EARTHQUAKE EFFECTS ON THE KAIAPOI AND RANGIORA PVC-U PRESSURE PIPELINES

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ABSTRACT

The 8.7 km Series 2, DN 500, PN 9, PVC-U lifeline water main from Kaiapoi to Rangiora was constructed between March 2010 and September 2011. The construction spanned the September 2010 to June 2011 earthquake sequence that caused significant damage in Kaiapoi and the surrounding areas. The pipeline route was less than 1 km from some of the worst liquefaction damage in the greater Christchurch area.

This paper covers some of the design and pipe material selection issues considered in this successful project, and gives details of the relatively minor damage that occurred to the pipeline.

The earthquake performance of two other major PVC trunk wastewater pipelines in the Kaiapoi-Rangiora area that were completed within 6 years before the 2010/2011 earthquakes is also covered briefly.

The conclusions suggest that the present (and growing) trend towards the use of PE 100 pipe for most new work is a costly over-reaction to perceived risks.

KEYWORDS

Earthquake damage, liquefaction and lateral spreading, PVC-U pipes, solvent jointed PVC pipe fracture, pipe materials selection

1 INTRODUCTION

The general damage caused by the September 2010 to June 2011 earthquakes has been well documented in previous publications over the last five years.

This paper summarises the performance of three of Waimakariri District Council's (WDC) PVC lifeline pressure pipes as this information has not been widely communicated to date. Two of these pipelines suffered minor (but preventable) damage. The third was subjected to significant liquefaction and lateral spreading effects and one leak occurred (from a joint pull-out).

This paper primarily focuses on the DN 500 trunk water main from Kaiapoi to Rangiora. The design details and statistics of this major lifeline are briefly outlined and the damage that was sustained as a result of the sequence of earthquakes is described.

Two other PVC lifelines are also briefly described - the DN 450 PVC-U effluent gravity/force main from Rangiora to Kaiapoi; and the Peraki Street sewage rising main.

2 TRUNK WATER MAIN KAIAPOI TO RANGIORA

Until 2010, Rangiora, WDC's main center, had relied on water supply from a number of relatively low-yielding bores with variable quality water.

Secure, high-quality ground water from the aquifers underlying most of the Canterbury Plains was present within 9 km, on the outskirts of Kaiapoi, WDC's second largest town. High-yielding bores could be established in an area on the true left bank of the Kaiapoi River, immediately downstream of the State Highway 1 Bridge. All that was needed to provide a high quality water supply to Rangiora was a trunk water main and pumping station to deliver the water to a storage reservoir in Rangiora.

2.1 THE DN 500 TRUNK WATER MAIN STATISTICS

The key statistics of this pipeline are:

Total length: 8.7 km
Pipe: Blue, Series 2 DN 500 PN 9 PVC-U, manufactured in 3 m and 6 m lengths
Deflection Socket: Maximum deflection angle recommended by pipe manufacturer 3º (confirmed on site)
Actual ID: 518.5 mm (mean)
Designed Capacity: 320 L/s

Series 2 (S2) pipes to AS/NZS 1477 were chosen for their specially designed sockets that allow for angular deflection of up to 3° at each joint. This deflection, combined with a proportion of the pipes being supplied in 3 metre lengths allowed for pipes to be safely laid on curved alignments without the need for special bends. Table 1 shows the radius of curvature for various joint deflection angles as well as for 3 m and 6 m pipe lengths.

Effective pipe length (m)	3	6
Radius of curvature (m) @ 1°joint deflection	172	344
Radius of curvature (m) @ 2°joint deflection	86	172
Radius of curvature (m) @ 3°joint deflection	57	115

Table 1: Radius of curvature for various joint deflections and pipe lengths

By making use of the allowable angular deflection at the joints, it was possible to greatly reduce the need for bends and their associated thrust blocks.

2.2 ALTERNATIVE PIPE MATERIALS CONSIDERED

The alternative pipe materials that were considered for this trunk main were;

- PN 12 PVC-M (PVC-O was not available in this diameter)
- 558 mm OD x 4.8 mm wall concrete lined steel (CLS)
- DN 500 PN 35 Concrete lined Ductile Iron (CLDI) – an Alternative Tender for PN 20 CLDI was also considered but rejected
- DN 630 PN 8 PE 100 Polyethylene (PE), PE 100

Any of these materials (except perhaps PN 20 CLDI) were potentially satisfactory, including for earthquake risk considerations, with proper attention to design detail and installation.

