6. GEOTECHNICAL EFFECTS ON CRITICAL STRUCTURES DURING THE MARCH 5TH FLOOD EVENT

Flood induced geotechnical failures were investigated by the GEER team during their deployment for the March 5th flood event. Bridge scour was investigated on bridges along the Avon and Heathcote Rivers. The GEER team visited the port in Lyttelton to explore damage that may have been induced by the flood event. Updates to GEER's reconnaissance conducted after the February 2011 Christchurch earthquake are also presented that could not be previously released due to economic sensitivities for Lyttelton Port Christchurch (LPC). Lastly, the potential failure of a newly constructed earth retaining wall in the Port Hills is explored.

Bridge scour

Scour represents one of the major failure mechanisms of bridges (Melville and Coleman, 2000). In particular, the increase in water flow velocities during heavy rain and flood events can lead to increased sediment erosion in the vicinity of bridge piles, and by doing so, potentially lead to failure of the bridge. Due to the complex and interdisciplinary nature of the processes (Sumer and Fredsoe 2002), the prediction of scour and potential bridge pile failure is still a subject of research. In Christchurch the impact of the previous earthquake related damage to the bridges and possible changes in river morphology represent another variable that is still in the process of being considered and investigated.

The GEER team conducted a rough survey of possible scour at four Avon River bridges identified in Figure 6-1 and two Heathcote River bridges identified in Figure 6-2. Figure 6-3 shows how the water depth was sounded along the bridges, using a diving weight and a marked rope. Indications for scour were mainly found at Pages Street Bridge and Wainoni Road (Bower) Bridge (both crossing the Avon River; Figure 6-1). However, large uncertainties have to be considered regarding the simple and coarse sounding technique. Detailed investigations including more measurements around the foundations would allow more definitive conclusions to be made. In the following sections, a background of the bridges is given and the results of the soundings presented.

Figure 6-1 Bridges surveyed regarding possible scour along the Avon River.

Figure 6-2 Bridges surveyed regarding possible scour along the Heathcote River.

(a)

(b)

Figure 6-3 (a) Depth soundings at Anzac Drive Bridge and (b) depth reading using a marked rope.

A) Avon River Bridges

Bridge Street Bridge

The South Brighton Bridge, or Bridge Street Bridge, crosses the Avon River in an east-west orientation, connecting the suburbs of South New Brighton and Bromley (Figure 6-1). It is the final crossing on the Avon before it enters the Avon-Heathcote Estuary, and provides the primary link for the suburbs of South New Brighton and Southshore.

Original structure

The original bridge was constructed in 1981 and had a total length of 65 m over three spans of in-situ cast concrete supported by precast post-tensioned concrete I-beams (21.5 m-22 m-21.5 m) and a total width of 15.2 m. Details of the original plan and elevation are provided in Figure 6-4 and Figure 6-5. To construct the bridge, two approach embankments approximately 4 m in height were extended out into a wetland area, with the bridge structure spanning the river channel.

The spans are supported by octagonal precast concrete piers with hammerhead pier caps and seat-type concrete abutments. Elastomeric bearings have been used to isolate the super-structure in both the longitudinal and transverse directions. Both piers and abutments are supported by raked pre-tensioned reinforced concrete octagonal piles (450 mm wide and 18.7 m in length). These are installed at the piers with a rake of 14° from vertical. Each abutment has ten piles, and each pier is supported by a pile cap with twelve piles.

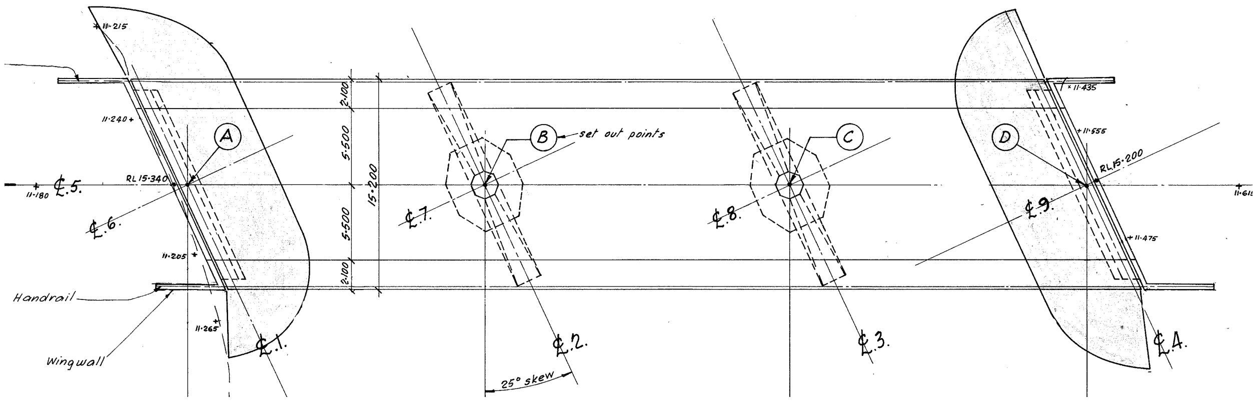

Figure 6-4 General planform design of South Brighton Bridge, with the left of the figure the western edge of the bridge (CCC, 1978).

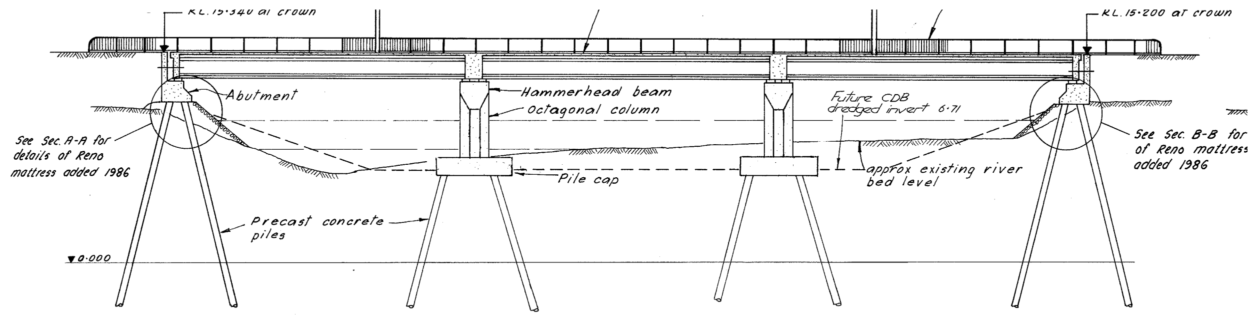

Figure 6-5 Profile view of South Brighton Bridge (CCC, 1978).

