SURGE MITIGATION IN A MODERNISED IRRIGATION SYSTEM

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EXECUTIVE SUMMARY

As part of the Hanwood Infrastructure Modernisation Project in the Murrumbidgee Irrigation Area, a low-cost solution to mitigate pressure surges within the low-pressure but high-volume transfer system was implemented to allow use of lower pipe classes with associated pipework savings. Transient Surge modelling showed on-farm pump trip and rapid valve closures were capable of causing high pressure surges, which could reflect as negative pressure waves, posing risks to large-diameter, low-pressure class pipework. These surges were alleviated through inclusion of miniature surge towers, resembling standpipes. Once constructed, the standpipes were modified to limit water expulsion while maintaining surge mitigation efficacy.

INTRODUCTION

The Hanwood Infrastructure Modernisation Project involved the replacement of an ageing channel supply system in the Murrumbidgee Irrigation scheme near Griffith with an integrated water delivery system that minimised wastage. Over 14 km of irrigation pipework, ranging from DN250 PVC up to DN1100 GRP, capable of delivering flows up to 32 ML/day with low head loss was designed and constructed as part of the modernisation works. The individual farm offtakes, sometimes capable of controlling over 12 ML/day, had the potential to introduce large pressure surges.

Large diameter, low-pressure class PVC pipework was identified early in the project as a low cost construction material and was planned for long sections of the system. Following surge analysis full vacuum conditions appeared likely, arising as a result of high pressure surges that would reflect at each end of the irrigation system. Strongly negative pressures were shown to be unacceptable in light of structural and geotechnical calculations performed on the large PVC pipework. The design team investigated mitigation measures that would enable use of the preferred, lower-cost pipe materials by protecting these mains from strongly negative pressures while preserving a system design that would be flexible to operate and easily maintained.

YEAR CASE STUDY WAS IMPLEMENTED

2014 to 2016 (design and construction)

CASE STUDY DETAIL

The case study focuses on the surge mitigation design and construction measures that were implemented as part of the Hanwood Infrastructure Modernisation Project.

Due to a poor result for the native soil modulus from geotechnical investigations, the surge mitigation focused on reducing the severity of high-pressure surges and resulting negative pressures that could damage large diameter, low pressure class PVC main.

A series of mitigation measures were designed and modelled using Bentley's HAMMER software. Mitigation measures for surges caused by operation of the valves, included specifying vee-port valves on farm sump float valves and the avoidance of the use of butterfly valves in preference of slower-to-close gate valves.

On-farm pump trip remained a risk to the system, and surge towers were proposed at key locations such as the connection point to the irrigation supply mains for on-farm pumps, and between scour points and the large-diameter PVC mains. Designing the surge towers in the form of standpipes, with a hooked discharge point,

allowed direction of the water toward the ground and prevent debris falling into the standpipe and transfer system.
Surge analysis showed that standpipes with a discharge point slightly higher than the static water level of the supply channel to the irrigation pipework would remove the risk of the high pressure surges that were otherwise capable of causing strongly negative pressures (Table 1). Standpipes were designed in heights ranging from 0.5 m to 3.5 m above ground; the relatively low height was made possible by the low elevation change between the supply channel and standpipe locations. Unlike pressure relief valves, standpipes require little maintenance or performance testing, and unlike air valves, standpipes provide a nearly unblockable form of vacuum-breaking infrastructure.
An added benefit of the standpipes was the overall lowering of maximum surge pressures in the system (Table 2), which allowed smaller thrust block design, by a factor of 2-3x bearing area. This provided constructability and cost benefits particularly on the larger GRP pipework, which ranged up to DN1100 on this project.
Once installed, the standpipes expelled water when high pressure surges were triggered, such as by pump shut down. However, the volume and frequency of expulsion at certain locations began overloading local drainage conditions (Figure 1), so a series of improvements were made following additional surge analysis to confirm the efficacy of the mitigation:

- Understanding customer behaviours and providing feedback to customers on the impacts of their on-farm system operations;
- Local surrounds were excavated and refilled with gravel to create a local sump;
- Several standpipes were raised slightly to decrease the frequency and volume of water discharged;
- Orifice plates were sized specially for certain standpipes where very frequent pump trip events were causing a high frequency of discharge.

