DESIGNING FOR RESILIENCE WHERE THE ONLY CONSTANT IS CHANGE

Richard (Rico) Parkinson, Environmental Engineer, Opus International Consultants
Chris Maguire, Project Manager & Water Resources Engineer, MWH Global

ABSTRACT

The Canterbury earthquakes damaged the wastewater pipes in Christchurch, reducing the security and resilience of the remaining network. An alliance between Canterbury Earthquake Recovery Authority, Christchurch City Council and New Zealand Transport Agency, and five non-owner participants created the Stronger Christchurch Infrastructure Rebuild Team (SCIRT). Working with many other companies they are all combining together for the vision of creating resilient infrastructure for Christchurch.

The liquefaction effects and damage of large flexible pipelines has not been well documented around the world, and initial investigations found very few examples. With multiple large diameter flexible pipelines being installed after the earthquakes, which included Pressure Main 11 (PM11), the design of these carried a large number of uncertainties. In particular, the soil strengths were thought to potentially change during a liquefaction event to a very low value, and then return to lower than the existing soil strength.

Designing Pressure Main 11 on its current soil strength no longer ensured a resilient design. To ensure redundancy against seismic effects for the installed pipeline, measures to mitigate the potential loss of side support were trialled. A geogrid / geotextile wrap around the embedment material was shown to provide additional support to the pipe after the side support was removed. This trial verified the structural design of the pipeline and removed the need for the additional mitigation measures.

KEYWORDS

Liquefaction, Earthquakes, Flexibility, Innovation, GRP, Thrust block, Trenching

1 INTRODUCTION

Following the September 2010 and February 2011 earthquakes in Canterbury there was substantial damage to the wastewater infrastructure network. Wastewater pipes were damaged due to seismic movement and liquefaction effects.

Damaged wastewater infrastructure included Pressure Main (PM) 11 A&B, two nominal diameter (DN) 600 cast iron pipes which carried approximately 30% of Christchurch's wastewater from the terminal Pump Station 11 to the Christchurch Wastewater Treatment Plant. The damage to PM11 A&B meant that there was now only one pressure main to transfer wastewater from Pump Station 11. The design of the replacement pressure main was fast tracked to provide resilience and to allow repairs to the remaining infrastructure. It was decided that the pressure main should be constructed using DN1200 Glass Reinforced Plastic (GRP), as it had performed well in other wastewater mains in Christchurch.

Designing for the effects of seismic movement and liquefaction on large flexible pipelines carried a number of unknowns. The largest uncertainty was the varying soil strengths, which are thought to vary during a liquefaction event and which can cause a long term reduction in the residual soil strength.

Designing flexible pipes such as GRP based on static soil strength no longer ensured a resilient design. This gap in the current understanding of flexible pipeline design under seismic events experiencing liquefaction led to the investigation, analysis and design of measures to mitigate the potential loss of side support caused by reduced soil strengths.

Christchurch City Council requested that the project was to be delivered within SCIRT. To enable PM11 to be delivered as a fast tracked project required a complex delivery model, where the designs had to be produced in stages with construction being carried out simultaneously, while the investigations into the mitigation measure were being carried out. The SCIRT structure and culture enabled this flexibility in design and delivery to achieve a successful outcome.

2 SCIRT STRUCTURE AND CULTURE

SCIRT, a virtual organisation operating within an alliance led contractual arrangement between owner participants Canterbury Earthquake Recovery Authority, Christchurch City Council and New Zealand Transport Agency, and five non-owner participants (City Care, Downers, Fletchers, Fulton Hogan, MacDow). Along with the many other companies involved, they work cohesively together in the SCIRT vision of "creating resilient infrastructure that gives people security and confidence in the future of Christchurch".

From the outset one of the key goals of SCIRT was not only to create resilient infrastructure for the people of Christchurch, but to raise the bar for the industry as a whole in New Zealand through open sharing of engineering knowledge and construction techniques.

In the traditional setting, the idea of different commercial organisations openly discussing ideas and sharing detailed technical knowledge about projects is rare. However SCIRT is designed to openly share information about the best possible technical approach to design and construction around earthquake resilience, pushing the industry benchmark for resilient earthquake design higher than previously possible.

This collaboration was demonstrated well in the design of PM11, with over 30 people involved from more than 10 different organisations, all working together to achieve the best possible design.