Earthquake Damage

The bridge was affected by the Darfield, Christchurch and 13 June 2011 earthquakes, with some minor additional land damage following the 23 December 2011 earthquake. The bridge sustained moderate to severe damage following the Darfield earthquake, severe damage following the Christchurch earthquake, and this was further damaged following the 13 June 2011 earthquakes.

Both abutments settled and back-rotated as a result of lateral spreading. Following the 13 June 2011 earthquakes, back-rotation of the western abutment was equal to 10°, while the eastern abutment had 9° of back-rotation. The slumping of soil around the abutments due to lateral spreading exposed the tops of the abutment piles. Hinging at the top of the piles was accompanied by horizontal flexural cracks and spalling in the exposed sections of the piles under both abutments. Following the Darfield earthquake only minor cracking of the piers was observed, with a single flexural crack at the water line in the west pier. There was no serious damage to the bridge superstructure, however greater subsidence at the abutments compared to the piers meant that the superstructure developed a hogged profile.

Retrofit of structure

Retrofit of Bridge St Bridge commenced in 2013, involving strengthening of the bridge structure and stabilisation of the river bank and embankment slopes at the abutments with a jet grouted column lattice structure to mitigate liquefaction and lateral spreading effects. Four 1.2 m diameter concrete filled steel tube piles will be installed at each abutment to a depth of approximately 40 m into dense gravels. The superstructure will be jacked level to reduce stresses caused by the hogging, and abutments were rebuilt with geogrid (Keepa et al., 2014). This work is estimated to be completed in mid-late 2014.

Scour

With the original river bed level (Figure 6-5), scour would correspond to the octagonal columns, probably reaching the pile caps and making them a scour protection. With full exposure of the pile caps, scour would be expected to develop in a different shape, in response to the sharp pile cap edges. However, destabilization of the bridge due to scour is very unlikely, because of the support provided by the concrete piles. Surveying was limited due to construction work (Figure 6-6, Figure 6-7, and Figure 6-8). Figure 6-8 shows the soundings generally indicating a deepening towards the east in the channel, and the downstream side was generally deeper by ~30-40 cm. An irregularity was found at a distance of 24-26 m from the western lightpost which served as datum. Due to the limited soundings, it cannot be determined if the shoaling or the deepening represents the irregularity, or if this might be related to scour processes and/or an increase of erosion during the flood. A shoaling could be related to a gravel bank deployed around the piers for a remediation of the pier pile caps. A more detailed investigation after the conclusion of the construction work would answer this question.

Figure 6-6 Sounding at South Brighton Bridge with construction work in the background on 19 March 2014.

Figure 6-7 Location of upstream (yellow) and downstream transects superimposed on aerial photo from 24 December 2011 (Canterbury Geotechnical Database 2012).

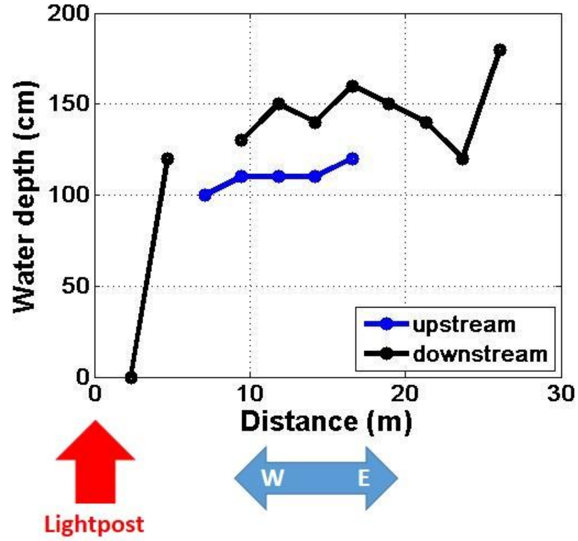

Figure 6-8 Soundings at the Avon's Bridge Street Bridge. Zero represents the western lightpost of the bridge. Construction work restricted the sounding particularly on the upstream side, and in close vicinity of the piers.

Pages Road Bridge

The Pages Road Bridge, or New Brighton Bridge, crosses the Avon River in an east-west orientation on the eastern edge of the city, connecting Christchurch to the suburb of New Brighton. It was opened for traffic on May 2nd 1931. The bridge acts as a crossing point for a number of utility services crossing the bridge path.

Original structure

Pages Road Bridge is a cast in-situ monolithic reinforced concrete structure which was designed in 1924, and constructed in 1930-31. Details of the plan and elevation are given in Figure 6-9 and Figure 6-10. The bridge has a total length of 22.5 m over three spans (6.7 m-9.2 m-6.7 m) and a total width of 16.8 m.

The deck is supported by two concrete wall piers, with the superstructure fully built into these and the abutments (Figure 6-11). Both piers and abutments are supported by 350 mm wide octagonal reinforced concrete piles, each 7.3 m long. Each pier has 14 vertical piles, while each abutment has eight piles supporting the backwall and two piles supporting each wing-wall.