The design report on materials for this project stated that the most reliable materials under earthquake conditions would be fully-welded pipeline of concrete lined steel or PE. A steel pipe would also have a design working pressure of at least 21 bar, i.e. significantly higher than any of the plastics' pipes which would be PN 8 - PN 12. PVC-U was considered to be the second preference to CLS for this pipeline, but would present higher cost escalation risks due to resin price volatility at the time.

The initial recommendation was for 558 mm OD (CLS) pipe for the following reasons:

- Competitive installed cost, could soon be lowest if plastic pipe prices continue to rise
- Reduced risks due to more predictable failure mode (than PVC), greater mechanical strength, high pressure reserve with increases in capacity possible, and fewer joints
- Easy to repair in the event of failure

The principal disadvantage of CLS was the risk associated with corrosion. While impressed current cathodic protection (CP) was proposed for this continuously welded pipeline, CP does not have any effect on internal corrosion. Internal corrosion protection relies entirely on the concrete lining and the quality of its reinstatement at the joints.

The relatively low resistivity of the soil along most of the pipeline length (in many areas the pipe is laid below the groundwater level) would also contribute significantly to the risk of corrosion to ferrous pipelines.

A further potential risk with using a continuously welded CLS pipeline was also identified during the design process. This was the close proximity of 66 kV overhead transmission lines running parallel to the pipeline for approximately 3.5 km which had potential to cause both accelerated corrosion and safety risks during pipeline maintenance if there was a fault on the transmission line. This could result in workers being exposed to dangerous voltage gradients unless special procedures were followed.

While mitigation measures to reduce the risks associated with accelerated corrosion were possible, their reliability was uncertain and costs would have been significant. The safety risk proved more difficult to quantify and mitigate, particularly if using a cathodic protection system (which requires electrical continuity on the pipeline). These issues made PVC-U the preferred option. However, alternatives were allowed in the Tender Documents to ensure that the most cost-effective (balanced with acceptable risk) pipeline was adopted.

A joint venture of two experienced local Contractors, C & A Cox Ltd and Shayne Higgs Drainage Contractor Ltd submitted the successful tender for this ≈$5M pipeline project. Their preferred option was PVC-U from a handling and laying perspective, but they also offered an alternative of PN 20 CLDI at a slightly lower cost (which was not accepted).

PE 100 pipe was an acceptable option but it was not offered as the cost was greater than the PVC alternative.

3 EARTHQUAKE PERFORMANCE OF WDC PVC LIFELINES

3.1 THE DN 500 TRUNK WATER MAIN – KAIAPOI TO RANGIORA

The 7.2 magnitude Darfield earthquake (which caused most of the damage in the WDC towns of Kaiapoi and the neighbouring Pines and Karaki Beaches) occurred just 4 days after the first section of this new water supply trunk main had been successfully pressure tested and was left under 300 kPa pressure. When checked after the earthquake, the pressure had dropped to zero, meaning that something had broken. A walk-over inspection of this 4,234 m section of pipeline on 7 September 2010 found no signs of damage aside from subsidence (up to 100 mm) and minor tension cracking along the first 400 metres which is adjacent to the Kaiapoi River.

The joint venture contractors were off-site through September to November 2010 to assist with the immediate earthquake response efforts, except for a small crew involved with locating the leak, repairing it and re-testing in October.

A leak of 3 – 3.5 litres per minute was confirmed by a repeated pressure test on 13 October. Finding such a small leak proved a little difficult, as the noise generated was difficult to detect by acoustic leak correlation methods. The leak was eventually located on a DN 50 PVC offset branch to an air valve at running distance 1,640 m and repaired. A re-test on 17-Nov-2010 showed a water "loss" of less than 12 L/hr and reducing. This was <40% of the maximum acceptable for this length and diameter of pipeline (per AS/NZS 2566.2, test M4). No further testing was undertaken as the whole 8,708 m pipeline was to be tested after the second section was complete and tested. There are no photos of this pipe failure, believed to be Partial pull-out of a solvent socket.

An attempt to pressurise the second section of pipeline on 9-May-2011 also indicated a leak. The leak was located at a solvent jointed stub flange on the offset pipe to the air valve at 7,700 metres, see Photograph-1. A successful test was achieved on 17-May after repairs to the fractured pipe.

Photograph-1: View of fractured pipe and stub flange and DN 50 valve – where the stub flange was connected (Opus site records)

This fracture of the DN 50 PN 12 PVC-U pipe was caused by the February 22, 2011 Christchurch earthquake.

