DESIGN OPTIMISATION OF RESILIENT STORMWATER PUMP STATIONS

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ABSTRACT

Following the Christchurch earthquake sequence of 2010 – 2011, areas of the city are now more prone to flooding due to ground settlement. The New Brighton Road and Owles Terrace catchments in eastern Christchurch now require pump stations to convey surface waters when gravity outfalls cannot operate during high tides. During the design process of the remedial works, value engineering and early contractor involvement (ECI) workshops have enabled a cost-effective and innovative design to be developed. This has provided significant savings over conventional vertical axial flow pump stations which require deep excavations and significant ground improvements. The final design includes use of horizontal axial flow pumps, lightweight wet well structures utilising pre-cast concrete units and minimal ground improvements. Additionally, hydraulic modelling identified that two smaller pump stations (of 800 l/s capacity each) provides a more cost-effective solution than one larger pump station and associated greater capital investment in the conveyance network. The design is now in construction. This paper provides valuable lessons to the industry on how to improve the design of these important and large stormwater pump stations.

KEYWORDS

Stormwater pump station, horizontal axial flow pumps, Christchurch, earthquake, resilient design.

1. BACKGROUND

Due to the Christchurch earthquakes during 2010 – 2011, areas of Christchurch are now more prone to flooding as a result of ground settlement. This is one of the challenges being tackled by the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) alliance, with significant investment being required to repairing damaged infrastructure. The scale and complexity of the challenge has led engineers and contractors to investigate new and innovative ways to return the level of service back to the people of Christchurch.

The ‘New Brighton Road and Owles Terrace’ concept design project identified the need for three stormwater pump stations to service two catchments in east Christchurch, as shown in Figure 1. Both catchments are normally drained by gravity systems to the Avon River but, during rain events which coincide with high tides or storm surges, pump stations are required to convey accumulated surface water and mitigate flooding. They are not required for every storm event. The design was to provide an agreed level of service in a 1 in 50-year flood event with a 5 year tide, allowing for climate change. The concept design identified a required combined pump station output of approximately 6 m^3/s.

Figure 1: New Brighton Road and Owles Terrace Catchments

Following development of the concept design, the detailed design stage of these catchments was broken into two separate projects: the ‘Northern Owles Terrace Catchment’ and the ‘ANZAC Drive to Keyes Road Catchment’, although the latter project has been placed on hold.

The concept for the Northern Owles Terrace catchment included a single 2 m^3/s pump station. From the beginning, the design team saw the need for the design to be transferable between the other proposed pump station locations as possible means to reduce costs. Another fundamental element was that a significant cost to the project would be in the conveyance of these flows to the station and the construction of a deep pump station in poor ground conditions.

2. CONVEYANCE

The cost of conveyance could be reduced if the need to upgrade existing storm pipes could be reduced. This can only be achieved by increasing overland flow, which has limitations in this catchment. The real gain would be in providing pumping capacity closer to where it was required: at the existing gravity outfalls. Hence the two pump station option was developed. Although the option for two pump stations was considered during concept design, it was only on the basis of conventional stations, utilising vertical pumps which, in turn, require deep structures and ground improvements; more costly compared to a single pump station. The next challenge was to solve the cost of the pump station construction and provide a design that could be simply transferred to other projects. The location selected for the two pump stations are shown in Figure 4.

3. PUMP SELECTION

Before the design of the pump station could start, the selection of a pump that would allow the station depth to be minimised needed to be identified. Investigations identified that a horizontal axial flow pump would best meet these requirements. The final pump selection was to use Pleuger Flood Pumps built in Germany. These pumps are used in Europe and Asia, as well as in a number of drainage schemes in New Zealand. Discussions were held with the supplier and pump engineer based in Germany regarding the design requirements for the pumps. The pump installation is to the Pleuger design guide and the pump supplier was requested to confirm the final station design complied with their pumping requirements. There are no stand-by pumps; this decision was based on a risk-assessment whereby if one station failed, there was minimal risk of property flooding while the other was still operational. Based on this analysis it was agreed the requirement for further redundancy was not required. Figure 2 below shows the horizontal pleuger pump in plan.