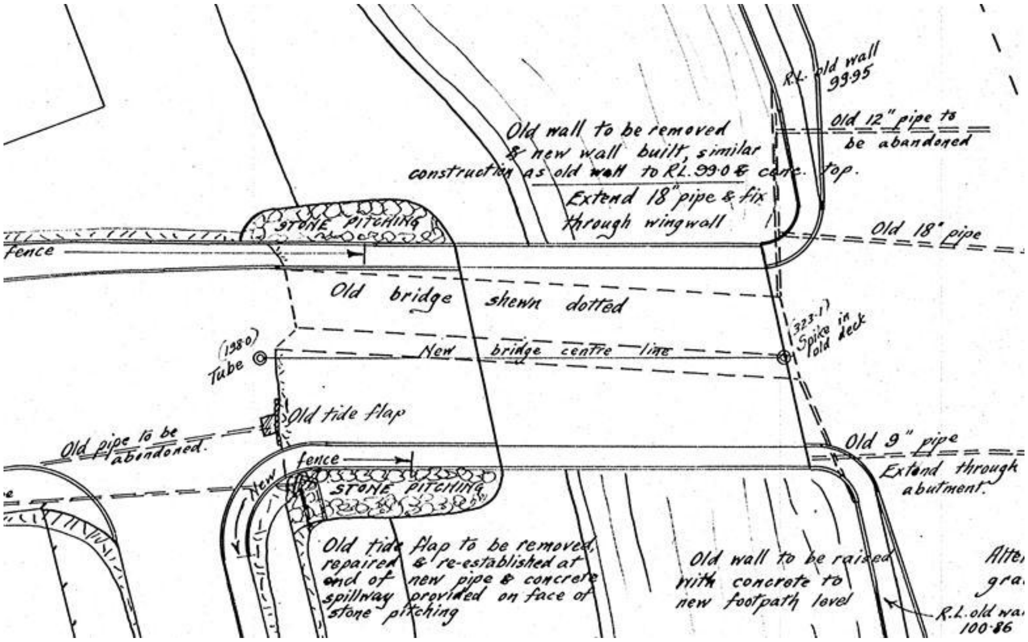

Figure 6-9 General plan of Pages Road Bridge, with the left of the figure the western edge of the bridge (Toogood, 1929).

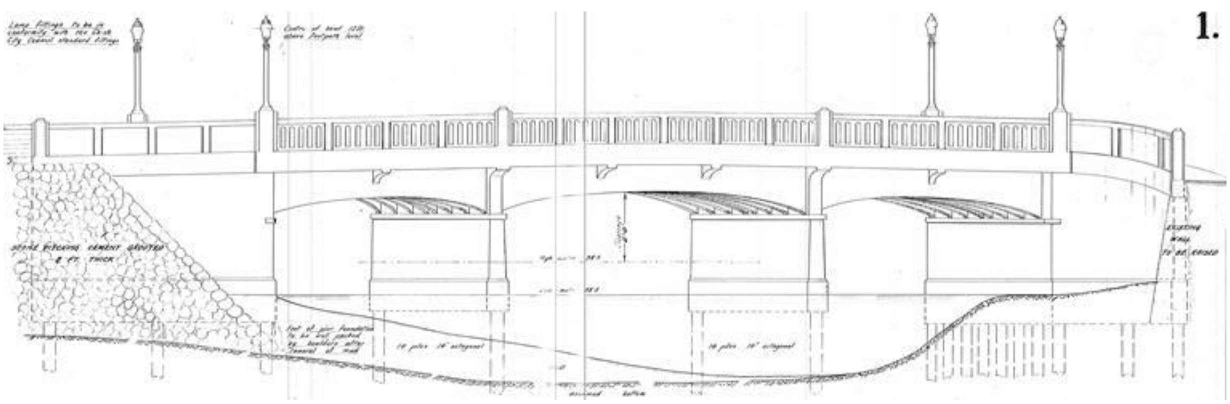

Figure 6-10 Elevation view of Pages Road Bridge (Toogood, 1929).

Figure 6-11 Pages Road Bridge on 19 March 2014.

Earthquake Damage

The bridge was mainly affected by the Christchurch earthquake, with some minor additional land damage following the 13 June 2011 earthquake. The bridge sustained moderate damage following the Christchurch earthquake due to liquefaction and lateral spreading, and this was further progressed following the 13 June 2011 earthquakes.

Both abutments developed minor back-rotation and cracking, and there was significant settlement of the approaches as a result of liquefaction and lateral spreading during the Christchurch earthquake. There was a slight increase in the abutment back rotation following the 13 June 2011 earthquakes. Minor cracking at the interface between the eastern pier and the deck beam was identified following the Christchurch earthquake.

Retrofit of structure

The planned retrofit of this bridge, involving improvements to the approach and abutments, had yet to commence at the time of the March 2014 flood event and post-flood GEER reconnaissance.

Scour

Figure 6-12 shows the sounding results at Pages Road Bridge indicating a deepening by ~ 0.4 m and narrowing of the Avon River downstream. The cross-bridge profiles do not indicate scour. However, at the western pier measurements at a distance of ~1 m (cross-profile) and at ~0.1 m were conducted. Downstream of the pier, the water depth equalled ~1.8 m, which was in accord with the general channel profile (Figure 6-12). Close to the pier foundation the water depth was only ~1.5 m, possibly corresponding to sediment accumulation in the lee of the structure as is typically seen when scour occurs. On the upstream side, a water depth of ~1.6 m was measured at a distance of ~1 m from the piers, while at the pier foundation a water depth of 1.8-1.9 m was measured over four soundings, likely representing a scour hole as typically seen at the upstream side of a structure. Thus, the results hint at scour at the pier foundations of Pages Road Bridge with erosion reaching scour depths and sediment accumulations in the range of ~ 0.3 m. Such scour depths will unlikely represent a hazard, however, monitoring of scour development should be considered in cases of an increasing occurrence of flood events, and results might be considered for the retrofit of the bridge.

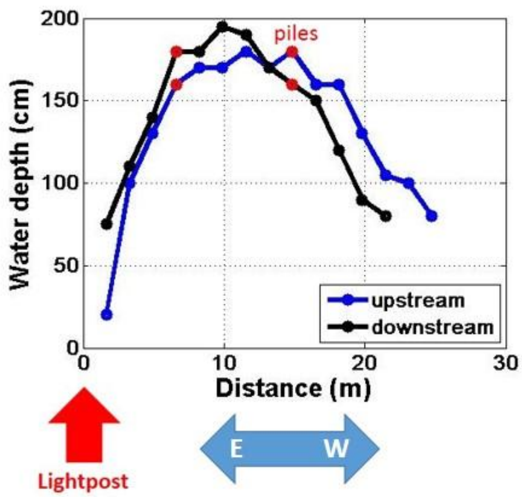

Figure 6-12 Soundings at Pages Road Bridge. Measurements level with the piles are indicated as red circles. Zero corresponds to the eastern lightpost.

Wainoni Road Bridge (Bower)

The Wainoni Road Bridge, or Bower Bridge, crosses the Avon River in an approximately north-south orientation on the eastern edge of the city, connecting the suburbs of Wainoni and New Brighton. The bridge was opened in 1942.