The full 8.7 km pipeline was pressure tested on 31-May-2011 after the two sections were joined. After an initial inconclusive result due to air, a re-test was conducted the following day after flushing and bleeding air from the line. The results of this second test were satisfactory, and the pipeline was accepted.

3.2 DN 450 TREATED SEWAGE GRAVITY/FORCE MAIN – RANGIORA TO KAIAPOI

In 2005, a DN 450 gravity/force main was installed between Rangiora and Kaiapoi to deliver treated effluent to WDC's District Ocean Outfall via the Kaiapoi oxidation ponds.

For a significant part of the year, this pipeline has sufficient capacity to convey the treated effluent by gravity, but pumps are also installed and operate when additional capacity is required. It runs parallel and in close proximity to the DN 500 trunk watermain for a significant part of its 10.6 km length.

The pipe chosen for this lifeline was; white, Series 2 DN 450 PN 9 PVC-U, supplied in in 6 metre lengths.

There was no recorded damage to this pipeline immediately following the 2010 and 2011 earthquakes. However, in August 2015, a leak was discovered at an unrestrained joint between a section of DN 500 PE pipe under the main trunk rail line and the PVC-U pipe.

While it is possible that this joint (which had been leaking for some time) could have been leaking before the earthquakes, the ground shaking during the earthquakes is the most likely cause. . The operating pressure in this pipeline is relatively low and the leak had gone unnoticed in a free draining area of long grass.

This particular joint had not been detailed in the contract documents but was left for the contractor to construct as a design – build detail using appropriate materials (pers. Com. Gerard Cleary, WDC).

It is worth noting that the air release valves on this pipeline were mounted directly on top of tees on the main pipe, compared to the offset air valve design used for the trunk water main adopted to allow them to be installed above ground, close to fences.

3.3 DN 300 PERAKI STREET WASTEWATER RISING MAIN

This 2004 rising main has a total length of 1,113 metres and consists of Series 1 DN 300 PN 9 PVC-U pipe. It has a short section of directionally drilled DN 355 PE pipe under the Kaiapoi River.

It traverses some of the worst areas of liquefaction and lateral spreading damage in Kaiapoi - Hilton Street, Black Street, Raven Quay and a section between the bowling club (destroyed by the September earthquake) and the Kaiapoi River.

PVC was chosen for this pipeline as it can be a lot more straightforward to construct as shorter lengths of trench are required to be open at any one time. This can be particularly useful when working in streets or private property. (Pers. Com. Gerard Cleary, WDC)

Sufficient joint pull-out occurred at one location to allow leakage (see Photograph-2). This was the only leak that occurred on this main. After the June 2011 earthquake, 90% of its length was inspected by CCTV to assess the amount of axial movement (joint pull-out) that had occurred at the pipe joints. The only un-inspected section was the flooded section of PE pipe under the river.

The CCTV survey (carried out after the leaking joint had been repaired) showed that a significant number of joints had pulled-out sufficiently (up to 130 mm) to make the risk of full disengagement unacceptable if further significant after-shocks occurred (ProjectMax report).

The recommendation of the (ProjectMax) report was that a total of 250 metres of the pipeline where the joint pull-out was greater than 50 mm – 60 mm should be replaced, even though none of these joints were leaking. This recommendation was accepted by the WDC's insurers and new sections of PVC pipeline were installed with one section relocated further from the river.

Photograph-2: View of the joint pull-out and leak that occurred as a result of the September 2010 earthquake (Photo - Gary Boot WDC)

4 DISCUSSION ON DAMAGE AND MITIGATION MEASURES

4.1 THE DN 500 TRUNK WATER MAIN

The DN 500 elastomeric ring jointed PVC pipes on this 8,708 m long trunk main withstood the 2010 and 2011 earthquakes without any damage or joint leakage. Two minor failures occurred on solvent cement jointed DN 50 PN 12 PVC-U offset connections to air valves. This design was used to allow the air valves to be located above-ground and adjacent to nearby fence lines to avoid having chambers in the 'middle' of farm paddocks. Figure-1 shows the typical design detail for these offset air valves.