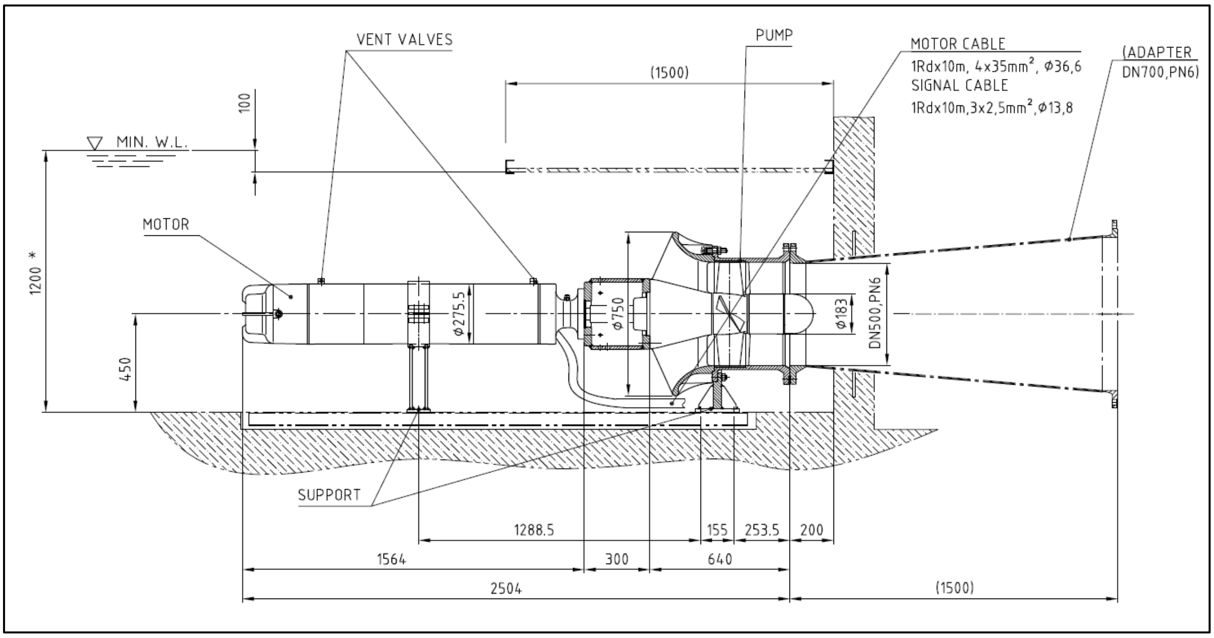

Figure 2: Pleuger Horizontal Axial Flow Pump

4. PUMP STATION DESIGN

The pump station design team was from the SCIRT Red Team, which has designed the majority of the pumps stations for the rebuild. Design of the pump stations can be broken into the following key areas which have an impact on cost and resilience:

- Ground improvements
- Depth
- Structure
- Connections
- Re-use of the design in other projects

The ground conditions in the locations of these pump stations is poor. In terms of earthquake resilience, ground improvements are undertaken to protect the structure from differential settlement and/or settlement. The approach taken for these stations is that the stations should settle with the surrounding area to avoid it remaining higher than the catchment. Differential settlement needs to be minimised, but the pump station structure and connections can accommodate some settlement. The design needs to allow for repair of damage caused by differential settlement without requiring a full rebuild. There is a balance between resilience and cost – a conventional station would require a deep structure with extensive ground improvements to create a very strong structure; at significant cost. There is an alternative: keep the structure light and shallow, sitting on a raft foundation to limit differential settlement. Following a seismic event, this allows the low-cost repair option of excavating around and lifting the structure to re-level.

The structure itself had to be simple; it needed to be a pre-cast unit allowing construction off site, minimising time on-site. The decision was made to produce a standard design based on 1 m^3/s. Through benching, design flows can be reduced while, by installing units in parallel, flows can be increased – allowing the design to be utilised in other catchments of different capacities. The current station design is based on a maximum depth of 2.50 m. These can be constructed at any depth; apart from the reasons stated above weight of the structure had to be considered. We assessed all possible locations of future stations and access requirements for lifting in the precast units which provided a benchmark for weight of the structure to work to. Having a standard precast design also has benefits for the delivery team, which means there good cost implications.