A key element of the design process is the Early Contractor Involvement (ECI). This enabled the Delivery Team to share knowledge about constructability of the designs and to suggest design improvements or alternatives. This collaborative approach is not only between the design team and delivery team but is also encouraged between the different delivery teams themselves.

The Pressure Main 11 project was one of the first major projects to go through the SCIRT design and delivery process. A steady change in techniques, standards and best practices, meant creating a resilient design was an ever changing target at SCIRT. With the un-quantified effects of seismic loadings and liquefaction on pipelines being continually discussed and investigated locally, nationally and world-wide.

3 PM 11 LIQUEFACTION AND SEISMIC MITIGATION

Pump Station (PS) 11 conveys most of the wastewater from south west Christchurch to the central wastewater treatment plant at Bromley via the PM11 pipelines, servicing in excess of 100,000 people. The catchment of PS11 and the extent of the potential catchment when future network changes are completed is shown in Figure 1. PS11 was dependant on the continuous operation of a single 1200 mm diameter concrete pressure main after the earthquakes.

With the consequences of service failure and time to repair any pipeline damage, a second 1200mm pressure main 3.6km in length was to be installed to add security to the network. Figure 2 shows the route alignment of the new and old pressure mains. The alternative routes provide mitigation against large isolated land movements.

The existing pressure main was constructed from concrete. It was however, decided that the new PM11 was to be constructed from a flexible material to provide resilience to the network by having an alternative failure mode. GRP was chosen due to the minimal open excavation size required at any one time.

The existing 1200mm diameter concrete pressure main failed in three locations, all joint failures near thrust blocks. These failures are believed to have been caused by the differential settlement between the thrust blocks and the pipe. Geogrid and aggregate thrust blocks have been used to ensure the thrust restraints are a similar density to the trench embedment to reduce the potential for differential settlement (Photograph 1& Figure 3).

