SEISMIC RESPONSE OF BRIDGES LOCATED IN CHRISTCHURCH, NEW ZEALAND

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1. Abstract

Recent seismic activity in Christchurch, New Zealand significantly damaged the city's infrastructure. Research is being conducted on the bridges that were affected in this area. There have been numerous case histories completed in the past that examine the affects of earthquakes on bridge foundations. The results of these new investigations will lead to findings relating to lateral spreading due to liquefaction and soil-structure interaction. This report discusses the preliminary investigation of six bridges located along the Avon River, which flows through Christchurch. A series of tasks were assigned in order to provide National Hazards Research Platform (NHRP), the organization leading the bridge investigations, with pertinent bridge data. These responsibilities included creating summaries on the bridge foundations, calculating the mass of the structures, collecting concrete samples, developing displacement and rotation summaries on the damaged bridges, and analyzing their damage progression. This work was complied into a data set accessible to NHRP. They will use this information to decide which bridges will be fully investigated. The results of these case studies will be used to evaluate current design guidelines for bridge analysis and provide possible solutions to mitigate bridge damage in future earthquakes.

2. Project Overview

The City of Christchurch experienced a series of destructive earthquakes over these past few months. On September 4th 2010 a magnitude 7.1 earthquake struck the Darfield region of Canterbury, New Zealand. The epicenter of the earthquake was 40 km from the city of Christchurch, resulting in minor damage to the area's infrastructure (GNS, 2010). Not long after, a magnitude 6.3 earthquake hit the South Island of New Zealand on February 22, 2011. This took place only 10 km south of Christchurch (GNS, 2011). The event caused significant damage to the surrounding area. This recent seismic activity attracted researchers from all around the world, willing to help with the recovery and learn about the effects of the earthquakes. Organizations such as the National Hazards Research Platform (NHRP) responded with investigations of bridges within the region. The NHRP funds research associated to quantitative estimates of geological and weather-related processes such as earthquakes (NHRP, 2009). Their goal is to help New Zealand avoid or mitigate natural hazard risks. They evaluate preparedness, determine the quality of buildings and infrastructure affected by natural disasters, and develop risk models on vulnerable areas.

Dr. Liam Wotherspoon, Research Fellow at the University of Auckland and NEES REU Mentor, is currently working with NHRP in these investigations. Tasks include conducting preliminary inspections with compilation of data on each of the structures, performing case studies to better understand soil-structure interaction, and developing solutions to mitigate damage (Palermo et al, 2010). Currently, those involved in this project are inspecting the structures for damage progression and performing tests to determine changes in soil properties.

During these past two months a detailed database was constructed for a small collection of bridges affected by the recent earthquakes. Responsibilities included documenting information on the foundations of each structure, calculating the mass of bridge components, traveling into the field to collect concrete samples and measurements, and categorizing evidence of damage progression. The compiled work was reviewed by those associated with NHRP. They will use the information to determine which bridges will be selected for detailed inspections. These case studies may reveal new findings about soil-structure interaction as a result of seismic activity and solutions ways to mitigate bridge damage.

3. Literature Review

Liquefaction is a phenomenon that occurs during earthquakes and results in significant damage to buildings and infrastructure. During this process the strength of soil is weakened due to an applied lateral load (Castro, 1969). Before an earthquake occurs the ground is subjected to a stress from over lying soil. When soil experiences seismic activity the shaking movement causes its volume to reduce. Yet, this action does not occur immediately. The soil particles are first lifted into a suspended position before condensing. Contact forces between the individual particles are lost, causing a weakening in the earth. At this state there is no effective stress or inter-granular stress on the soil, and the ground experiences liquefaction. After liquefaction the particles sediment in water while expelling some pore water to the surface (See Fig. 1).

