usually drained by gravity – a process made more difficult by the city's low-lying, flat ground – were now stagnant pools and silt-filled, displaced pipes.

Dealing with the gravity pipe assessment was a massive challenge in the rebuild process.

In order to assess the degree of damage, it was also vital to understand the pre-earthquake and post-quake drainage performance utilising older asset records made available by local authorities. The asset environment, pipe specifics and land use all contributed to the overall assessment process.

An integrated design solution was factored into the assessments. Any changes to roading alignment, grades and falls could affect the requirements for storm water assets as roads provided a drainage path. Land changes also could affect overland flow paths.

For SCIRT, there were so many variables to consider in the search for succinct solutions.

Under the pump

At the peak of asset assessment, hundreds of people were cleaning out liquefaction from the underground pipe networks, and then evaluating the damage. The Christchurch sewerage system was barely operational, almost grinding to a halt. The above-ground damage was obvious. Manholes floated up while the surrounding areas slumped.

Pumping stations were packed solid with silt. At the treatment plant in Bromley in the city's hard-hit east, sedimentation tanks filled with sand and filters were left askew. The system was near to collapse as pipes and the plant works were drowned in silt.

In the east, liquefaction produced about 400,000

Heights of discovery: Workers carry out rock mapping and drilling in Rangatira Terrace.

tonnes of silt, which mixed with wastewater to become a major health risk. Up to 60 million litres of wastewater a day was flowing into backyards, waterways and the sea.

Ground control

Ground levels dropped, while other sections rose, leaving some gravity pipes flowing the wrong way and more properties at risk of floods during heavy rainfall. In tandem with the severely damaged storm water infrastructure, the complex issues facing SCIRT rapidly multiplied. Infrastructure had to be laid bare before designers, engineers and work crews could set the stage for a rebuild or repair.

For the thousands struggling without quality infrastructure connections to shattered homes and "liquid" land, a rapid response had to be aligned with an innovative asset assessment solution. All asset assessment functions would sit with SCIRT.

A dedicated investigations team would help slice six months off the design programme and save a great deal of money.

What lies beneath?

Geotechnical investigations to reveal the extent of infrastructure damage were a step into the unknown as the level of devastation largely lay buried in silt and liquefaction.

First, there were several vital questions to answer:

- What would be the criteria for assessing the condition of assets?
- How would assessment data be stored, analysed, and shared with designers and asset owners?
- Which investigation-related tools were needed?

To help shape the answers, SCIRT owner participants – the Christchurch City Council (CCC), the New Zealand Transport Agency (NZTA) and the Canterbury Earthquake Recovery Authority (CERA) – developed Infrastructure Recovery Technical Standards and Guidelines (IRTSG) "to identify the scope, objectives, intervention levels and standards for the rebuild of horizontal infrastructure".

The guidelines helped "inform … the technical assessment of damage (and) the design and construction of the repair and renewal of Christchurch City Council-owned (CCC) infrastructure", as well as the handover to local government.

Under the fluctuating scope of SCIRT, the guidelines for damage thresholds were regularly adjusted to target specific defects and severities that affected the required level of service. In turn, those refinements impacted on the assessment of data.

Initial information from CCC, CERA, City Care, the Earthquake Commission, Environment Canterbury, GNS Science, Land Information New Zealand, the Port Hills Geotech Group, and several other organisations helped guide the first steps. Site visits, site-specific geotechnical investigations, roading asset condition data, flood complaints, CCC archive design drawings, details of emergency work and the personal knowledge of CCC design, operation, and maintenance staff all added to the assessment mix.

Access and assess

As process and procedures evolved, SCIRT created an asset assessment management plan, outlining the approach to "condition investigations and analysis of Christchurch's road, wastewater, water and land drainage and storm water networks to determine the extent of earthquake-related damage". Services were to be returned to "more resilient levels of service than those prior to the September 4, 2010 earthquake".

Under the management plan, investigations would determine the degree of damage; provide information to designers to ascertain the type of repair or renewal; inform project definition work for "concept design and costing of repairs/renewal to determine whole of life costs"; and create an assessment methodology framework.

Investigators sought detailed network condition information in order to rate the section/sub-catchment of each asset type to shape the most appropriate (and economic) repair or replacement solution. Each asset group required a "tailored investigation".

Roads, bridges and retaining walls could be easily viewed. The severity of the damage could be rated without the need for sophisticated tools. By comparison, wastewater and storm water networks required measurements of level and gradient to determine hydraulic integrity and cleaning and inspection to determine the structural conditions.