Figure 1: Pump Station 11 Catchment Area

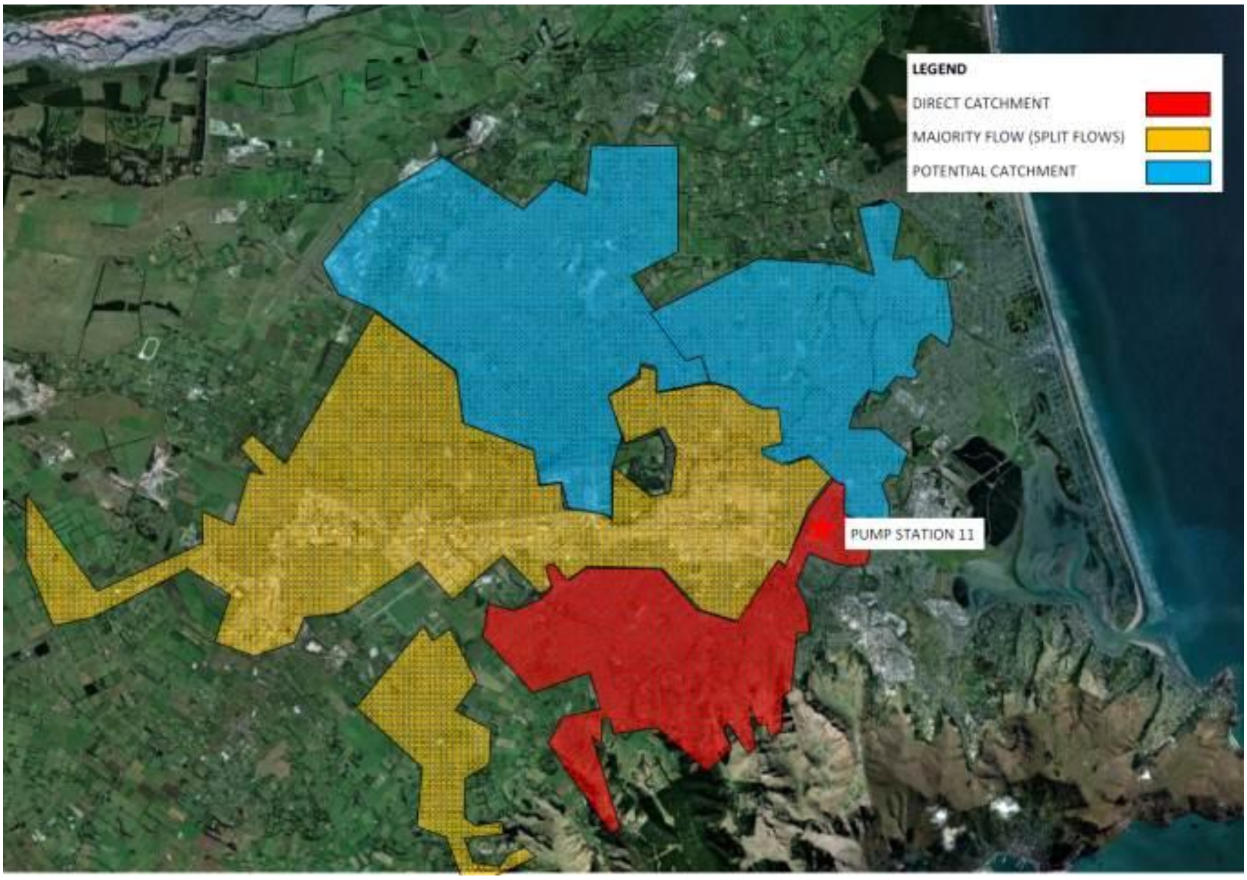
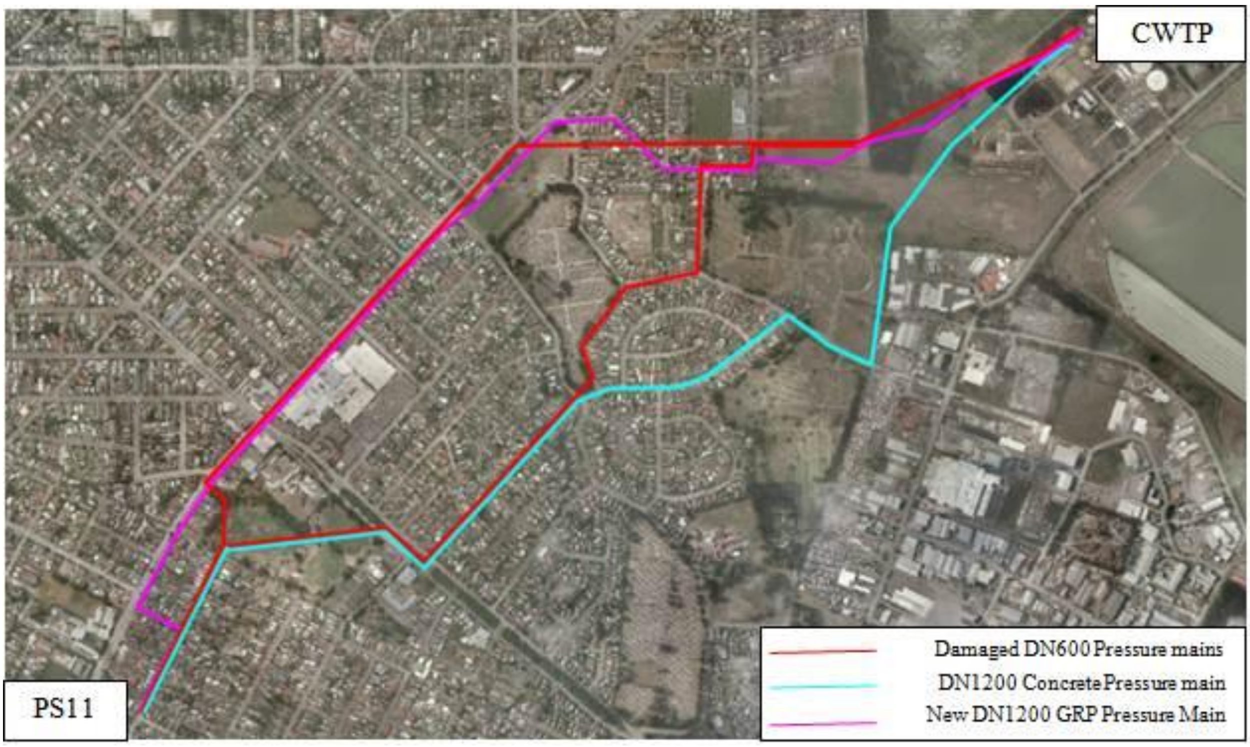
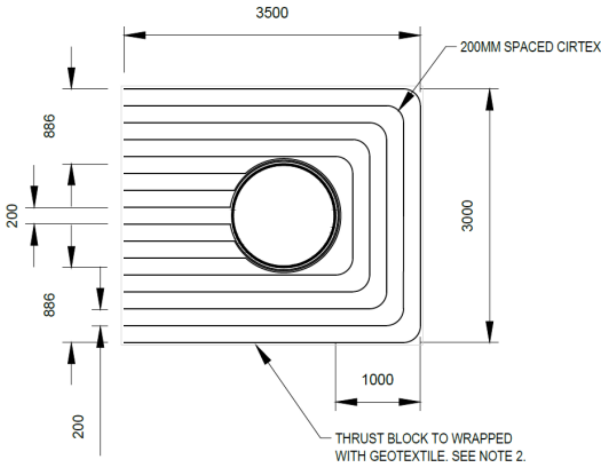


