Lessons learnt from the Darfield Earthquake –
A Bridge Consultants Perspective

A.G. Rooke & M.J. Cowan

Opus International Consultants Ltd, Christchurch, New Zealand

ABSTRACT: As the New Zealand Transport Agency’s (NZTA) Regional Bridge Consultant in Canterbury and the West Coast, Opus International Consultants Ltd were required to respond to the M\text{w}7.1 earthquake that struck 40km west of Christchurch on September 4\textsuperscript{th}. This involved the coordination and execution of inspections to confirm the serviceability of bridges in the immediate aftermath of the earthquake along with follow up inspections to record the extent and severity of damage suffered during the event. In addition, Opus also undertook the inspection of some 500 local authority bridges in Christchurch and the Banks Peninsula. All NZTA inspections were completed and a report on damage sustained issued within five days. Christchurch City Council inspections were completed and reported within two weeks of the event.

This paper explores Opus’ response to the earthquake as bridge consultant for two different clients. It reviews the procedures implemented by Opus in responding to the earthquake and identifies some of the lessons learnt both during the immediate response and subsequent inspections in the following days and weeks.

Damage observed from a range of bridge sites is presented and the benefits of having a comprehensive well maintained bridge information system to assist in the response to emergency events is highlighted.

1 INTRODUCTION

At approximately 4:35am on September 4\textsuperscript{th} 2010, a M\text{w}7.1 earthquake struck at 10km depth and some 40km west of Christchurch near Darfield. At the time of writing, there have been in excess of 4,500 aftershocks broken down by magnitude as follows:

- \( > M_w 5.0 \) – 14
- \( > M_w 4.5 \) – 31
- \( > M_w 4.0 \) – 116
- \( > M_w 3.5 \) – 405
- \( > M_w 3.0 \) – 833
- \( < M_w 3.0 \) – 3146

In the first few hours following the initial event the extent and severity of damage to the bridge stock in the affected area was unknown. What was clear was that a significant earthquake had occurred and initial reports received suggested a number of lifeline bridges had sustained considerable damage.

For typical bridges within Canterbury, the earthquake has been estimated as having a return period of 200-300 years (depending on location).

As Regional Bridge Consultant for NZTA and bridge asset management consultant for Christchurch City Council, the Opus bridging team was required to assist with all three phases of response to the September 4\textsuperscript{th} Event:

- Immediate Response – Assess status of structures and advise on serviceability.
- Service Continuity – Identify initial measures required to restore basic access and undertake follow-up inspections in order to plan for full recovery.
- Recovery – Plan for full restoration of service.

This paper focuses on Opus role as Bridge Consultant for these two organizations, typical bridge damage observed and how a well maintained Bridge Information System can assist in responding to such events.
2 CLIENT OVERVIEW

2.1 NZTA

Opus (Christchurch) are the New Zealand Transport Agency (NZTA) Regional Bridge Consultant (RBC) for Regions 11 & 12 (Canterbury and West Coast) and are responsible for the management of some 860 bridges and major culverts on the State Highway Network.

![Regions 11 & 12 Network Coverage](image)

Figure 1: Regions 11 & 12 Network Coverage

Opus have held this position for some 15 years and prior to that fulfilled the same role as Works Consultancy Services. We have amassed a wealth of knowledge about the network in this time and, to ensure that information is not lost, we have developed and maintain a robust Bridge Information System (OBIS). OBIS supports the bridge management process by capturing and providing ready access to key asset management information such as condition information, maintenance history, as-built records and risk profiles (e.g. outputs from seismic and scour screening exercises).

In addition to the Regional Bridge Consultant, NZTA also engage Network Maintenance Consultants (NMC) and Network Contractors (NC) who are responsible for overall management/maintenance of the State Highway Network.

2.2 Christchurch City Council

Opus have operated in the role of bridge asset management consultant to Christchurch City Council (CCC) for the last five years and, prior to this fulfilled the same role for the Banks Peninsula District Council (amalgamated with CCC in 2006). CCC hold a great deal of information on the Banks Peninsula bridge-stock and have a well maintained OBIS system. Ready access to information for the remaining Christchurch City wards is at an earlier stage of development.