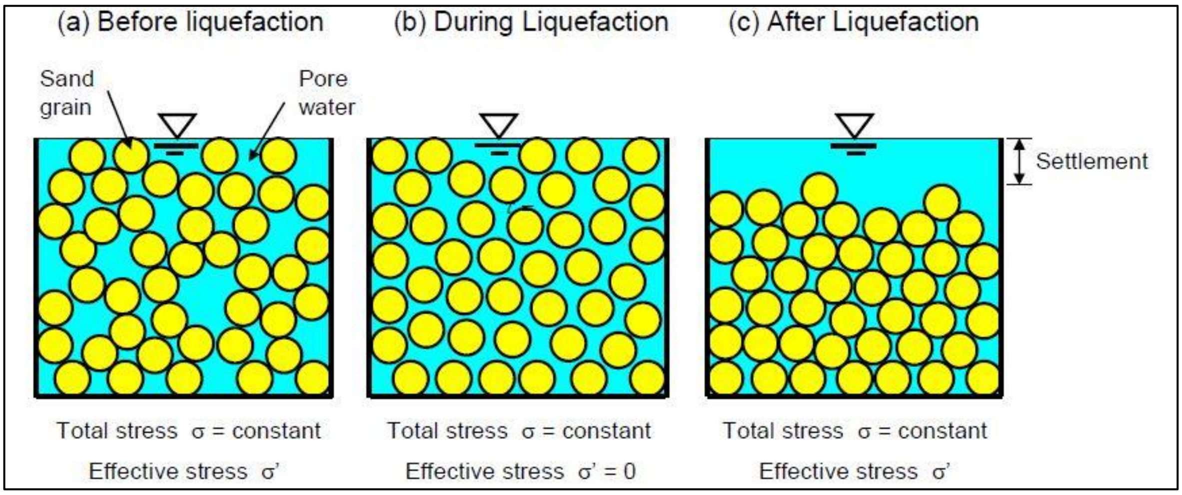


Figure 1: Process of liquefaction

Liquefaction by itself causes no harm but when it is accompanied by some form of displacement it can lead to severe damage to the built environment. Engineers study this phenomenon so that they can understand its behavior and develop solutions that will prevent liquefaction from significantly damaging our infrastructure. They have learned that it can take on many forms. For example, lateral spreading is the movement of large sections of soil as a result of liquefaction (Committee on Soil Dynamics of Geotechnical Engineering Division [CSDGED], 1978). It generally develops on slopes and moves toward a free surface such as a river (See Fig. 2). These displacements can range up to several meters, forming large cracks in the ground. Buildings and bridges built on or across the failures are known to experience displacement or rotation in their foundations. Depending on the severity, this may lead to the collapse or buckling of these structures.

Figure 2: Road damage due to lateral spreading along the Avon River, New Zealand

Numerous case studies performed over the years have uncovered major advancements in understanding the behavior of liquefaction (Berrill & Yasuda, 2002). These findings also led to the development of solutions to mitigate its effects on the built environment. An article by Earthquake Engineering discusses the case histories of the 1964 M7.5 Niigata, Japan Earthquake, the 1987 M6.3 Edgecombe, New Zealand Earthquake, and the 1995 M7.2 Hyogoken-Nambu earthquake. This research provided evidence that liquefaction does not protect structures from seismic shaking by providing base isolation. In all three cases accelograms that were placed at the sites showed strong shaking transmitted to the ground surface before liquefaction occurred. Shake-table and centrifuge testing on piles submerged in liquefiable soil also displayed bending moments applied to the piles both before and after liquefaction took place. Therefore, liquefied soil would not prevent damage to buildings and bridges located within the area. Berrill and Yasuda also concluded that the displacement of the lateral spreading stratum of soil is continuous only when there is not a low permeable layer over lying the liquefied layer.

The historic earthquakes that were investigated by Berrill and Yasuda displayed severe damage to pile foundations. These events have placed an emphasis on developing ways to improve pile design (Berrill & Yasuda, 2002). Two procedures, the lateral pressure method and the seismic deformation method, are major advancements towards possible solutions. They both predict the bending moments and shear forces applied to the pile by ground movement and permanent soil displacement. These loads are combined with that of the superstructure to calculate the response of the pile. Yet, it is important to mention that these approaches were designed following the earthquakes that were previously cited and may not be useful in other scenarios.