Standpipes were found to be an effective mode of surge relief in this low-pressure, high-flow irrigation transfer system. Customer communication was used to both inform post-installation modifications, and alter customer behaviours to reduce the magnitude and impact of standpipe flows. The adoption of standpipes allowed specification of PVC pipework with a lower pressure class than would have otherwise been possible, providing cost savings to the whole project.

Murrumbidgee Irrigation acknowledges that the Hanwood Modernisation was a sub-project of the Round 2 Private Irrigation Infrastructure Operators Program (PIIOP) project, which was supported by Australian Government funding totalling $175,122,911.

Table 1: Modelled maximum and minimum pressures in large PVC pipework before and after inclusion of standpipes, across all pipework DN450-DN575 (relevant to structural integrity)

Scenario	Maximum pressure	Minimum pressure
Without standpipes	400 kPa	-100 kPa
With standpipes	133 kPa	-45 kPa

Table 2: Modelled maximum and minimum pressures in GRP pipework before and after inclusion of standpipes, across all pipework DN675-DN1100 (relevant to thrust block design)

Scenario	Maximum pressure
Without standpipes	350 kPa
With standpipes	150 kPa

Figure 1: Standpipe installed at a surge-prone location

The standpipe at this location had dealt with several pump trips in quick succession. Photo taken prior to modifications, such as orifice plate installation, that reduced flows from standpipe to prevent waterlogging surrounding ground, while maintaining the efficacy of the standpipe.

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ABSTRACT

Management of transient pressure surges is a common requirement to prevent buckling of flexible pipework laid in poor ground conditions. Selecting pipework with sufficiently-thick pipe wall to withstand buckling with minimal support from surrounding soil may not be the most cost-effective solution. Alternatively, surge can be mitigated through the inclusion of appropriate measures to protect thinner-walled pipework, allowing the use of lower cost pipework materials. In this case study, surge mitigation comprising surge tower 'standpipes' was designed as cost-effective alternative to increasing pipeline wall thickness across several kilometres of large-diameter PVC located in soils with low native soil modulus in the Murrumbidgee Irrigation Area..

INTRODUCTION

The Hanwood Infrastructure Modernisation Project involved the replacement of an ageing channel supply system in the Murrumbidgee Irrigation scheme with an integrated water delivery system that minimised wastage. Over 14 km of irrigation pipework, ranging from DN250 PVC up to DN1100 GRP, capable of delivering design flows up to 32 ML/day with low head loss was designed and constructed as part of the modernisation works. The farm offtakes, sometimes capable of controlling over 12 ML/day, had the potential to introduce large water hammer effects or pressure 'surge'. Surge is introduced through the retardation or acceleration of flow, such as may be caused by the change in opening of a valve (Streeter & Wylie, 1975).

METHODOLOGY

General approach

Large diameter (DN450-DN575) low-pressure class (PN9) PVC pipework was identified early in the project as a low-cost construction material and was planned for large sections of the system. Following surge analysis, full vacuum conditions appeared likely, arising as a result of high pressure surges that would reflect at each end of the irrigation system. Strongly negative pressures were shown to be unacceptable in light of structural and geotechnical calculations performed on the large PVC pipework. The design team investigated mitigation measures that would enable use of the preferred, lower-cost pipe materials by protecting these mains from strongly negative pressures while preserving a system design that would be flexible to operate and easily maintained.

Steady state analysis

We first developed a steady-state hydraulic model in Bentley's HAMMER software (Haestad Methods Solution Center) to optimise the sizing of transfer pipework that would replace the irrigation channels serving customers in the Hanwood area. The model incorporated GIS data to provide the 2D location of pipework and outlets, and level survey data to identify required operating water levels to be delivered by the piped system. Murrumbidgee Irrigation's standard supply rules were applied to determine the required flow rates for each supply branch and farm offtake of the modernised system.