Original structure

Wainoni Road Bridge is a three span reinforced concrete structure with the deck supported by two concrete wall piers.

Earthquake Damage

The bridge was mainly affected by the Christchurch earthquake, with slumping and minor lateral spreading of the approaches to the bridge. This only has a minor effect on the bridge structure.

Retrofit of structure

There had been no retrofit applied to this bridge at the time of the flood event.

Scour

The soundings shown in Figure 6-13 were conducted only on the downstream side of the bridge only due to traffic. The channel profile appears generally approximately symmetric. Different measurements have been conducted in the vicinity of the pier foundations. Behind the piers, the water depths corresponded well to the general profile, possibly showing some slight sediment accumulation at the southern pier foundations. However, both corners were characterized by significant deepening by 0.3-0.7 m. Approximately 4 m downstream of the southern pier, sediment accumulation of ~ 0.4 m was identified. This was not confirmed at the northern pier. Nevertheless, these results suggest the development of some scour at Bower Bridge. A more sophisticated survey strategy is recommended to investigate the scour and possible related hazards in more detail. The coarse and very simple method presented here is certainly not sufficient to draw any definitive conclusions.

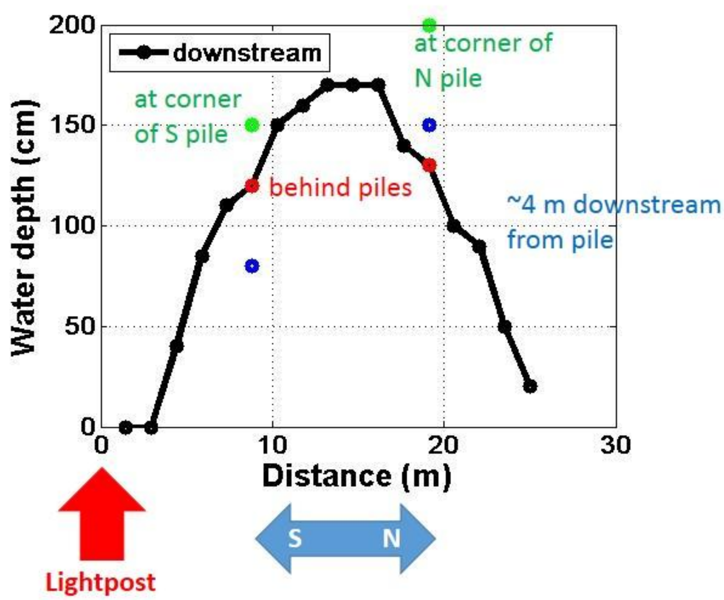

Figure 6-13 Soundings at Bowers Bridge. No measurements were conducted on the upstream side of the bridge due to traffic. Regarding measurements at the pier pile foundations, red circles indicate sounding behind the square piles, green circles at the corner and blue circles ~ 4 m downstream.

Anzac Drive Bridge

The Anzac Drive Bridge, shown in Figure 6-14, is located on State Highway 74 and crosses the Avon River in a north-south orientation. The bridge also acts as a crossing point for a number of utility service lines.

Figure 6-14 Anzac Drive Bridge on 19 April 2014.

Original structure

Anzac Drive Bridge is a reinforced concrete structure which was constructed in 1999. Plan and elevation views of the bridge from the construction plans are shown in Figure 6-15 and Figure 6-16. The bridge has a total length of 48.4 m over three spans (14.9 m-18.6 m-14.9 m) and a total width of 21.7 m.

The superstructure consists of simply supported precast double core units. The superstructure is supported by cast in place wall-type abutments and two four-column bents. The piers are supported by 1.5 m diameter steel shelled reinforced concrete piles 20 m in length, and are not connected by pile caps. Each abutment is supported by grade 300 steel H-piles 22 m in length, with 16 at the northern abutment and 15 at the southern.

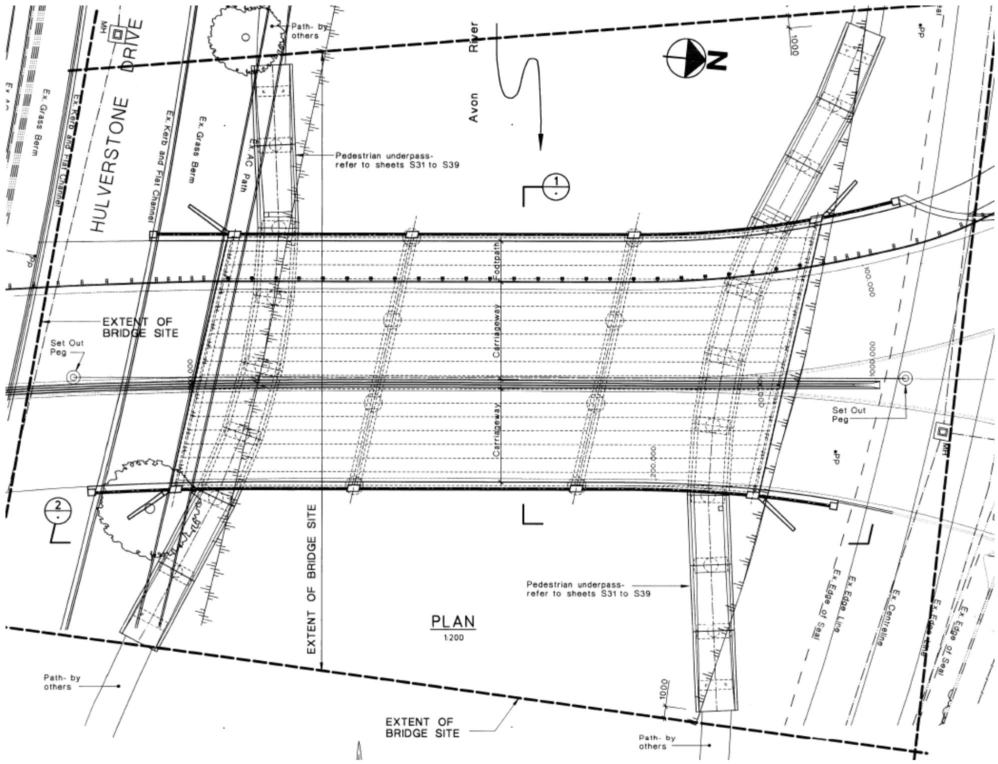

Figure 6-15 General plan of Anzac Drive Bridge, with the left of the figure the southern edge of the bridge (CCC, 1999).