There are many questions involving liquefaction that are still unanswered, such as whether lateral spreading has a cyclic mobility that stops with ground shaking or continues after the end of shaking (Berrill & Yasuda, 2002). As earthquakes continue to occur, researchers will work to answer these questions and improve design methods.

Since September 2010, researches from all around the world have traveled to New Zealand to study the effects of the recent earthquakes. The organization, National Hazard Research Platform, is one of the research groups currently studying these events. One of its projects involves performing detailed investigations on bridges damaged by the recent seismic activity. They believe that these case studies will provide new information on lateral spreading behavior (Palermo et al, 2010). This information could then be used to evaluate current guidelines for lateral spreading analysis as well as develop possible solutions to decrease the damage of bridges in lateral spreading zones.

4. Research Summary

The purpose of this research was to provide NHRP with useful information on a selection of bridges damaged by the recent earthquakes. Throughout the program host mentor, Dr. Wotherspoon assigned tasks that contributed to future detailed bridge investigations. The work completed throughout the program was complied into a data set that contains information on six bridges located along the Avon River, which flows through the City of Christchurch. The bridges that were inspected are Fitzgerald Avenue, Gayhurst Road, Avondale Road, Anzac Drive, Pages Road, and Bridge Street. A map indicating their locations can be found in Figure 3.