A number of Early Contractor Involvement (ECI) workshops were held to further develop the concept into an optimised detail design. These workshops were invaluable, with everyone being fully involved and working towards the same goal. The key features which came out of these workshops were pre-cast wet well fixed to a 500 mm concrete base. Following a seismic event, the pre-cast unit can be removed from the base and re-levelled. This also reduces the overall weight of the pre-cast unit through having the main base separate.

The final structure design is set at 4.80m long x 2.50m wide x 2.50 m deep. The roof is removable and has a lid within, allowing removal of the pump. Figure 3 below displays the concept of the stations structure.

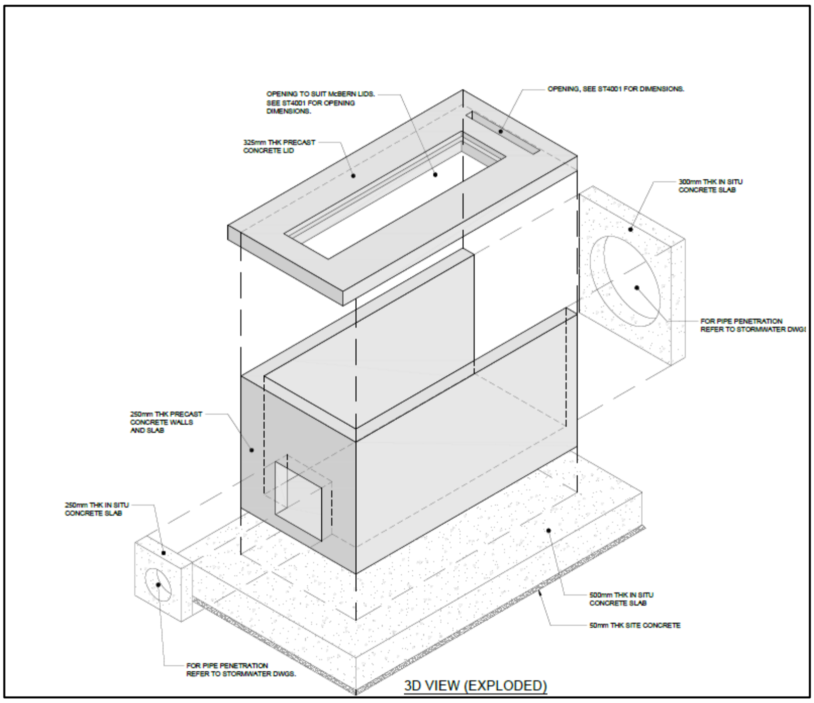

Figure 3: Stormwater Pump Station Structure

5. CONNECTIONS

A commonly-identified failure point of pump stations during the earthquake events was at the pipe connections. This was typically caused through rigid connections shearing at the face of the structure. The shallow depth of the designed structure minimises the load on the pipe connections during an event while the discharge pipe has a flexible joint between the pressure main and cast-in spool. The gravity main into the station is connected to the upstream network manhole. The pipe joints are socket joints, wrapped in a geogrid to prevent material entering the station if the joints are pulled apart during an event. Restraining these joints has been avoided as this would require transferring load back into the pump station. To allow the station to be lifted and re-levelled there is a break-out connection at the inlet and discharge of the station.

6. PUMP OPERATION

As part of detailed design the catchment was modelled. Scenarios were run to identify the optimal locations for two pump stations which required minimal capital works for conveyance. The two sites identified are shown on Figure 4. The stations are known as Beresford Street Pump Station and Owles Terrace Street Pump Station. Further modelling was carried out to understand the interaction between the pump operation and network conveyance to meet the required Level of Service. The stations are connected directly to the network; therefore, the buffering storage is held within the pipe network itself. This required the station operation under various flow scenarios to be carefully assessed.

Modelling of the two stations under these various scenarios allowed the control philosophy reduction of each station from 1000 l/s to 800 l/s. This also proved that two smaller stations within the catchment, rather than one larger unit, provided significant savings in capital investment in the conveyance network.

