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Importance of Smart Monitoring Systems for Efficient Vacuum Sewer Performance and Modelling the Network

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***Abstract*— A vacuum sewer system is one of the well-established alternative sewer technologies of modern times. The main objective of this study is to review the performance of vacuum sewer systems in post-earthquake Christchurch and assess the importance of real-time monitoring systems for the efficient and cost effective operation of a vacuum sewer network. The paper concludes that there are operational and cost benefits in installing smart monitoring systems across vacuum sewer networks. Modelling the operation of vacuum sewer systems correctly in a hydraulic modelling platform is important for hydraulic model building and calibration works. Modelling vacuum sewer systems poses a number of challenges such as the correct representation of differential pressure, modelling pressure interface valves, simulation runtime and stakeholders' requirements. This paper highlights the different challenges when modelling vacuum sewer systems and summarises alternative methods that can be applied to model vacuum sewer networks.

***Keywords*—vacuum sewer operation, modelling vacuum sewer, monitoring vacuum sewer, efficient vacuum sewer, vacuum sewer performance.

I. INTRODUCTION

The Canterbury region of New Zealand was significantly damaged due to earthquakes in 2010–2011. The wastewater network of Christchurch faced massive damage, especially in the east of the city. Widespread liquefaction had a huge impact on the gravity network of Christchurch. In many areas, inflow and infiltration had increased significantly and sewage flow to the treatment plant had also increased by around 33% due to the earthquakes.

A vacuum sewer system is one of the well-established alternative sewer technologies of modern days [1]. In Christchurch, vacuum sewer systems have been constructed in different areas of the network where a high level of liquefaction due to the earthquakes caused widespread damage in the previous gravity sewer network. A vacuum sewer system has a wide range of benefits such as a reduced risk of overflows in the downstream network as a result of developments, capital cost savings due to a centralised transfer station, and the reduction of inflow and infiltration [2].

In a vacuum sewer system, a vacuum pump creates a vacuum on the collection tank and then shuts off. Wastewater from each property is transferred by a private gravity lateral to a collection chamber. There is a vacuum interface valve in the chamber. This valve maintains atmospheric pressure in the upstream sewer lateral pipe between the house and the valve, whereas in the network downstream of the valve there is vacuum pressure (typically 50 to 65 kPa) created by the vacuum pump [3,4]. There are vacuum mains which are connected to the chamber that extend the vacuum to the valve pit [4]. Wastewater is sucked out and finally the differential pressure propels wastewater towards the vacuum pump station where all waste from the area is collected and transferred to the treatment plant. Figure 1 shows a typical vacuum sewer system.

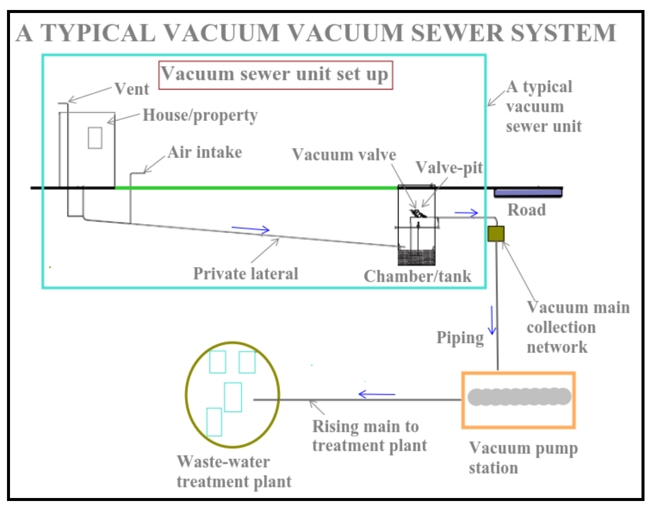

Fig.1: A typical vacuum sewer system

This paper will critically review the performance of vacuum sewer systems in post-earthquake Christchurch and investigate the importance of valve monitoring for the efficient and cost effective maintenance and operation of the vacuum sewer network. The paper will examine how hydraulic modelling tools can be used to model a vacuum sewer network, its limitations and drawbacks.

In this paper, Section I presents introduction. Section II discusses vacuum sewer systems in Christchurch. Section III illustrates the importance of smart monitoring systems for efficient and cost-effective vacuum sewer operations. Section IV discusses different methods to model vacuum sewer technology in a hydraulic modelling platform. Section V concludes the work.

II. VACUUM SEWER IN CHRISTCHURCH

As part of post-earthquake rebuild works in Christchurch, pressure sewer, vacuum sewer and enhanced gravity systems were installed in different parts of the network. As shown in Figure 2, vacuum sewer systems were installed in three earthquake-damaged suburbs: Aranui, Shirley and Prestons.