There are some 160 bridges and major culverts in Banks Peninsula with a further 320 around Christchurch City.

3 ESTABLISHED EMERGENCY PROCEDURES

3.1 Opus Procedures

Opus operate and maintain a local Business Continuity Plan that is intended to ensure Opus will continue to function/resume operations in order to meet the needs of our clients in the event of an emergency. It provides information on:

- Dealing with emergency events at our offices (including data security, inspection of offices following events, protocols for establishing temporary and support offices immediately following an event etc.);
- How we interface with clients with whom we have contractual
agreements to assist; and,
- How we interface with other major clients who are Lifelines Utilities as defined under the Civil Defence Emergency Management Act 2002 or are key clients.
- Contingencies for establishing longer term business continuity.

3.2 NZTA Procedures

As part of the Bridge Management Contract, Opus must respond to emergencies such as bridge strikes, floods, earthquakes etc. This is set out in the “State Highway Emergency Procedures and Contingency Plan” (EMP) which requires:

- NZTA or the NMC to advise the Bridge Consultant whenever an emergency bridge inspection is required;
- The Bridge Consultant to arrange for an emergency inspection as soon as possible;
- If emergency action is required to temporarily strengthen or to close a bridge, or to perform any other work, the Bridge Consultant shall communicate immediately with the State Highway Network Consultant to implement such action.
- Immediately following the inspection, the Bridge Consultant shall notify the NZTA/NMC of the action he recommends.
- The Bridge Consultant to forward a written report outlining the results of the inspection and recommendations for any further investigations, strengthening, repair or other actions required, and the timing of such work.

3.3 CCC Procedures

In the case of Christchurch City Council, Opus had no contractual agreement to assist in an emergency and therefore we have no specific procedures in place. However, in our role as bridge asset management consultant, we made contact with the Council to offer support and were requested to assist with their response. In this instance, we were acting under direct instruction by the Council who were following their own established procedures.

4 RESPONSE PHASES

Immediately following the earthquake, it was apparent that emergency inspection of bridges would be required and we were faced with a number of challenges:

- Power/Communication: Power was lost to many suburbs of Christchurch, also taking out most landlines (dependant on power). Fortunately, the cell phone networks remained intact and were not overloaded so it was still possible to establish contact with key personnel.
- Condition of Opus Office: Was the office intact? Was power/communication available? Could it be used as a response centre?
- Understanding the location/magnitude of event: Where was the epicentre? How big? What was the likely affected zone?
- Extent of damage: Initial reports indicated significant damage to a number of lifeline structures. It was clear from personal experience that extensive liquefaction had occurred resulting in significant damage to many infrastructure assets. How had the bridge stock fared?

4.1 Initial Response

Our initial focus at this stage was fulfilling our obligation to NZTA and the first hour following the event was spent establishing contact with the NMC team leader, understanding the extent of the earthquake, agreeing priorities, establishing the welfare of team members and mobilising inspection staff.

By 5:30am the following had been established:

- Location and magnitude of earthquake;
- Opus office intact, communications and power available. Response centre being established there;
- Key personnel mobilised and briefed on initial response;
• Reports of significant damage to a number of lifeline bridges on SH1S.

By 10:00am, emergency inspections had been undertaken on some 20 State Highway bridges in the Christchurch area at the request of the NMC. In addition, inspectors were tasked to inspect bridges known to be at-risk of damage during a seismic event. Contrary to initial reports, only two State Highway bridges were initially closed, both due to liquefaction induced subsidence and lateral spreading of the approach embankments (despite ongoing reports of many more by various media agencies). A frustrating aspect of that first day was conflicting reports regarding condition, resulting in repeated inspections of the same structures.

All drive over inspections had been completed by the Network Contractors in North Canterbury and South Canterbury by 3:00pm with no further requests for emergency inspections having been made. In addition, our West Coast based bridge inspector had completed an inspection of critical structures on SH73 (one of two alpine passes between Canterbury and the West Coast) with no reports of damage.