Figure 4: Stormwater Pump Station Plans

7. GEOTECHNICAL DESIGN

The stormwater pump stations that utilise horizontally aligned pumps are relatively shallow structures normally with a depth of 3-4 m to the base of excavation. The proposed works involve installation of precast concrete units with a depth of no more than 3.3 m. Considering the consequence of differential settlement and lateral displacement of pump station structures on operation, to maximise 'value' the design philosophy of utilising shallow foundations and accepting movement of the pump station with requirement for earthquake repair has been adopted. The following stormwater pump station performance objectives for a design earthquake are as follows:

1. Differential settlement of the structure will occur. Though magnitude is limited to allow continued operation of the pump station, or to allow for reinstatement within a short period after the earthquake.
2. Accept that the pump station will translate with lateral spread, with foundations not resisting movement. Provide flexible pipe, service and utility connections.
3. Provide allowance within pump station inlet design to allow for the pump station to settle less than adjacent ground. Consider differential settlement from one to two ULS earthquakes.
4. Provide a design that mitigates pump station uplift under liquefied conditions.
5. Provide mitigation measures on supply gravity pipes to prevent collapse or erosion of fines from the soil into the pipes following lateral spread and likely pipe separation.
6. Re-levelling of the pump station and repair of connecting infrastructure will likely be required following a significant earthquake; detailing of the design to reduce the costs and duration for repair will be required.

The site for both pump stations is prone to lateral spreading and large seismic settlements because of being located alongside waterways. The main risks to the both the pump stations are from lateral spreading, buoyancy uplift and differential settlement. No extensive ground improvement is required because of the light weight of the precast structures. In order to reduce potential differential settlements affecting the operation of the pump stations, the precast units for wet well will be founded on a 500 mm thick geotextile (NZTA F/7 strength Class C geotextile) and geogrid wrapped (TenCate Miragrid GX 40/40) CCC GC 65-40 ballast base of approximately 7.5 m by 5.0 m. This option will provide some stabilisation and will limit the rate of differential settlement across the structure. The ballast base will be founded on the medium dense sand layers below each site. The pump station structures have been designed to move with the surrounding ground during seismic activity. The robust nature of the pump station structure will limit structural damage to a level which can be economically repaired.

In case of a significant earthquake event, there is a chance that the pump station structure suffers from differential settlement. In such an event these pump stations can be excavated and re-levelled at relatively low cost. To resist the uplift due to buoyancy, an extended base has been used with granular backfill on top. The light weight pre-cast wet well is bolted to the base but removable for re-levelling. The proposed design philosophy provides a balance between affordability and an appropriate level of resilience in the design.

8. OPERATION & MAINTENANCE

Access covers have been provided at both pump stations for the removal of pumps. These covers are mounted flush with the ground level so as to not cause any obstruction to the pedestrian traffic. Removal of the pumps will be by a Hiab type crane.

For each station, the off-take from the main network has a screen to protect the pump. The screen is placed to provide some self-cleaning through being parallel to the gravity flow. Access covers have been provided for the regular maintenance of the screens. A high level alarm is located in this manhole to alert operational staff that the screen requires cleaning.

9. COST SAVINGS

As stated at the start of the paper, the scale of the rebuild requires the design and delivery teams to look for new and innovative ways to return the level of service back to Christchurch. This project has achieved this. The cost savings to this project were $3.6M, achieved through reduced pump station construction costs and a reduction in the need for upgrading of the stormwater network.

10. CONCLUSION

The approach of using shallow flood pumps has provided significant savings over conventional vertically-mounted pumps. Lightweight Localised Pump Stations utilises a new innovative design philosophy which focuses on the use of horizontal axial flow pumps which enables shallow and lightweight structures to be used. This has a number of advantages from design through the lifecycle of the asset, these include:

- Design templates are able to be transferred to other projects with minor amendments,
- Construction duration and temporary work costs are able to be greatly reduced as deep excavations in poor ground with a high water table is not required,
- Stations can be located to serve existing infrastructure or low points, minimising the amount of reticulation required to convey flows to a centralised point,
- In the case of earthquake damage, repair costs, duration and complexity of repairs are reduced as the structure is relatively small and lightweight allowing the structure to rotate and/or differentially settle and remain operational with minor damage,
- The relative small size of the structures allows for significant cost saving relating to land acquisition and legal costs as the structures are able to be located within the road reserve,
- In the event of a localised pump station failure resilience is increased as flows can build up and overtop to neighbouring stations which localises flooding within the catchment.

This all would not have been possible without a team of designers and contractors coming together with a common goal.

11. ACKNOWLEDGEMENTS

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