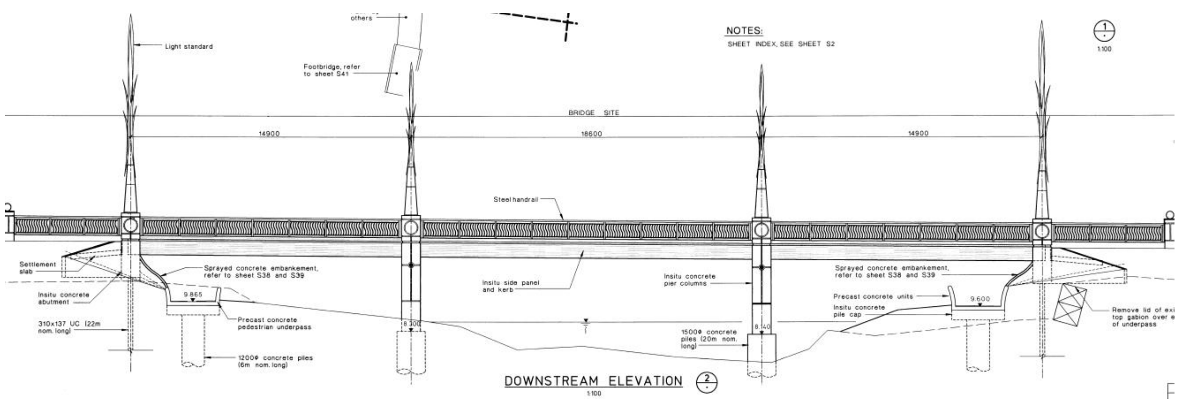

Figure 6-16 Elevation view of Anzac Drive Bridge (CCC, 1999).

Earthquake Damage

The bridge sustained moderate to severe damage following the Christchurch earthquake due to liquefaction and lateral spreading, and this was further progressed in the subsequent events, mainly the 13 June 2011 earthquakes.

Both the abutments settled and back-rotated as a result of the lateral spreading in the Christchurch and June 2011 earthquakes. Following the Christchurch earthquake, the northern abutment developed approximately 4° of back rotation, while the southern abutment to back rotated by 6° and displaced towards the river. There was slight additional rotation of the abutments following the 13 June 2011 earthquakes.

Following the Christchurch earthquake, both pier frames suffered extensive cracking of the concrete columns and beams as well as the beam-column joint regions of the pier cap. Spalling of the concrete cover appears to be primarily as a result of interaction between the transverse motion of the bridge and the rotation of the piers due to lateral spreading. There was no serious damage to the bridge superstructure.

Retrofit of structure

No details of the repair and retrofit approach are available at this stage.

Scour

Figure 6-17 shows the riverbed profile determined from soundings. The riverbed at Anzac Drive Bridge is defined by directing the major part of the flow through the piers. No significant variation in morphology can be observed at the piers. Immediate deepening in front and slightly more at the pier foundations corners can possibly be related to scour, but (i) has no significant impact on channel morphology, and (ii) from this limited data set, cannot be determined if related to scour.

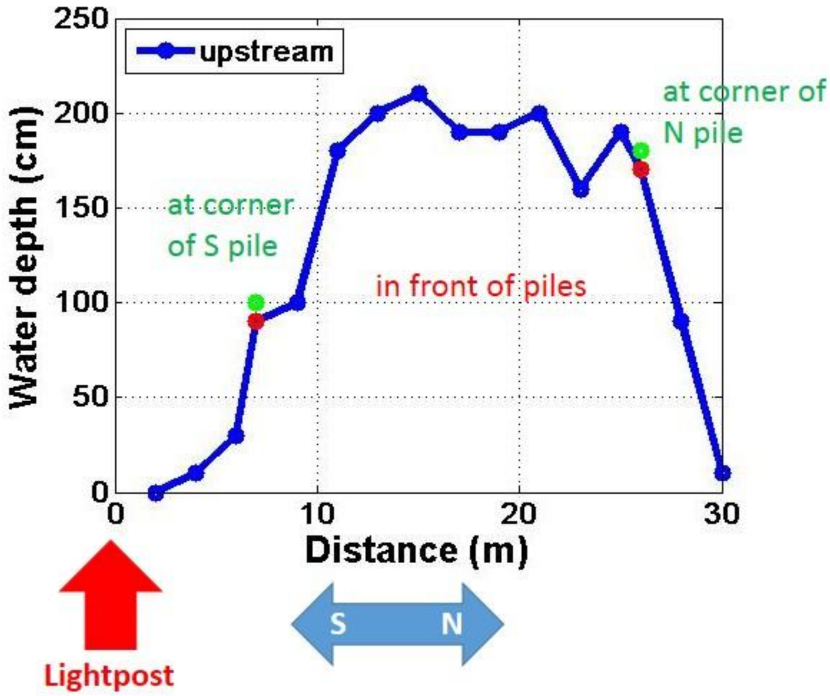

Figure 6-17 Soundings at Anzac Drive Bridge. Only upstream measurements were possible due to traffic.

B) Heathcote River

Heathcote River Bridge

Figure 6-18 Heathcote River Bridge on 20 March 2014.

The Heathcote River Bridge shown in Figure 6-18 is located on State Highway 74 and crosses the Heathcote River in a north-south orientation. The bridge also acts as a crossing point for a number of service lines.

Original structure

Heathcote River Bridge is a reinforced concrete structure which was constructed in 1963. The bridge has a total length of 52 m over three spans and a total width of 10.6 m.

The superstructure consists of 10 prestressed concrete precast I-beams simply supported at the abutments. The superstructure is supported by reinforced concrete abutments and three column reinforced concrete piers and pile cap. The piers are supported by ten 4.32 m vertical octagonal reinforced concrete piles. Each abutment is supported by the same number of raked piles.

Earthquake Damage

The bridge was undamaged during the Darfield earthquake. During the Christchurch earthquake there was a significant amount of lateral spreading and cracking of the approach soils and approach settlement. There was approximately 1° of back rotation of the north abutment towards the river.