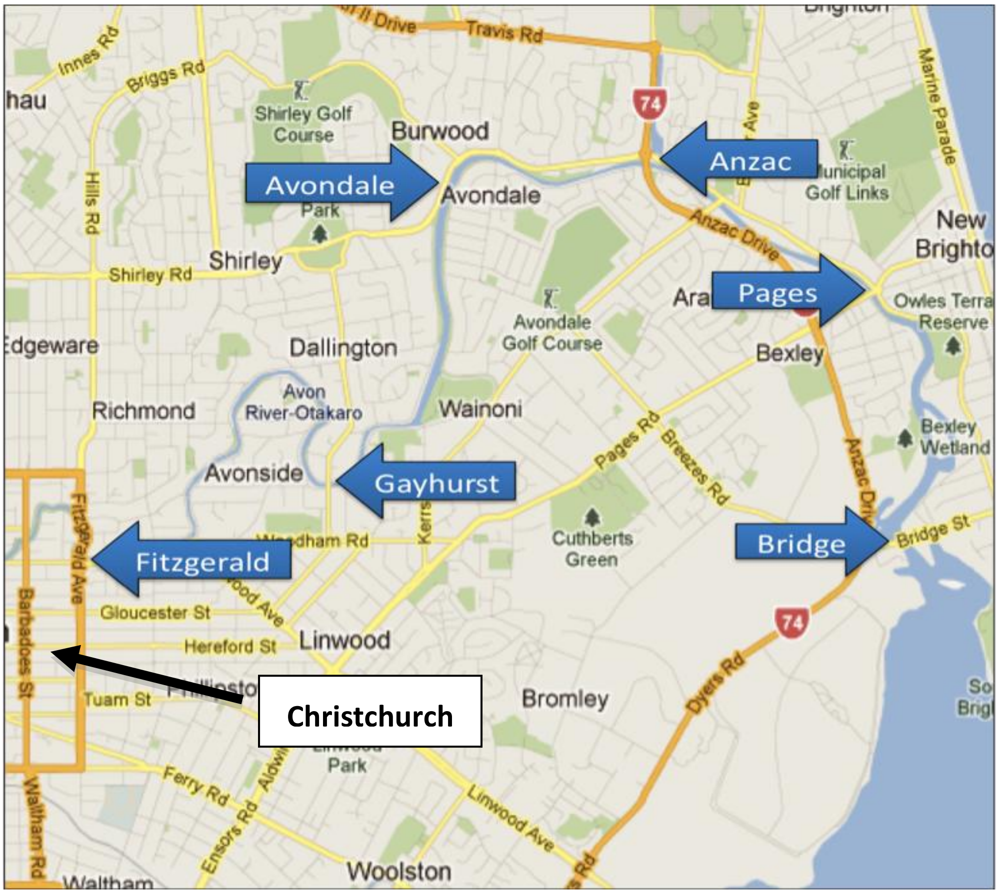


Figure 3: Map indicating the location of bridges under inspection

4.1 Bridge Summaries

One of the first tasks pertaining to the Christchurch bridge damage investigations was to create summaries of the selected bridges. The summaries discuss the bridge pile details that were obtained from the original bridge drawings (See Fig. 4). It included information such as pile material properties, longitudinal reinforcement, transverse reinforcement, dimensions, rake (angle), construction date, and any other relevant information referring to the foundation. Collecting this information required many hours of examining the drawing details for each bridge. It was difficult to collect all of the information for the bridges constructed in the early twentieth century because these plans were completed by hand, making them harder to view. Due to fewer design regulations during this time, engineers could have also omitted this information by choice. If certain data could not be located it was mentioned in the summary. If the bridge contained various types of piles their information was also included.