Manholes needed to be assessed across the undulating cityscape. Technologies needed to be developed to measure the movement of pipes from the original alignment as the ground shifted and separated during multiple tremors. Images needed to be captured of the twisted underground networks.

To address these challenges, innovation and adaption became the stock-in-trade for SCIRT.

Methodical approach

A diverse range of methodologies was employed to ascertain the extent of damage, including a web-based data manager and a custom-fit asset management tool.

SCIRT also needed to find or create the right tools for the expanding rebuild.

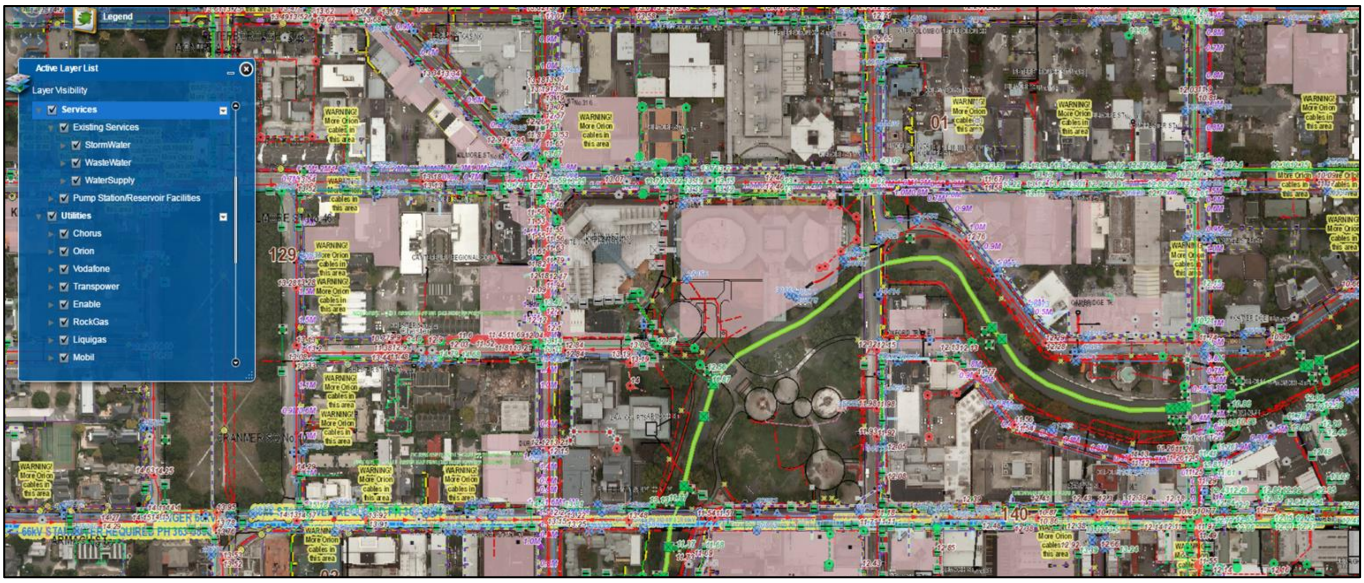
From the Geographic Information System (GIS) Viewer to the Pipe Damage Assessment Tool (PDAT), a unique rebuild challenge required a different perspective on damage assessment.

Point of view

First up, SCIRT tailored a web-based GIS Viewer to manage all spatial data relating to the rebuild. A multitude of individuals and organisations, including design and delivery teams, utility service providers and the city council, could log in and access the latest updates.

The GIS Viewer functions included:

- Storing asset information.
- Storing condition information and assessment results.



Spaghetti junction: A GIS view reveals underground and over-ground services and utilities in Christchurch's central business district.

- Identifying project areas and attributing costs to individual assets.

Utilising GIS and an asset management tool, InfoNet, the data assessment played a crucial role in ensuring the multiple sources of damage information were reviewed and prioritised to meet the SCIRT schedule.

Mine of information

InfoNet, a purpose-built infrastructure management system for water distribution, wastewater collection and storm water networks, could schedule inspections, analyse pipe defects and grade issues, as well as aid repair priorities within the network.

Using InfoNet, which was tailored to SCIRT needs, operations managers, engineers and planners managed, integrated, validated, analysed and reported on network data.

Up-to-date information was compiled in the InfoNet database, and made available to the wider SCIRT organisation. Asset information was also transferable to the city council. All asset assessments were imported to GIS from InfoNet.

Level of gravity

SCIRT undertook a major pipe investigation programme to assess each gravity pipe asset. Four major tools were utilised to best inform the rebuild, along with a predictive tool:

- Manhole level survey
- CCTV
- Pole camera
- Pipe profile
- Pipe Damage Assessment Tool (PDAT)

In order to compare pre-earthquake and post-quake grades, a manhole level survey across the city collected data on pipe inverts and pit lid levels. A comprehensive database will be delivered to CCC at the completion of the rebuild.