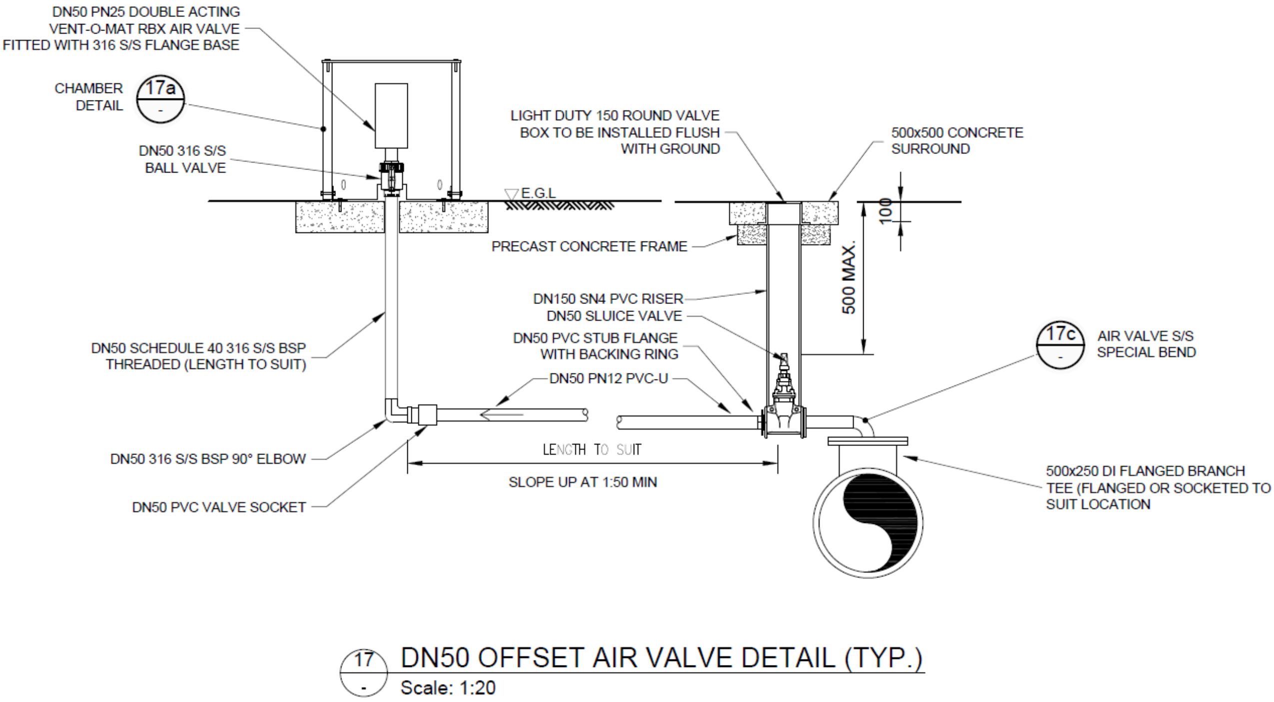


Figure 1: Elevation of a typical offset air valve

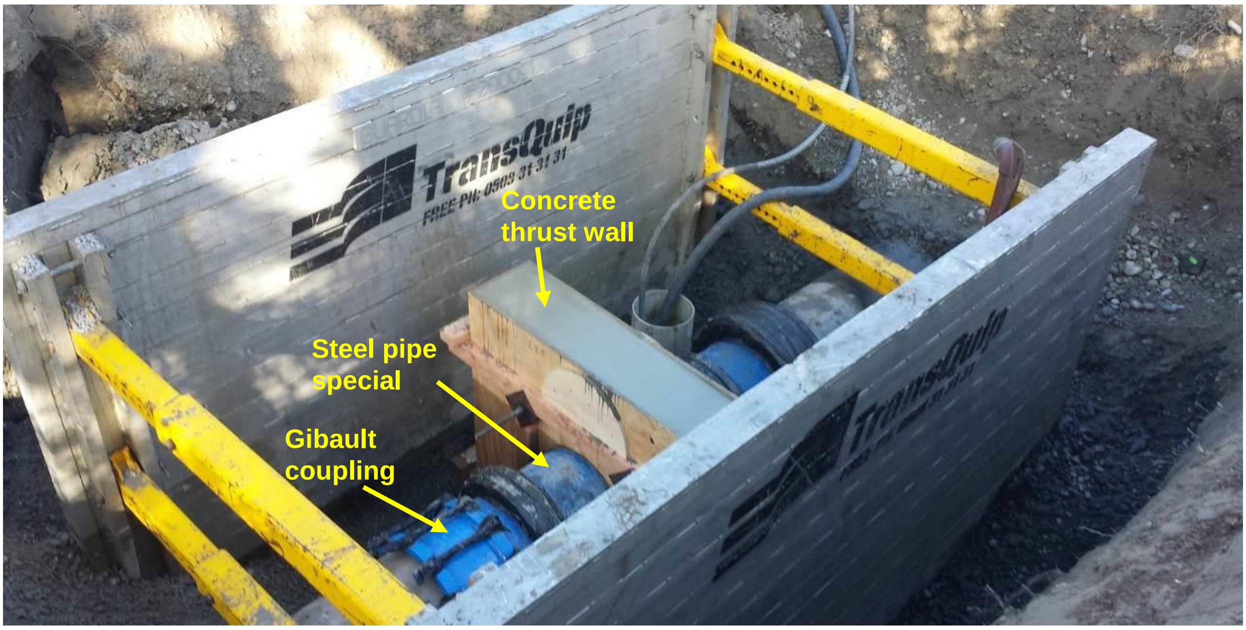
These solvent jointed PVC air valve offset pipes were connected between two fixed points and as such there was limited flexibility. Any significant earth movement would be likely to cause fracture of the PVC-U pipe or solvent joint pull-out, however, only two of these offset pipes failed.