An example of the hydraulic profile is provided below, showing the hydraulic grade line vs. target head at customer delivery points along a series of supply system branches. It can be seen that as the pipework would replace channels, the system needed to provide high flow rates at relatively low head loss per km – in the illustrated case, up to 32 ML/day with less than 2 m/km headloss, and in some sections lower than 0.5 m/km.

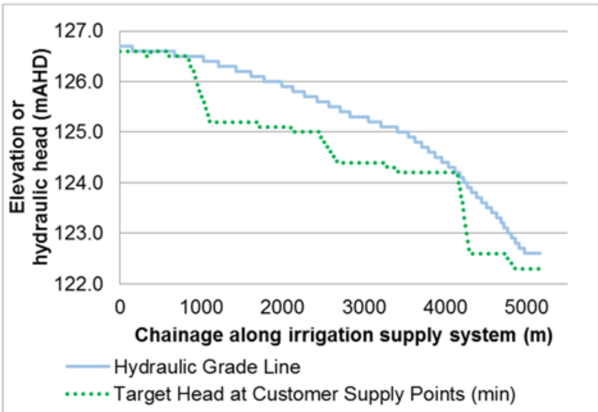

Figure 1: Example HGL along one path of system.

Structural analysis

A structural analysis of the preferred pipework materials according to AS2566 was performed using information provided by manufacturers, results of geotechnical analysis on native soil modulus, and trench design.

The structural checks indicated the larger-diameter, lower pressure class PVC pipework would be at risk of buckling if the internal pressure fell substantially below atmospheric pressure. Specifically: under the observed geotechnical conditions, MPVC PN9 in sizes DN450 and DN575 would not pass AS2566 structural analysis for buckling with full internal vacuum (approx. -100 kPa.g), requiring either that these sizes be constructed in PN12 MPVC, or that full vacuum conditions be mitigated to allow PN9 MPVC to remain a viable material.

The assessment showed that the GRP pipework did not require protection from full internal vacuum.

Surge analysis

The hydraulic model was used to analyse a range of surge events expected to occur at some time over the life of the pipework, namely:

1. Simultaneous pump trip of all irrigation pumps to be directly-connected to the supply pipework (power failure scenario);
2. Pump start of each directly-connected pump (non-simultaneous);
3. Gate valve closure at each the major scours and irrigation offtakes (non-simultaneous);
4. Float valve closure at those irrigation offtakes utilising a float valve with internal vee-port plug to control levels in an offtake sump with a slowed rate of closure.

The analysis showed that full vacuum conditions could be expected in the larger PVC pipework following simultaneous pump trip and gate valve closure. Gate valve closure was assumed to occur by manual operation, but the surge created by such closures could be significant. Figure 2 shows an example of the pressure envelope created by the surge from valve closure.

Simulation results for individual pump starts and float valve closures suggested these were also capable of introducing negative pressures to the pipework, but these were of smaller magnitude and of no significance to the pipework structural integrity.

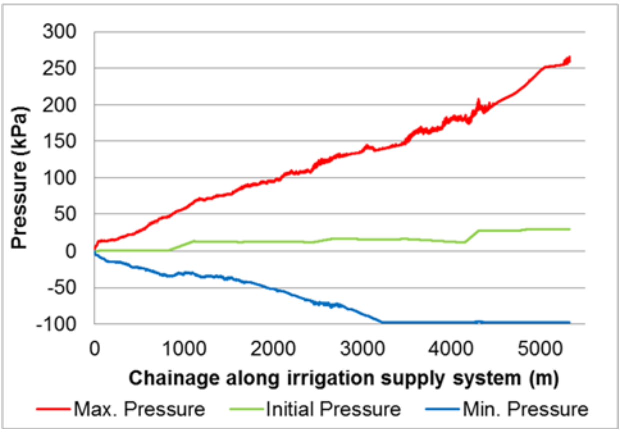

Figure 2: Example of pressure envelope following valve closure.

Surge mitigation options

Three options were proposed to address the occurrence of full-vacuum conditions in the larger PVC pipework:

1. Install all PVC DN450 and DN575 pipework as PN12, as this was shown to be vacuum competent through the AS2566 checks;
2. Install air valves at regular locations to avoid the occurrence of full vacuum conditions;
3. Install surge mitigation solutions to prevent the occurrence of full-vacuum conditions within the large-diameter PVC.