Figure 2: PressureMain11 Alignments



Photograph 1: Thrust block installation

Figure 3: Thrust Block Design



Geotechnical investigations were undertaken and the results showed that the alignment of the pipeline is highly susceptible to liquefaction. The investigation showed that liquefaction settlement along the pipe route could vary from 0 to 140 mm for a 1 in 500 year seismic event and 0 mm to 150 mm at the same locations in a 1 in 2500 year event.

The new GRP pipeline provides mitigation against these potential settlements by using a double bell coupler that allows for a 1 degree rotation. This rotation equates to 100mm per 5.7m pipe length.

The joints have been positioned for maximum pull out resistance rather than providing a compressible length in the joint; as most of the observed joint failures to pipes in the area were due to pull out rather than compression of the joints.

All joints are also wrapped in a geotextile sock to reduce the risk of point loads being applied to the coupler which can cause cracking (Photograph 2). This may occur if aggregate becomes wedged in the joint from the rotation during seismic movement.

The mobility of soils during liquefaction can cause settlement of the pipeline, but the additional pore water pressures it creates can also cause uplift, seen as liquefaction boils breaking through road surfaces.

To mitigate this, a composite compacted aggregate raft reinforced with geogrid was installed to help prevent movement against the upward thrust from the excess pore water pressures (Photograph 3).

Photograph 2: Geotextile sock over coupler

Photograph 3: Embedment installation

4 TESTING AND DESIGN VERIFICATION

With a limited understanding of the effects of liquefaction on a large flexible pipeline, one of the risks was the potential short term loss of side support causing deflection and potential collapsing of the pipeline due to the weight of non-liquefiable backfill material crushing the pipe.

One case of a pipeline collapsing was found during the back ground research investigation (Davis, 2000). It was believed the weight of backfill crushed the corrugated iron pipe when the soil around the pipeline liquefied. The GRP used in PM11 was not at risk of collapse, but may exceed the long term allowable deflection for the pipe and reduce the overall operational life of the pipe. This instance could occur if the side support was reduced to near zero during liquefaction allowing the backfill weight to cause the pipe to vertically deflect. This deflection could be fixed in position as the supporting soil regained its strength after the liquefaction event.

Pressure Main 11 has been designed in accordance with normal practices outlined in AS/NZS2566.1:1998, this however does not allow for the potential loss of side support caused by liquefaction, and the differential settlement along the length.

To determine if this risk may compromise the pipes lifetime's performance under the design code, a trial to measure the observed deflections was carried out on a combination of installed trench mitigation measures and compared to predicted deflections.

The mitigation measures proposed for the pipeline were:

- A layer of geotextile (Class C2) wrapped around the bedding, haunching and backfill to prevent migration of fine to ensure the structure of the trench and backfill