These failures could have been easily prevented had a compression joint been used at each end of the DN 50 PVC pipe.

4.2 THE DN 450 TREATED SEWAGE GRAVITY/FORCE MAIN

The DN 450 elastomeric ring jointed PVC pipes withstood the 2010 and 2011 earthquakes without any damage or joint leakage. The only leak that developed was at the gibault joint connection between the DN 450 PVC-U pipe and the DN 500 PE pipe that was directionally drilled under the main trunk railway line.

The repair works included a coated steel pipe special with a puddle flange and concrete thrust wall to prevent the PE pipe from moving. Photograph 3 shows the steel special, thrust wall and the gibault type coupler used to connect the PVC pipe to the steel special.



Photograph 3: View of The coated steel special, concrete thrust wall and gibault type coupler (Photo Rob Frizzell WDC)

This leak could have been prevented if an end-load bearing coupler had been used, or preferably, a thrust wall had been constructed when the pipeline was installed.

4.3 THE DN 300 PERAKI STREET WASTEWATER RISING MAIN

For the most part, the DN 300 elastomeric ring jointed PVC pipes withstood the 2010 and 2011 earthquakes with negligible or acceptable joint pull-out. However, one joint disengaged sufficiently to leak (Photograph 2) and the joints along approximately 250 metres of the pipeline were considered to be at risk of pull-out if further earthquakes occurred (ProjectMax report). One particularly section in the vicinity of the Bowling Green was relocated further from the river. These at-risk sections were re-laid with funding from WDC’s insurance.

Had the liquefaction and lateral spreading risks been recognised at the design stage, the susceptible areas could have been avoided, or if that was not possible, PE pipe could have been installed in those areas.

5 CONCLUSIONS

Since the 2010 and 2011 earthquakes there has been a nationwide trend towards designing and specifying PE 100 pipes for most new major pipelines. While this, no doubt, pleases the PE pipe manufacturers and the suppliers of fusion welding equipment and electrofusion fittings, asset owners should consider their risks and chose pipe materials carefully. The installed cost of a PE 100 pipeline can be ≈20% greater than an equivalent pipeline of PVC-U, M or O. Such savings could, arguably, have reduced the Christchurch re-build costs, but that is another story.

A recent example (a 2016 design and build contract) that had been tendered with two pipe alternatives showed that the PE option was $98K more than the $567K PVC alternative). Installation was in road berm areas with no risk of liquefaction.

While this author agrees that a properly designed and installed PE 100 pipeline is likely to provide the most earthquake and ground movement resilient pipeline option, this resilience comes at a cost both in terms of initial capital cost and ongoing inconvenience (e.g. making repairs or new connections) and does not entirely eliminate risk.

With high quality PVC pipe, attention to design detail, and installation in accordance with best practice, PE pipelines are not necessary to achieve satisfactory earthquake resilience for the majority of new pipelines.

By identifying and avoiding potentially liquefiable areas, especially those that are located close to a river, drainage channel or depression where lateral spreading could occur, the risk to any pipeline will be eliminated or, at worst, greatly reduced.

If flexible joints are provided (possibly plus rocker pipes) on branch connections and at other anchored points, the risks of pipe failure can be greatly reduced. This author is aware of "high risk" asbestos cement pipelines in Christchurch City that only failed during the earthquakes because there had been inadequate flexibility between the pipes and bends cast into a concrete thrust block.

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REFERENCES

ProjectMax report Assessment of Earthquake effects on the Peraki Street, Kaiapoi, Wastewater Rising Main, July 2011.

Gerard Cleary WDC - Pers.com. 2016