Option 1 would require an increase of pipe class of from PN9 to PN12 of 1.3 km of DN450 and 2.6 km of DN575.

Option 2 would require more air valves to be installed than the design would have otherwise required for the purposes of air expulsion. Although this additional cost may not have been significant, this option also carried the risk of the air valves becoming blocked (e.g. due to algae and debris accumulation) and/or being isolated or from the system (e.g. air valves could be left isolated following maintenance by mistake, or isolated to prevent observed leakage). This option was considered too risky to be retained as the preferred option in mitigating full vacuum conditions.

Option 3 would require a method of releasing positive pressure surges. Examination of the modelling results showed large positive pressure waves are created by pump trip and valve closure events, which reflect within the system to create to negative pressure waves and full-vacuum conditions. Mitigation would therefore need to focus on positive pressure surge release. Two options for surge mitigation were considered:

1. Surge towers placed at origins of major positive pressure surge and/or at the end of DN450 and DN575 pipework;
2. Surge relief valves placed at origins of major positive pressure surge.

Surge towers are typically designed as upright, narrow tanks, open to atmosphere, with a top elevation higher than the steady-state operating head range such that flows do not escape the tower during normal operations in the system. They provide surge pressure relief by allowing a flow path out of the system, into the empty storage in the upper portions of the tower, with the water level rising in the tower until the water level in the tower rises to balance the surge pressure in the pipeline (Marriott, 2009). If the water level exceeds the tower height due to insufficient volume or elevation in the tower, the tower may overflow to the surrounding environment, though this still dissipates momentum from the pipeline. Surge relief valves provide a similar function, though are only opened to the atmosphere when the system pressure exceeds the configured trigger pressure. As the modernised irrigation system at Hanwood would experience a normal operating head range within approx. 3 m of ground level, it was decided that the surge tower option would be preferable to pressure relief valves, owing to the following factors:

- Surge towers require little or no maintenance as they have no moving components, unlike pressure relief valves;
- Surge towers provide direct protection against negative surges as they provide a large-diameter opening that is always open to atmosphere, unlike pressure relief valves;
- The majority of cost associated with either option was associated with the civil works required to manage flows from discharge events, making each option similar in overall installation cost.

Surge mitigation analysis

The sizing and location of the surge towers to mitigate the occurrence of full-vacuum conditions was determined through further surge analysis, making use of HAMMER's 'surge tank' element with simplified inputs to allow the tank to resemble a simple surge tower. Analysis demonstrated that seven (7) surge towers of approx. 200 mm diameter were adequate to protect the approx. 4 km of larger-diameter PVC pipework from full-vacuum conditions, and thus allow use of PN9 pipework rather than PN12 pipework.

Table 1 also provides a comparison of the maximum and minimum pressures experienced by the DN450 and DN575 pipework across all modelled surge scenarios.

Table 1: Modelled maximum and minimum pressures in large PVC pipework before and after inclusion of surge towers, across all pipework DN450-DN575 (relevant to structural integrity)

Scenario	Maximum pressure	Minimum pressure
Without surge towers	400 kPa	-100 kPa
With surge towers	133 kPa	-45 kPa

Figure 3 shows how the pressure envelope created by the surge from valve closure has been reduced by the inclusion of surge towers, which shows a marked reduction in the magnitude of surge pressures compared to the unmitigated results shown in Figure 2.

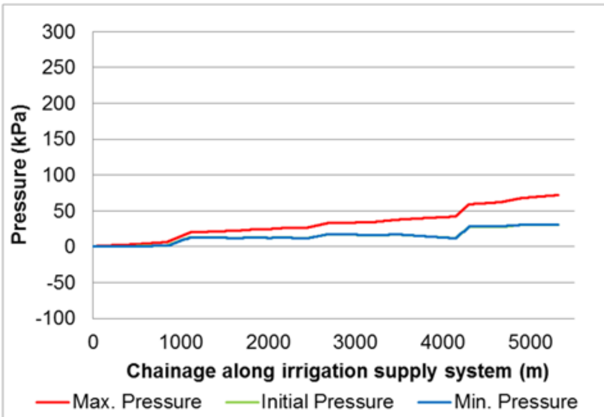

Figure 3: Example of pressure envelope following valve closure, with inclusion of surge towers.