Scour

The soundings at Heathcote River Bridge are shown in Figure 6-19 and indicated that most of the flow is going between the two pile groups. No significant water depth variations were noted at the foundations, while downstream a slight deepening in the center of the channel by ~ 0.2 m was observed, likely eroded due to compression of streamlines between the piers.

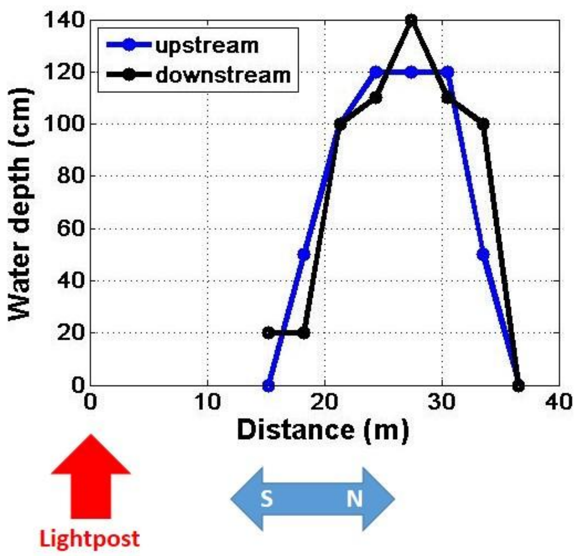

Figure 6-19 Soundings at the Heathcote River Bridge.

Rutherford Street Bridge

The Rutherford Street Bridge is shown in Figure 6-20 and located on State Highway 74. It crosses the Heathcote River in a north-south orientation. The bridge also acts as a crossing point for a number of service lines.

Figure 6-20 Rutherford Street Bridge on 20 March 2014.

Original structure

Rutherford Street Bridge is a reinforced concrete structure which was constructed in 1983. The bridge has a total length of 39.7 m over three spans and a total width of 18.6 m.

The superstructure consists of 13 reinforced T-beams simply supported at the abutments. The superstructure is supported by tall reinforced concrete abutments and two wall-type piers. The piers are supported by twelve 4.5 m raked octagonal prestressed concrete piles. Each abutment is supported by the same foundation system.

Earthquake Damage

The bridge was undamaged during the Darfield earthquake. During the Christchurch earthquake the high abutment walls rotated and displaced horizontally, closing the abutment joint gaps, and the approach had settled by approximately 0.1 m. Lateral spreading may have been a factor causing this damage.

Scour

The soundings shown in Figure 6-21 highlighted that flow is funneled through the two pier structures, but no indicators for scour were observed.

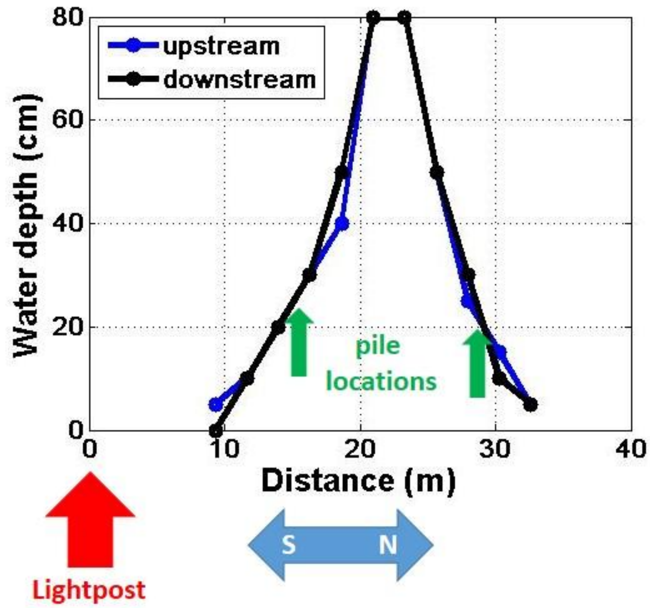

Figure 6-21 Soundings at Rutherford Street Bridge. Pier pile locations are indicated in green.

Lyttelton Port of Christchurch

The GEER team visited Lyttelton Port of Christchurch (LPC) on 21 March 2014 for an update on the port’s development after the earthquakes in 2010 and 2011 and to investigate possible flood impacts on the port (Figure 6-22).