All indications were that the State Highway Bridges had fared well, with damage limited to approaches (the repairs of which were in hand), and by mid-morning we started to turn our attention towards other key clients. Contact was made with all local authority clients to offer assistance as required.

Our ability to respond to NZTA in a prompt manner that first day was due in part to the robust procedures put in place that clearly outlined responsibilities within both Opus and NZTA. While, loss of the cell phone network and/or damage to the office would have hampered our ability to respond, the Business Continuity Plan ensured that an inspection of the office was undertaken promptly to establish status and that this was communicated to key personnel straight away. Furthermore, the State Highways Emergency and Contingency Plan in setting roles and responsibilities ensured that resources were available, lines of communication were clear and each party was able to focus on their role.

In addition to the emergency procedures, familiarity with the bridge stock also contributed to the speed of response along with ready access to key asset information through the OBIS system. In the event of there being no power, a hard copy of the most essential information is also maintained.

Christchurch City Council requested assistance with inspection of their bridge stock on Monday 6th September starting with bridges in those areas most affected by liquefaction (Avon and Heathcote Rivers along with Brooklands). The inspection of some 480 bridges was completed in five working days (using up to six inspection teams) and served as both initial response and service continuity inspections. To address the needs for an initial response, a report was issued to the client at the end of each working day listing those bridges inspected with a simple colour code identifying whether the bridge was unfit for service (red), significant damage had been sustained but remained serviceable (orange) or had suffered only minor or no damage (green). Where damage had been sustained, a brief comment regarding the nature of damage was included.

The benefits of having ready access to accurate asset information was clearly demonstrated during these inspections as bridges on the Banks Peninsula (160 bridges) were completed by one inspection team over the course of five days while bridges within the city (320 bridges) took five inspection teams five days to complete. Familiarity with the bridge stock and ready access to pre-existing and up to date condition information for the bridges enabled their rapid assessment.

4.2 Service Continuity

As stated previously, it soon became clear that NZTA bridges had performed well. On that first morning all but two bridges remained serviceable. The two affected bridges had been closed due to the effects of liquefaction on approach embankments but both had been reopened (with restrictions) by the Saturday afternoon once the approaches had been temporarily reinstated.

On the Sunday, our focus moved to programming and preparing for follow-up inspections for NZTA bridges. The purpose of this phase was to undertake a co-ordinated, prioritised and comprehensive inspection of bridges within the region in order to:

- Identify and address any underlying safety risks;
- Identify and quantify extent of any damage attributable to the earthquake;
- Prioritise and cost (Rough Order) any remedial works for full recovery.
In prioritising the inspections, it was agreed that we would focus initially on bridges within the city (given the increased traffic demand on these structures) and then radiate outwards. Four inspection teams were mobilised for the Monday morning and, using OBIS, inspection packs were prepared for each team. These included a list of bridges, inventory reports, latest inspection reports and condition photographs along with as-built drawings. In addition, bridges identified as being at risk during a seismic event* were highlighted and the “risk event” described to provide guidance to inspectors.

* In 1999, NZTA commissioned the seismic screening of all State Highway bridges, the results of which were used to develop a prioritised national retrofit programme. Since then NZTA have invested heavily in the retrofit of key lifeline structures.

In total, 160 NZTA bridges received a follow-up inspection of which nine were noted as having sustained damage. The inspections were completed over the course of three days and a written report issued to the client on Thursday 9th September. Four inspection teams were active on NZTA bridges during the first day but this was reduced to two on subsequent days (with NZTA approval) to assist with Christchurch City Council inspections.

Again, being able to access all key asset information in one location (OBIS) was instrumental in being able to undertake these inspections in an efficient manner.

As previously discussed, the Christchurch City bridges were inspected over the course of five days and served both as initial response and service continuity inspections. The inspection results were reviewed over the following five days in order to assist service continuity. The benefits of having ready access to pre-existing and current condition information for the bridge stock was once again highlighted as a review of the Banks Peninsula inspections was completed in a very short period relative to the city bridges.

4.3 Recovery

Planning for restoration works is currently underway. However, as the bridge stocks performed well compared with other infrastructure, much of the remedial work identified has been assigned a lower priority.