A further benefit was provided by the surge towers. By reducing the maximum pressures that occur throughout the irrigation supply pipework, the size of the thrust blocks on all pipework was able to be reduced. This result was of most benefit to the construction of thrust blocks for the larger GRP pipework (DN675-DN1100), which had an expected reduction of maximum pressure from 350 kPa to 150 kPa, and accordingly saw a proportional reduction in thrust block dimensions due to a reduced bearing area requirement.

Cost and additional benefits

The cost of installing the surge towers was compared to that of installing the higher pressure class of PVC pipework. Seven surge towers, complete with foundation slab and drainage modifications had an estimated cost of approx. $100,000. The cost difference of installing 1.3 km of DN450 and 2.6 km of DN575 as PN12 rather than PN9 MPVC was estimated at approx. $135,000, meaning the standpipes would provide a net saving of approx. $35,000. In addition to the difference in the capital costs of the options, the surge towers would provide additional benefits. Although not quantified in terms of cost, these benefits included:

- Reduced thrust block size throughout the system, with associated reduction in construction complexity and cost;
- Management of unanticipated surge events, in addition to those originally foreseen and modelled;
- General reduction of the magnitude of surges throughout the supply system, providing protection to on-farm equipment directly connected to the system.

The additional benefits resulted in the surge towers being the preferred approach to address the surge issues.

Design, deployment and modifications

The surge towers were designed to be simple to construct and provide a discharge point to the side of the tower riser. In the proposed DN200 diameter, the surge towers could be simply constructed as self-supporting structures using flanged DICL pipework. A ground-slab was designed to further stabilise the above-ground pipework against wind loading. The pipework was designed to discharge approx. 1 m to the side of the tower riser using two 90-degree bends. This resulted in the surge towers to resemble hooked standpipes, to which they are alternately referred.

The standpipes were expected to discharge infrequently, and as such were initially designed to make use of existing drainage features for water expelled during surge events. However, over the commissioning period, additional and frequent surge events (e.g. repeated pump backwash activities) were triggering repeated water discharge that overwhelmed drainage measures at some locations (see Figure 4). Where required, one or more of the following modifications were made to these standpipes:

- Trenches dug adjacent to the standpipe slab, and backfilled with crushed rock to provide a local drainage/infiltration sump;
- Extending the height of standpipes by 0.5 m where installation had resulted in the discharge level being very close to the static water level;
- Insertion of an orifice plate between one of the flanged joints in the standpipe to reduce the rate of flow.

In the cases of the height extension and orifice plate insertion, additional hydraulic analysis was performed to assess the impact on surge mitigation and appropriately size the measures while remaining within the maximum and minimum pressure requirements of the design.

Figure 4: Standpipe at a surge-prone location with flooded surrounds, prior to flow-control modifications.

Performance

The standpipes have been relieving surge pressures from the Modernised Hanwood Irrigation System for the last two irrigation seasons. Based on the observed performance of their expulsion of water following a surge event such as valve closure or pump shut-down, they appear to be fulfilling the design intent of mitigating high pressure surge waves.

Conclusion

In this study, we investigated the use of surge tower 'standpipes' to mitigate surge in a low-pressure, high-flow irrigation supply system, with the intent of protecting large-diameter PVC from negative pressures that may have caused buckling of pipe under various surge events such as pump trip and scour valve closure. Through transient analysis, the design and placement of standpipes was optimised to result in a solution that was found to be more cost-effective than the alternative approaches of increasing pipeline pressure class (i.e. wall thickness), or installing pressure relief valves. Several simple modifications, including elevation height increases and addition of orifice plates were found to be a necessary modification at some of the standpipes, in order to decrease the volume of water expelled following a surge event.

ACKNOWLEDGEMENTS

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