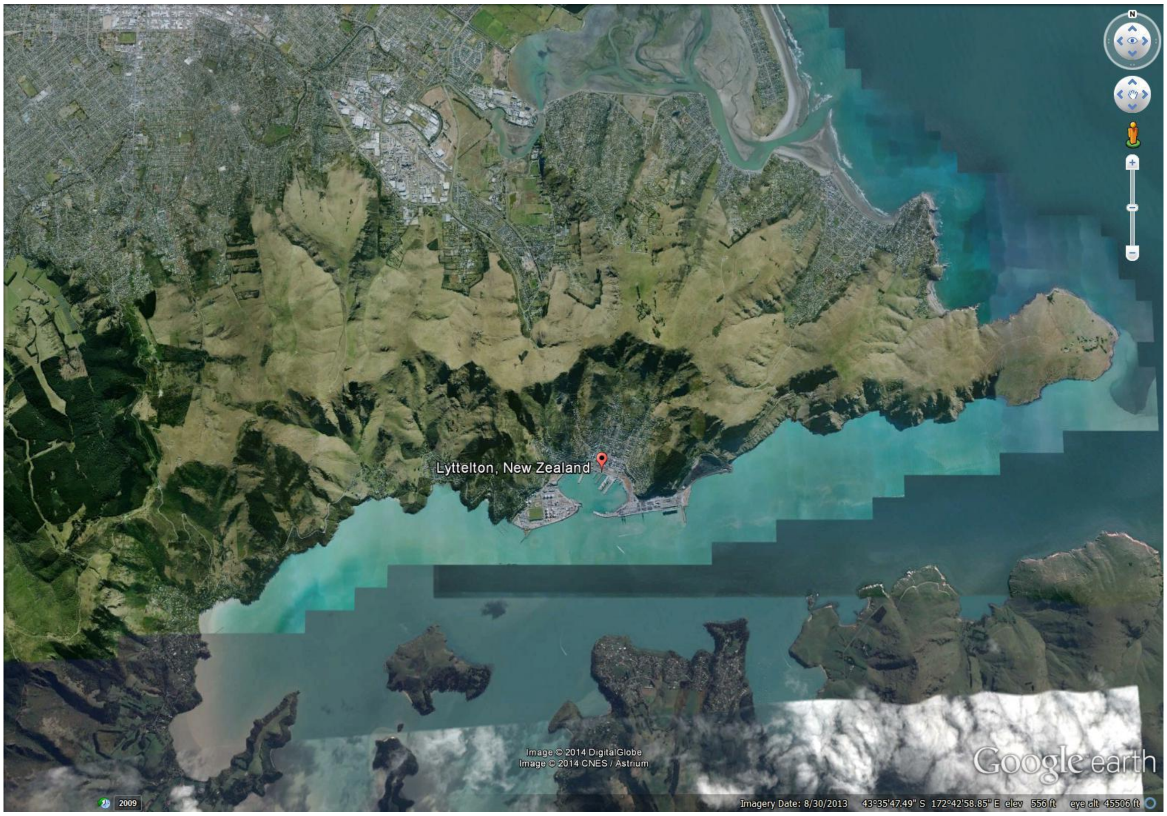

Figure 6-22 Google Earth image showing the location of Lyttelton (43° 36’ 13.61” S; 172° 43’ 9.79” E) in comparison to the city of Christchurch. Additionally, the image highlights Lyttelton’s location at the foot of the steep slope characterizing particularly this northern region of the harbour. While the port location offers a great advantage regarding the protection from energetic wave action, heavy rainfall events in conjunction with steep slopes might represent a hazard here.

Port Overview

LPC is the NZ South Island’s biggest port and documented 525 ship visits and the handling of 185,748 Total Container Volumes (TEUs) in the second half of 2013. The port was able to sustain its steady increase in revenues (6.4%) to $57.6 million (July-Dec 2013). This highlights the performance success during and post-earthquakes, despite the immediate vicinity to the epicenter of especially the 2011 earthquake and significant damages to port structures. The port has specialized facilities for containerized cargo, coal, fishery products, forestry products and petrochemical products (LPC, 2005). The layout of the main wharves at the port is indicated in Figure 6-23. Prior to the Canterbury earthquake sequence the majority of this cargo was handled on the four Cashin Quay wharves. The Z berth was used by the fishing industry, the Oil Wharf by the petrochemical industry, and the remainder handled dry bulk, vehicles and passengers. All wharves are supported by vertical pile foundations that are constructed of hardwood timber, reinforced concrete or steel tubes.

Figure 6-23 Layout of Lyttelton Port of Christchurch highlighting the main wharves (Ragued et al. 2014).

Earthquake Damage

The port was initially damaged during the Darfield earthquake, with subsoil movements resulting in settlement and lateral deformation. In the main port area these movements were attributed to a slope failure in the soft clay and silty sand layers, and were not believed to be due to any liquefaction effects. However, liquefaction and lateral spreading in the Oil Terminal area affected the Oil Wharf, tanks and pipe work.

More significant movements and damage to wharves, breakwaters, quays and reclaimed land occurred as a result of the Christchurch earthquake, with up to 0.5 m of vertical movement and 1 m of lateral movement recorded. There was further significant movement and damage from the 13 June 2011 earthquakes. Cashin Quay moved seaward, and piles, beams and tiebacks fractured. Paved areas were cracked due to lateral movements, and container cranes were knocked off their rails. Following the June earthquakes, temporary stabilization works were put in place. Wharf damage at Z berth mean that it could not be used following these events.

After the earthquakes the port was operating with a third less land in the Cashin Quay area due to the damage and repair works. Despite the severity of the earthquakes, the port was basically operational within hours following the Darfield earthquake, and within 96 hours following the Christchurch and 13 June 2011 earthquakes (LPC, 2011).

Port development post-earthquakes

A mediation process with the port insurers concluded in December 2013. A settlement of claims arising from earthquake damage involves the payment of $450 million (gross). An amount of $66 million has already been expended on keeping the port operational after the earthquakes, while the remaining funds will be invested in future port development. The extended mediation process also contributed to the fact that some earthquake damage was still visible during the NZ-GEER team visit in March 2014 (Figure 6-24).

Figure 6-24 Example of visible earthquake induced damage to Cashin Quay in March 2014.

Early development of the port structures after the earthquakes has been mainly focused on the Te Awaparahi Bay land reclamation shown in Figure 6-25 and the investigation of engineering strategies to stabilize Cashin Quay wharves 1-3 (Figure 6-22). For the latter, stabilization with piles to sustain a vertical port wall or a sloped rubble-mound support structure have been considered. The Te Awaparahi Bay land reclamation has already reached an expansion of 5 hectares using reusable rubble from demolitions in Christchurch, half of the 10 hectare initial target (Figure 6-25 and Figure 6-26). The gained land will offer the required space for a further increase in shipping activities, and arguably offered an adhoc solution for demolition material from Christchurch once the reclamation had overcome legal issues arising from initial emergency, uncleaned and uncontained reclamation works and the decontamination and containment of fill was sorted out. Further planned developments will include the expansion of cruise boat tourism in LPC.

Figure 6-25 Planned area of reclamation in Te Awaparahi Bay (LPC, 2011).

Figure 6-26 Te Awaparahi Bay land reclamation area on 21 March, 2014.

Impact of March 2014 flood

Most of the port structures were not affected by the flood. However, Figure 6-27 shows two tanks damaged by debris from a slope failure below Brittan Tce on the afternoon of March 5th. This landslide initiated during the heavy rainfall event.

The debris from the landslide damaged one tank storing 1.2 million liters of jet fuel, leading to a leak that forced the evacuation of 19 households in the immediate area and closure of nearby roads. This evacuation was in place for two days while fumes dissipated and some of the fuel was pumped into other undamaged tanks. The majority of leaked fuel was captured in the concrete walled containment area around the tank. Some of the leaked fuel entered the stormwater system and was released into the harbor before the spill could be contained.

Another tank also storing fuel was dented by the slope failure debris, but its contents were not affected.

Another slope failure above Simeon Quay resulted in structural damage to a substation that supplied power to the port, which could have cut power to the port if the failure progressed. However, the slope failure did not progress and this was avoided. The port had backup generators in place to run basic port functions.