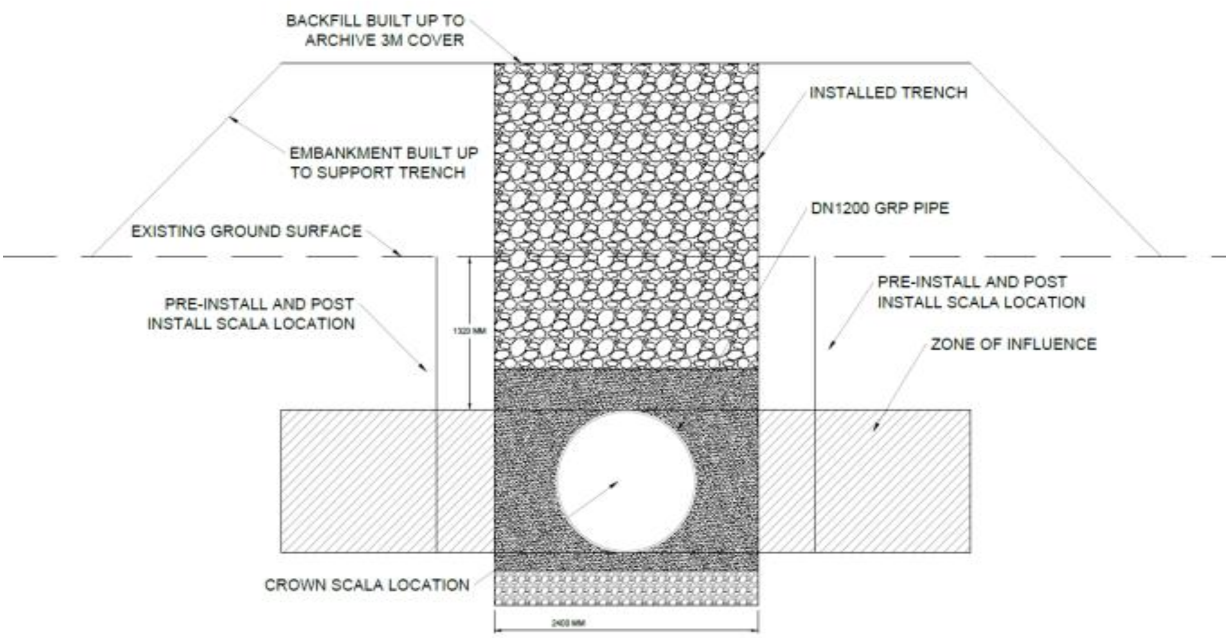
- A layer of geo-grid (Secugrid 30/30 Q1) wrapped around the bedding and haunching of the trench to provide improved lateral support to the pipe if the outside of the trench liquefied and lost its strength (Photograph 4)

- A layer of geo-grid (Duragrid 30/30) between the AP20 bedding and 300mm AP40 base to provide a rigid and consistent base for the entire pipeline

Photograph 4: Geogrid embedment wrapping *Photograph 5: Installation of pipes for testing*

The trial consisted of installing three lengths of pipe, each one with a different combination of mitigation measures, then removing the side support outside the embedment zone. The deflection of the pipe was measured using a laser profiler; pre construction, during construction and post removal of the side support within the zone of influence.

Figure 4: Testing installation design



The 3 lengths of pipe were installed using the same construction methodology, with the following combination of mitigation measures installed for the different lengths:

- A “control” length installed with the base geo-grid mitigation.
- A “geotextile” length installed with the base and geotextile mitigations installed.
- A “geo-grid” length installed with the base, geotextile and geo-grid mitigations installed

Eight laser runs were completed, with one being completed prior to any embedment material being placed (#1). One run was immediately after the installation of embedment and backfill (#2) and one was complete three days later (#3).

Three laser runs were complete (#4-6) during the removal of the supporting material (up to the area of zone of influence of the pipe). One run was completed immediately after the removal of the material within the zone of influence (#7). The final run (#8) was complete 3 days after with no side support.

Table 1 summarises the observed deflection results of the three installed pipes, along with the predicted and allowable value using AS/NZS2566 calculations.

Table 1: Deflection Summary

	Pre- construction	Post-construction	Support Removed
Run	#1	#2-6	#7-8
Control	0.15-0.55 (0.35)	0.6-0.95 (0.79)	1.35-1.8 (1.62)
Geotextile	0.3-0.35 (0.29)	0.95-1.5 (1.18)	2.2-3.1 (2.6)
Geo-grid	0.25-0.45 (0.25)	0.7-1.45 (0.84)	1.1-2.3 (1.37)
Predicted	0.0	1.58-2.15	5.0-10.0
Allowable	-	3	3

Figure 5 shows the measured deflections from the laser profiler. Blue is pre-construction laser profile measurements, red is post-construction and green is with the support removed.