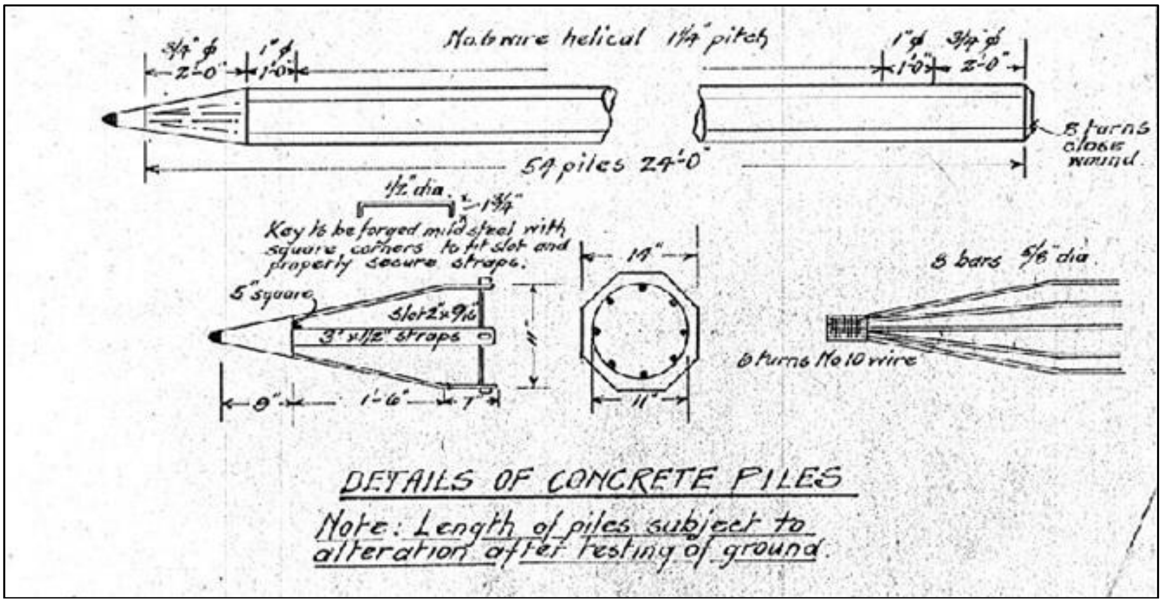
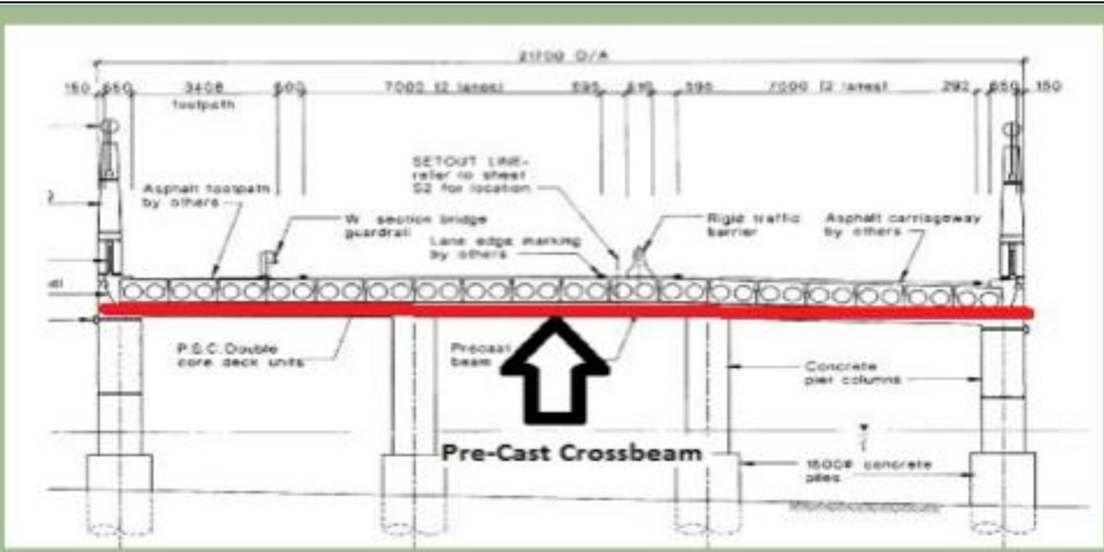
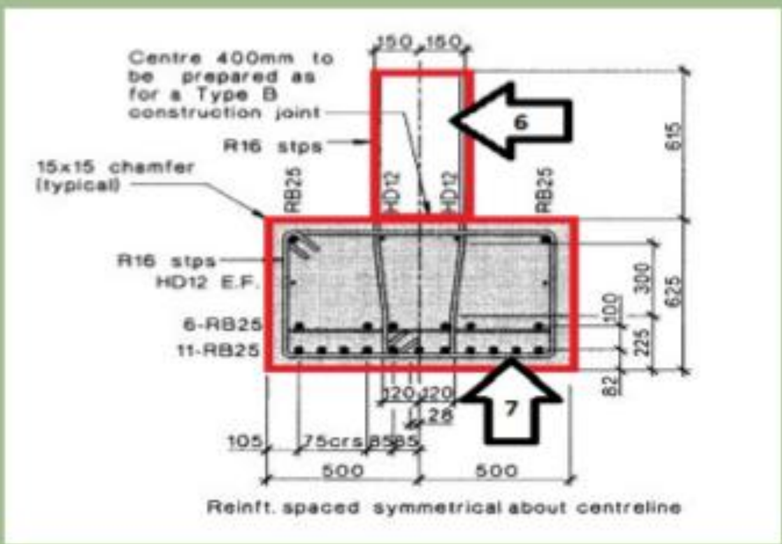


Figure 4: Pile details of Pages Rd. Bridge taken from original bridge drawings

The second portion of the bridge summaries estimated the mass of bridge components. This data was used to determine the load applied to the individual piles by the superstructure. Once the necessary dimensions of the bridge sections were located their volume was calculated. A conventional density of reinforced concrete was then applied to the volume in order to find the mass of the component. Generally, each bridge contained calculations on the abutments, piers, deck and crossbeams. After each of the essential bridge masses were found their values were divided up between the pier and abutment piles and then divided again by the number of piles within each foundation. Brief explanations of how some of the sections were calculated were included in the summary. This was done so that the process could be easily understood. A section of a bridge summary can be seen in Figure 4.