Figure 6-27 Tank impacted by landslide that initiated during periods of heavy rainfall.

Concerns were expressed regarding the safety issue and current closure of (Old) Sumner Rd. These roads represented an alternative access route to Lyttelton and the port in the case of tunnel closure. Significant destabilization of the steep slopes along these roads as shown in Figure 6-28 made them a major safety issue and led to closure. An alternative trucking route to the port is highly desired as a backup to the tunnel. The tunnel entrances are subject to risk of closure due to landslides, which risk may even increase during heavy rain events. If it came to a flood in the tunnel at the same time, the port could theoretically become inaccessible. No such observations were made during the flood and heavy rainfalls in March 2014, but it was mentioned as a possible concern related to flood and heavy rainfall events.

Figure 6-28 Steep slopes and destabilized debris still represent a risk for Sumner Rd.

Lyttelton stormwater failure

The over topping of the storm water inlet shown in Figure 6-29 at the top of Canterbury Street in Lyttelton led to progressive failures downstream during the March 5th flood event. This storm water inlet is at the top of the drainage system and collects water that flows off the top of the Port Hills in an undeveloped section above Lyttelton. The GEER team found the culvert unplugged and free flowing at the time of its field reconnaissance. Evidence was found that the inlet became plugged at some point during the storms leading to overtopping of the collection basin and undermining/erosion downstream of the inlet structure as shown in Figure 6-29b.

(a)

(b)

Figure 6-29 Storm water inlet at the top of Canterbury Street that was overtopped during the March 5th event (Canterbury Street: -43.596225°, 172.723001°).

Water then eroded the pavement and base course exposing the storm water pipe as shown in Figure 6-30a. As shown in Figure 6-30b, the erosion of pavement and the base course continued down Canterbury Street. Repairs to the streets shown in Figure 6-30c had been made at the time of the GEER team's reconnaissance.

(a)

(b)

(c)

Figure 6-30 Erosion as a result of the storm water inlet in Figure 6-29 overtopping. (Photos (a) and (b) courtesy of Michael Hayes) (c) Canterbury Street restored to grade (93 Canterbury Street: -43.596590°, 172.722847°).

Further down Canterbury Street, water eroded the retained earth and street above a retaining wall shown in Figure 6-31, which had previously failed and been replaced in 2013 by SCIRT. The new retaining wall consists of a wet cast block. As shown in Figures 6-31c and 6-31d, the drainage system behind the wall was found to be plugged at the time of the GEER teams visit on March 22, 2014. SCIRT reported that the wall was found to be safe. GEER found no noticeable horizontal wall movement. SCIRT also reported damage to a new retaining wall being constructed on Sumner Road as a result of the flood event.

(a)

(b)

(c)

(d)

Figure 6-31 (a) Storm water flowing over the Canterbury Street retaining wall. (b) Erosion of Canterbury Street and retained earth above the wall. (c) and (d) plugged drains directly behind the wall as a result of upstream erosion seen in Figure 6-30 (a and b). Photos (a) and (b) courtesy of Michael Hayes (73 Canterbury Street: -43.599005°, 172.722243°).

GEER found evidence of numerous plugged inlets to the storm water system such as that on Selwyn Street in Lyttelton, shown in Figure 6-32. In interviewing the local community GEER found that locals unearthed the plugged inlets to enable the runoff to enter the storm water system. The Selwyn Street example in Figure 6-32a and b shows a small slump that fell from above the drainage inlet and plugged it resulting in the flow being routed down Selwyn Street instead of into the storm water system.

It’s plausible that had the culvert not been unplugged during the storm event that water pressure behind the walls in Figures Figure 6-32c and Figure 6-32d could have resulted in failure, or failure of another type further downstream. A previous landslide below the sheet pile wall in Figure 6-32c had occurred prior to the 2010-2011 Canterbury earthquake sequence resulting in damage to the home below which is no longer present.

(a)

(b)

(c)

(d)

Figure 6-32 Unplugged culvert on Selwyn Street above crib retaining wall, Photo courtesy of Michael Hayes (a). Post cleanup by CCC at the drain inlet (b). Previous slope failure and installed sheet pile retaining wall (c) adjacent to crib wall with culvert out let picture left (d) (17 Selwyn Road: -43.598748°, 172.716026°).

Avon River stop-banks

Before the Canterbury earthquake sequence, the crest level of the majority of stop-banks were at a river level (RL) or stage of 11.2 m (CCD datum). Along Hulverstone Drive in Avondale, the stopbank crest level was at 10.9 m (Harris, 2003). The 11.2 m RL was based on a 1% annual exceedance probability storm surge event with 0.2 m of freeboard (GHD 2012). The crest level for much of this system was at a similar elevation as the residential areas surrounding the river.

Although subsidence occurred as a result of the Darfield earthquake along the Avon River the majority occurred as a result of the Christchurch earthquake. As a result of that subsidence, CCC constructed a new system of stop-banks along both sides of the river from the edge of the CBD to the mouth of the Avon River to the east. In some locations, stop-banks had to be built over a meter above the ground level of the surrounding areas.

Prior to a pergiean spring side or king tide event in July 2011, more than 11 km of stop-banks were built up to a 10.8 m RL along the Avon River in four days. A silty gravel was used for construction, as this was easily accessible and was reasonably impermeable. In some areas sand bagging was used as a temporary means of flood control. Due to the time constraints imposed by the king tide event, no improvement of the soils below the stop-banks could be carried out to mitigate the effects of liquefaction and lateral spreading in future earthquakes. These new stop-banks were damaged multiple times during the most severe aftershocks. This system of temporary stop-banks performed reasonably well during the king tide event.

Following the emergency king tide event in July of 2011, the stop-banks were restored to a RL of 11.2 m. The primary design used 3:1 or 4:1 battered slopes with a 2.5 m wide top where space was available. When space was limited along the river's edge diamond block walls and reinforced earthen walls were used in place of the stopbank design.

During the March 5th flood event the Avon River stop-banks performed as expected by CCC. The March 5th flood event also happened to coincide with a pergiean spring tide which caused flood waters to be retained behind the stop-banks once the river level had dropped below the flood water level. This posed a lack of drainage which may extend or exacerbate a flood depending upon the duration and intensity of the event.

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