5 DAMAGE SUSTAINED

Only two state highway bridges were closed following the earthquake, both due to liquefaction-induced subsidence and lateral spreading of the approach embankments as opposed to structural damage to the bridges themselves. These were returned to restricted service on the same day and to full service within one week. Structural damage was observed to a total of nine State Highway bridges (of 160 inspected) and ranged from minor spalling (where adjacent elements made contact), moderate cracking/spalling of diaphragm members and the failure of isolated linkage bars (SH1S Kaiapoi River/Rail Bridge) through to permanent displacement of the superstructure (causing expansion joints to lock up) at SH1S Chaney's Overpass.

Photograph 1 – SH1S Chaney’s Overpass – Lateral spreading of approaches and displacement of superstructure
Given the relatively low return period of the earthquake (200-300 years) it is not surprising that structural damage was isolated and relatively minor. While inspections suggest that some of the seismic linkage retrofit systems installed by NZTA over the previous 10 years had been activated during the earthquake, none approached failure and it is reassuring that none of the retrofitted bridges exhibited structural damage.

Of the Christchurch City Council structures, six bridges (four footbridges) sustained major damage necessitating temporary closure, 13 bridges sustained damage but remained serviceable with a further 105 bridges (14 footbridges) exhibiting minor damage.
As for NZTA bridges almost all damage sustained by Christchurch City Council bridges was due to interaction of the sub-structure with subsiding and laterally spreading river banks/embankments. Damage observed included hinging of a small span masonry arch, rotation of abutments, deformation and displacement of rubber bearings, flexural cracking of piers/exposed piles, spalling of diaphragms and crushing of mortar bearings.

Footbridges closed following the earthquake typically exhibited significant damage to their superstructure. As for the road bridges, damage/failures occurred in those areas where liquefaction was experienced and lateral spreading of the river banks had occurred.

Overall, State Highway and Christchurch City bridges fared well in the earthquake (as did other bridges in the Canterbury region) with very little damage being a direct result of shaking during the event. Of the approximately 640 bridges inspected, no State Highway bridges had significant damage and only 6 Christchurch City Council bridges sustained major damage necessitating closure. Greater disruption occurred as a result of the damage caused to approaches and river banks from liquefaction-induced effects (i.e. lateral spreading and settlement).

6 CONCLUSIONS

In total, some 640 bridges were inspected in the seven days following the September 4th Darfield earthquake. The emergency inspection of some 20 state highway bridges were completed in the first five hours following the earthquake.

A managed and rapid response to the 2010 Darfield Earthquake event was possible due to the following reasons:

- Emergency and contingency plans were in place that set in motion actions and clearly defined roles and responsibilities for such an event;
- Communication was maintained. If the cell phone network had failed, mobilisation and
briefing of personnel would have been hampered, as would liaison with the Network Maintenance Consultant. Alternative communication is available for the Network Maintenance Consultant and Network Contractor and should extend to the Regional Bridge Consultant

- A well-maintained Bridge Information System (OBIS) afforded ready access to key asset information and allowed the rapid production of inspection briefs, up to date condition and as-built information for ease of assessing damage sustained (and significance) during the earthquake;

- The seismic screening exercise undertaken by NZTA in the 1990’s ensured that those structures known to be at risk in the event of a earthquake had been identified and, where seismic retrofitting had not been completed, the “risk event” was well understood, providing a focus for inspection.

State Highway bridges and Christchurch City Council bridges within the affected region typically performed well. This is attributable to:

- Bridges did not typically experience design level ground acceleration;

- The majority of older bridges within the region are short to medium span structures where design for relatively high gravity load effects affords a greater level of robustness for seismic performance. This is compared with other building related infrastructure of the same era (i.e. prior to modern design requirements for seismic actions).

In most cases, damage was as a direct consequence of liquefaction-induced subsidence and lateral spreading of river banks/approach embankments and, even though structural damage may not have eventuated, the bridges were still required to be closed due to vertical settlement of the approaches relative to the bridge decks. The damage potential of liquefaction-induced effects was highlighted by this event.