Picture of imperfection

SCIRT also took a step closer to the action with closed-circuit television (CCTV) and the pole camera (polecam), placing the focus on pipe damage.

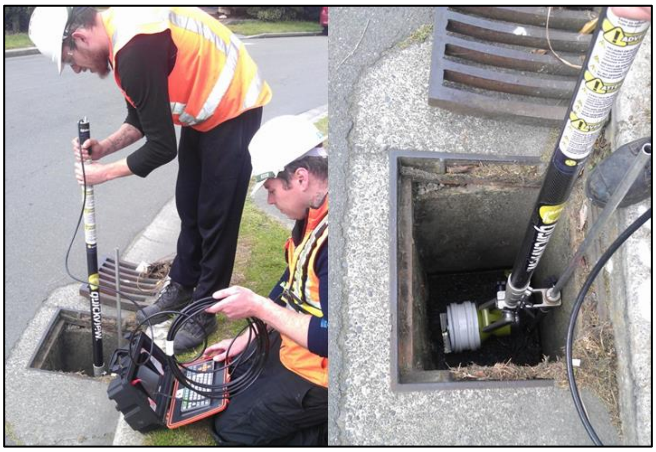
About 20 CCTV crews frantically searched for damage as the clogged pipes hampered inspection. However, there were major concerns over the CCTV programme. It could take up to four years and $125 million to inspect and analyse the footage of the gravity-fed pipes. SCIRT's evaluation and response had to be swift and precise.

However, CCTV operations did provide an additional benefit by clearing pipes of liquefied silt and debris that reduced capacity. The collection of X, Y (horizontal and vertical) coordinates during CCTV inspection further supported planning and process.

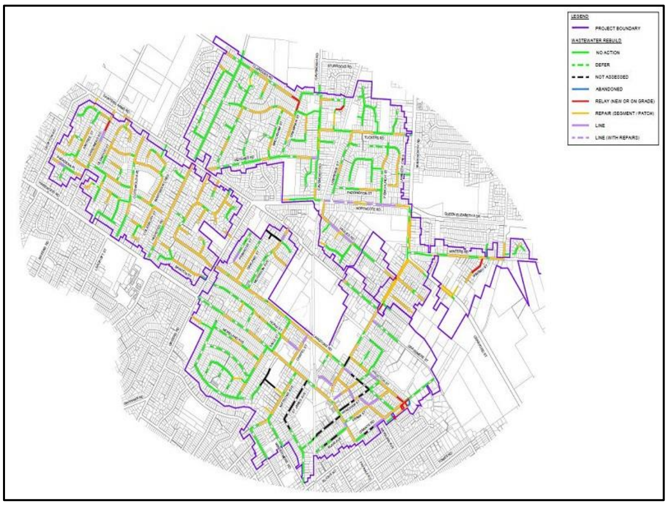
In total, SCIRT clocked up 35 terabytes of investigative CCTV. (CCTV was also used post-construction to check repairs and provide an as-built asset condition.)

Pole cameras were utilised for quick structural assessments of short, large diameter pipes. The high-resolution camera – with lighting and zoom capabilities – mounted on a pole was inserted in manholes or other pipeline structures to take images.

Polecam was the "go to" tool to get up close to storm water damage. In all, 15 per cent of the inspections were undertaken via polecam.



Snapshot: Workers focus on damage utilising a polecam.



Relay or repair: A PDAT output illustrates pipe work.

High-profile assessment

Among the other vital “tools” that set SCIRT on the right rebuild path were the profilometer, which measured the post-earthquake ups and downs of pipes, and the Pipe Damage Assessment Tool (PDAT), a risk-based pipe condition predictor.

Profilometers determined the profile of gravity pipes between manholes, utilising a level sonde pulled through a pipe. Dips greater than 30 per cent needed to be repaired.

Precision PDAT

A new approach was required – an innovative tool utilising parameters that could be seen and measured and could predict the level of unseen damage. The tool would use geotechnical, pipe asset, network performance and earthquake data. The Pipe Defect Assessment Tool (PDAT) – a desktop application that predicted earthquake damage to gravity-fed pipe networks with remarkable accuracy – was created.

Developed by SCIRT, PDAT was used to predict the structural condition of pipes, rather than using CCTV for each pipe. The prediction was based on CCTV images to date, pipe material, land damage, and location and orientation. Utilising GIS, the PDAT assigned damage attributes to individual assets. Trends were then identified between the indicators and pipe conditions. The most likely conditions were matched to the pipes without CCTV images. Investigations were defined for each asset class.