Figure 5: Ovality measurements

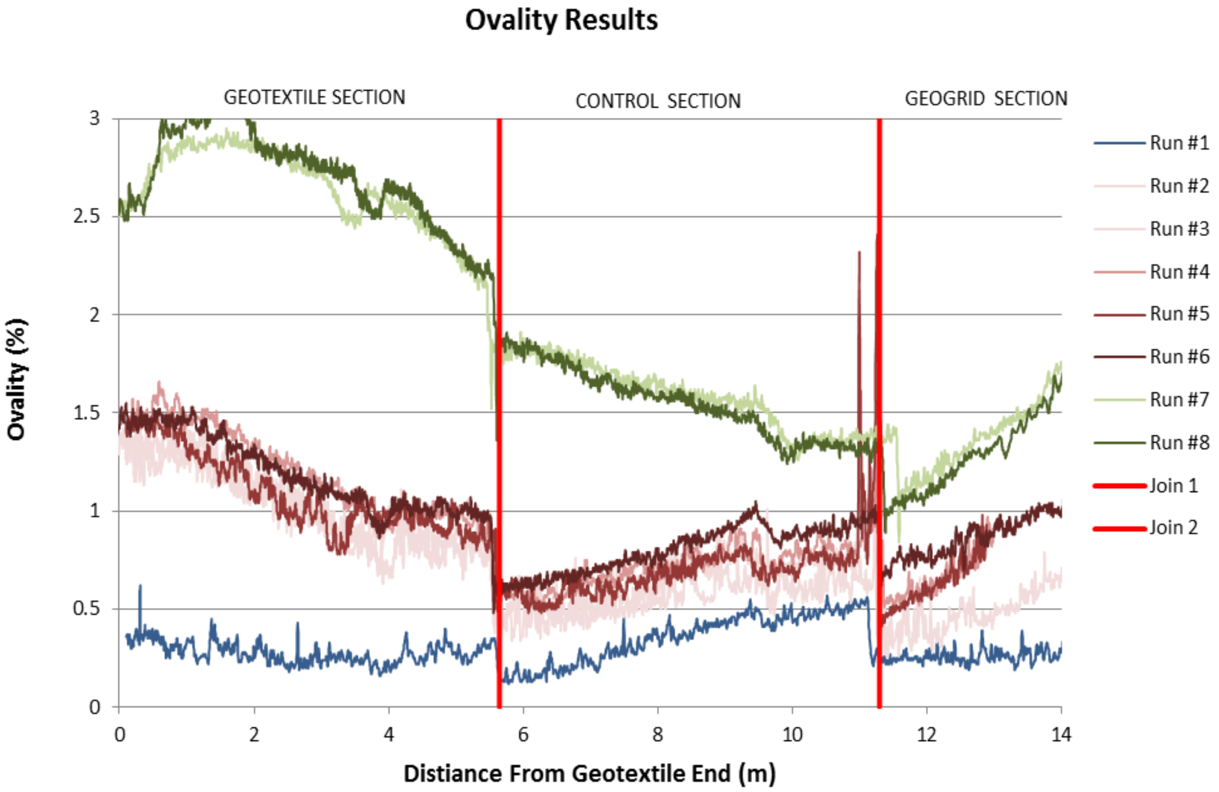


Figure 6: Adjusted deflection results

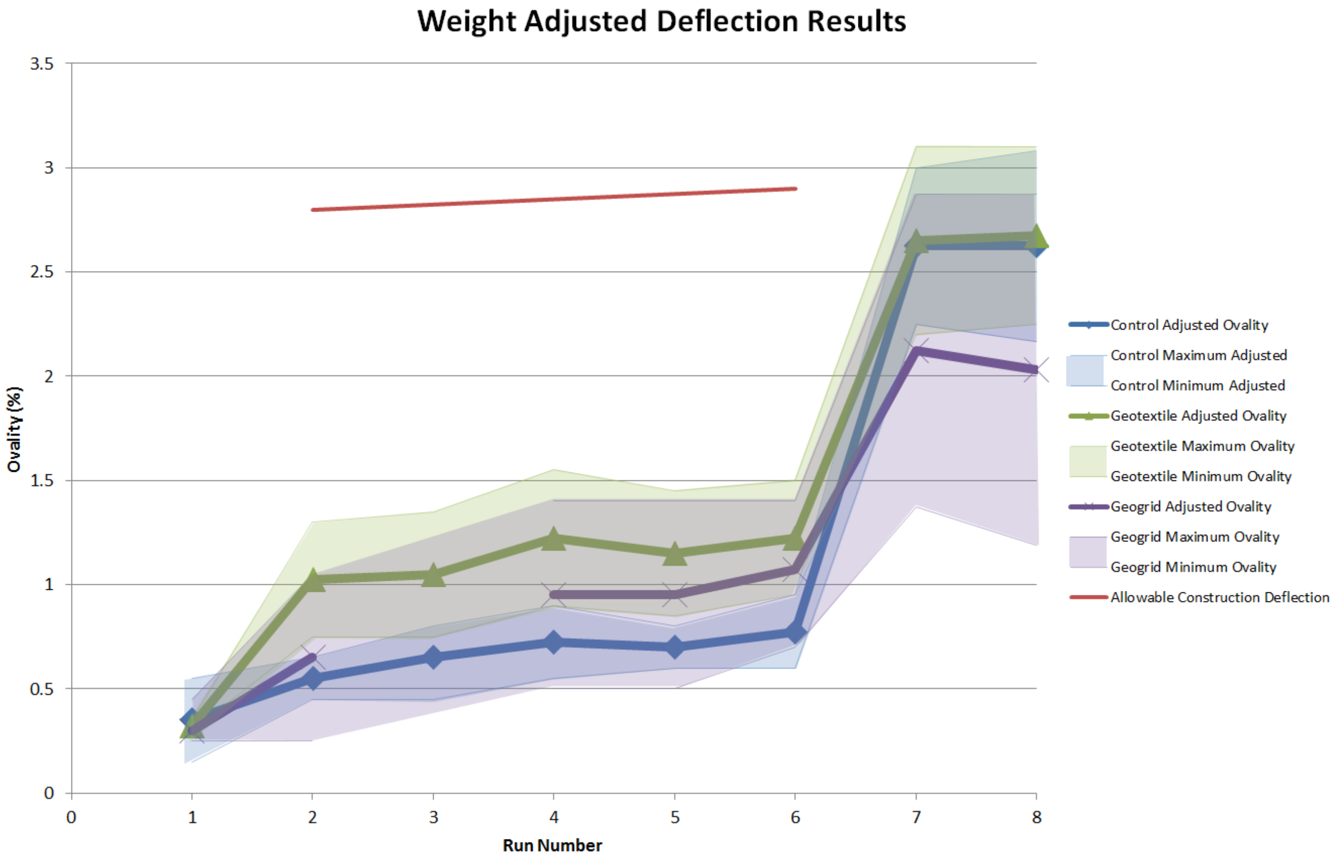


Figure 6 has had the deflections adjusted to allow for the observed loss of backfill material that remained above the pipe, the “geotextile” length lost very little backfill above the pipe, while the “control” and “geo-grid” lengths loss between ~20-40% of the backfill directly above the pipe.

This adjustment due to the backfill losses above the pipes, makes the results comparable, and shows that the geo-grid mitigation measure did improve the side support of the embedment material.

Due to the additional cost and time required to install the geo-grid for the project, the mitigation measure was not installed. The increased cost was not seen as value for money as the pipe was verified to be within its limitation, even with the complete loss of the side support.

The base mitigation measure was installed to ensure a uniform base was achieved, both to ensure consistent construction, and to reduce the potential settlement directly under the pipe. It also ensured easier construction as it provided a dry platform to lay the pipe and embedment material.

The geotextile mitigation measure was installed to reduce the potential effects of liquefaction material entering into the embedment structure and altering the embedment make up.

5 CONCLUSIONS

The investigations and analysis carried out to better understand the mitigation measures being installed on the pipe helped reduce the time and cost of the project, while also validating the design. Although not used in this project, the analysis helped to determine that geogrid wrapping of a pipes embedment is a potential solution against liquefaction effects by providing an increased support to the embedment material.

The SCIRT processes ensured that uncertainties were able to be investigated without delays to the delivery time frames for projects. The Delivery teams worked in conjunction with the design team to ensure the best design was achieved.

The vision of providing resilient infrastructure for the future of Christchurch while ensuring value for money has helped create an environment at SCIRT in which innovation and collaboration are integral in achieving successful design and delivery.

REFERENCES

Davis, C. (2000). Study of near-source earthquake effects on flexible buried pipes, ProQuest Information and Learning Company, Ann Arbor,50-53