Cross-section of Bridge



Cross-section of Pre-cast Beam

Calculations for the Volume of Pre-cast Crossbeams:

Length of Beam:	6.2 m
Volume of Top of Beam :	0.625 m^2 [6]
Volume of Bottom of Beam :	0.185 m^2 [7]
Total Volume of Beam :	5.019 m^3

All the precast beams were esitmated to be the same because their dimensions varied slightly.
One pre-cast crossbeam sits on top of four pier columns

Figure 4: Estimated volume of Anzac Drive Bridge Pre-cast crossbeam

This work also required a considerable length of time reviewing the bridge drawings, and there were some difficulties that arose. For example, some components were not always specified or a section of the bridge had an irregular shape. In order to correct this a scale was used if the drawing provided one. Other instances required the use of judgment and an estimation of the dimension was made. Throughout this compilation Dr. Wotherspoon would review the work and provide corrections and advice on how to improve the summary format.

4.2 Bridge Sampling & Testing

Another part of the investigation process provided an opportunity to travel to Christchurch to conduct fieldwork. One of the tasks involved operating a concrete coring system in order to collect concrete bridge samples from the abutments of the damaged bridges. Tests were conducted on site and later on in the lab. These tests were performed to determine the material properties of each bridge and take note of any changes due to the recent seismic activity.

Upon arriving at the site of each bridge, a brief examination of the structure would take place in order to determine the best area to collect a sample. A Hilti PS 35 Rebar Detector was used to locate the rebar positioned within the concrete. Next, the coring system was set and attached to the abutment of the bridge. The equipment that was used included the Hilti DD 130 Diamond Coring System and the Kipor IG3000X/E Generator. Three concrete samples were then taken from the abutment. Figure 5 shows how the sample collecting was completed. Two tests were immediately performed on the samples. A silver nitrate and phenol thalein test determined how much chloride and carbon penetrated the concrete, respectively. Both tests are performed by spraying a small amount solution on the samples. Depending on the color that appears, one can determine how much of the elements have entered the concrete. Assessments such as these are necessary because large amounts of these elements found in concrete can significantly compromise its strength. A fourth hole was drilled into the abutment to expose the rebar of the structure. A hardness test was then performed on the reinforcement. This experiment requires the use of an indenter and Birnell microscope. The indenter makes a small indent on the surface of the rebar and the microscope measures the diameter of the hole. With the measurement of the diameter, the strength of the rebar can be determined. This examination was conducted to see if deep cracks in the bridge allowed water to damage the reinforcement.

Figure 5: Collecting a concrete sample from Fitzgerald Avenue Bridge

The group was unable to collect samples from the Pages Road Bridge because the abutment was completely submerged in water, therefore making it inaccessible. It was decided that a boat would be rented in the followings weeks in order to obtain concrete samples from the bridge. Other than this minor setback, samples were collected from the rest of the bridges and the holes that were formed in the abutments were refilled with concrete to maintain their performance.

4.3 Bridge Displacement Summaries

The second week of fieldwork involved collecting measurements of bridge displacements and rotations. Each bridge was inspected for gaps either within the structure or between the bridge and the ground. The lengths of these cracks were then recorded using measuring tape. An electronic level was also used to detect rotations in the abutment due to lateral spreading in the soil. This data was compared to measurements that were taken a few months back in order to check for significant changes. After compiling this information, bridge displacement summaries were made for each bridge. The summaries included a brief paragraph explaining the purpose of the work, the changes in the measurements, and detailed sketches of the bridges with old and new measurements recorded. An example of a bridge sketch can be seen in Figure 6. While taking measurements of displacements and rotations of bridge sections it was determined that comparing these values to past readings may not be entirely accurate. This is due to the fact that the new measurements were not taken in the exact location of where the original measurements were obtained. This possible error is mentioned in the summaries.