The PDAT was found to be most useful for areas with strong damage trends. Where damage appeared to be random, CCTV still informed the rebuild.

PDAT reduced the reliance on costly and time-consuming CCTV surveys, ensuring a best-value approach by SCIRT.

With PDAT, the city’s wastewater and storm water networks were analysed. Nearly a third of the wastewater network – almost 500 kilometres – needed work by SCIRT.

Steer a rebuild path

For the road network, two levels of information were required:

1. Surface damage.
2. Sub-surface damage to the structural layers.

Surface damage was ascertained via data on carriageways, footpaths, cycleways and kerbs and channels. Condition grades were given to facilities and structures – such as bridges and retaining walls – with moderate to major earthquake damage.

Full network surveys identified the type and volume of damage. The information was collected through Road Assessment and Maintenance Management (RAMM) software, using specific defect codes collected with GPS coordinates and respective route position and route station data. Defects were quantified and a condition grade was assigned to sections of road to aid repair prioritisation.

Utilising RAMM, information was gathered to support either a repair, restore or rebuild option, based on the guidelines.

Polecam or CCTV surveys aided road drainage pipework or road culvert assessments, along with topographical surveys.

No burrowing required: SCIRT CCTV reveals an interloper in the storm water system.

Waste not, want not

To check the wastewater network, the assessments focused on:

- Hydraulic performance – the ability of gravity pipes to convey flow along pipelines.
- Pipe condition – the structural condition of the pipeline.

To undertake those assessments, SCIRT utilised:

- Network plans and information on the age of pipelines and material types available from GIS and as-built plans.
- Original manhole lid and invert levels (available from GIS and as-built plans).
- Post-earthquake manhole and invert levels data collected via surveys.
- Ground settlement data derived from survey benchmark levels and pre/post-earthquake light detection and ranging (LiDAR) surveys.
- Plans of ground shearing/cracking and liquefaction areas (observed liquefaction maps and the Liquefaction Resistance Index.
- Internal manhole inspections to ascertain pipeline displacement.
- CCTV inspection assessment (collected through the CCTV programme and polecam programme).
- Damage/repair history (available from maintenance records).
- Pipeline long section profile to establish dips (collected through the profilometer survey programme).
- Desktop-based prediction of pipe structural condition using PDAT.

Pipe condition surveys (CCTV, polecam, profilometer, PDAT) were stored in the InfoNet database. InfoNet stored the surveys, analysed damage against damage thresholds given in the IRTSG, and presented the raw survey information through to designers, network modellers and project definition staff. The process was competed by publishing assessment outputs to SCIRT's GIS system and through the direct upload of data by designers.

Solution station

Checks of pump stations and equipment required a specialist approach. Inspections were completed and defects loaded into Salesforce, a software solution that provided an interface for task management.

The inspections included:

- Thermal imaging of electrical equipment.
- Vibration analysis on major rotating equipment.
- Visual inspection of pump stations and ancillary equipment.

Any network investigation started with the trunk sewer, progressing up the catchment and sub-catchments.

Murky waters

For the water supply network, two aspects determined functionality:

1. Pipe condition – breaks, joint separation, displacements.
2. Undetected (significant) leaks – "short-circuiting" to adjacent damaged wastewater or storm water systems.

Network plans, the age of pipelines and material types, along with inspections, water flows, leak reports and leak detections all contributed to repair or replace decision-making.

To determine the extent of the damage to these pipes, more than 30 people from various backgrounds came together within a few months to inspect and fix the leaks.

However, not all leaks came to the surface. Listening for the sound of leaking water – when under pressure – also proved to be an effective way of finding pipe breaks.

In 18 months across a city reverberating with demolition and construction noise, the pipe repair programme – often undertaken during the night – was impressive both in scale and complexity.

Key outcomes

The achievement of four major outcomes sealed the rebuild path:

1. Consistent information that could be relied on.
2. Sufficient information to produce designs.
3. Systems in place to allow access to information.
4. Good as built information.

Lessons learnt

Amid the success, there were seven key lessons:

1. The cost of CCTV was very high post-earthquake.
2. The quality assurance of CCTV was important.
3. It was important to implement systems early to limit escalation.
4. Contractor performance should be monitored (especially with no-risk contracts).
5. Collect X, Y coordinates during CCTV inspection.
6. Choose a secure online solution for the storage and management of the footage.
7. Always consider the integration with a client management system.

Time for a close-up: Work crews use CCTV to check for underground damage.