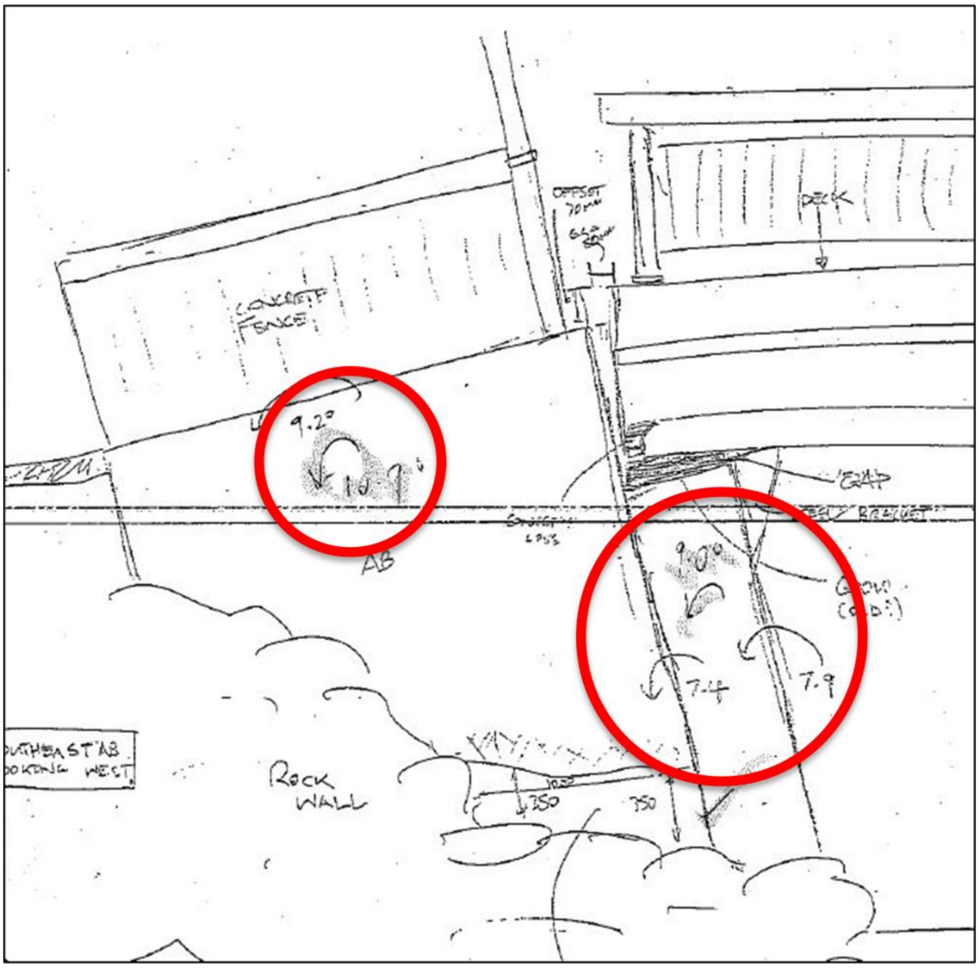


Figure 5: Sketch of Avondale Rd. Bridge showing slight increase in abutment rotation

4.4 Damage Progression

The final part of the research program dealt with recording the damage progression of the bridges. Since the 04/09/10 Darfield earthquake, Dr. Wotherspoon has recorded changes in bridge damage over the past few months by taking pictures. All the photos were complied, organized, and clearly labeled to show the damage progression of each bridge. An example of this can be found in Figure 6. This figure shows the damage progression of Gayhurst Road Bridge, north abutment wing wall/bridge deck connection. While completing this portion of the project it was sometimes difficult to determine what section of the bridge was being viewed in the pictures. In order to correct this, indictors within the background of the photos were used to determine the bridge section and its geographical location (i.e. North Abutment, West Side).

Figure 6a: September 20th 2010

Figure 6b: March 1st 2011

Figure 6c: June 17th 2011

5. Conclusion

This report discusses the initial stage to a larger investigation. The research that was conducted was mainly data gathering and will be used in applications throughout the project. The information was complied into a data set that will be available to those involved with the NHRP bridge investigations. The organization will analyze this data and decide which bridges will be selected for further examination. Field tests will be performed on the chosen bridge sites so that soil conditions can be determined. These preliminary examinations will then lead to case studies relating to soil-structure interaction. Results from these studies can evaluate current guidelines for lateral spreading analysis of bridges. They can also provide mitigation strategies for bridges built in zones prone to lateral spreading.

6. References

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