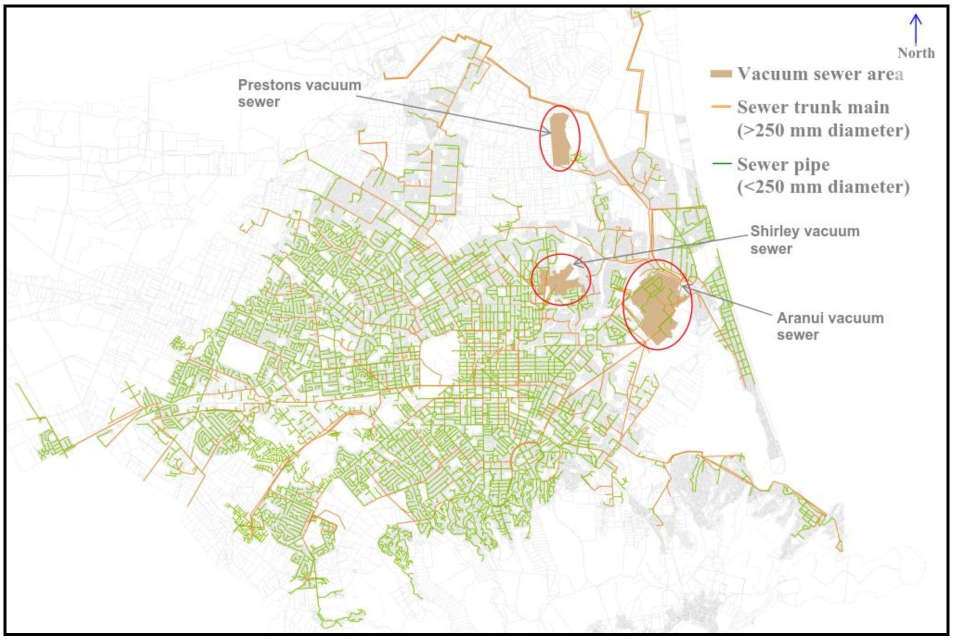

Fig.2: The vacuum sewer systems in Christchurch's wastewater network

Aranui is an eastern suburb of Christchurch whereas Shirley is a north-eastern inner suburb of the city. Prestons is a new development area situated north-east of Christchurch. Christchurch's topography is flat and a vacuum sewer was considered an ideal solution for different areas where the city experienced significant liquefaction. There are 1,085 vacuum chambers, 83 interceptors and 1,317 vacuum valves installed across the Prestons, Aranui and Shirley vacuum sewer areas. Typically, three or four houses are connected to a single vacuum collection chamber [3].

In Christchurch, two types of vacuum systems were installed: Airvac and Flovac. The structure of both systems is similar. In areas of high wastewater discharge – that is, locations where there are schools and commercial establishments – interceptors were installed which can have up to two valves. The vacuum sewer system was designed to provide storage of around 12 hours average flow for each property.

Vacuum sewers across Prestons, Aranui and Shirley were compared and the results are outlined in Table 1.

Table 1. Vacuum sewer in Christchurch suburbs

	Prestons	Aranui	Shirley
Number of chambers	367	794	156
Number of interceptors	-	40	43
Number of valves	367	874	242
Model type	Flovac	Airvac	Flovac
Vacuum pump sites	VS5003	VS5002	VS5001
Assessed load (kW)	211	270	144

The Aranui vacuum system is the largest of the three sites with approximately 794 vacuum chambers and 40 interceptors. Shirley is the smallest out of the three areas with 156 vacuum chamber units and 43 interceptor units. The type of system installed at Shirley and Prestons is Flovac. In Aranui, the vacuum system installed is Airvac. The key difference in an Airvac system when compared to Flovac is that the top chamber is completely isolated from the bottom chamber with no drainage. The vacuum system was designed in accordance with the Water Services Association Vacuum Sewerage Code of Australia, and Christchurch City Council approved addendum with some specific design requirements for large wastewater discharge points [3].

III. Vacuum Sewer Operation and Monitoring

In the Aranui and Shirley vacuum sewer areas there is no monitoring system – that is, no high level or valve monitoring – constructed across any of the chambers that have been installed. The operators and the maintenance contractors use the pressure instrument to identify faulty valves or any other potential problems. It has become a challenge to locate faults as the operations team has to go through a lengthy process to identify the exact problem and solve it. In many cases, the operators have to work for long hours at night to identify the problem.

In Prestons, a monitoring system was installed between vacuum chambers and the vacuum pump station. The data is recorded locally in a central control panel at the vacuum pump station site. The monitoring system has four key components: a valve monitoring device, a high level switch, telemetry in the air vent, and a couple of repeaters located on the light pole.

The energy costs of operating the vacuum sewer system were compared and are shown in Figure 3. A significant difference in energy consumption was found between the systems with the Aranui vacuum sewer having the highest consumption of the three.

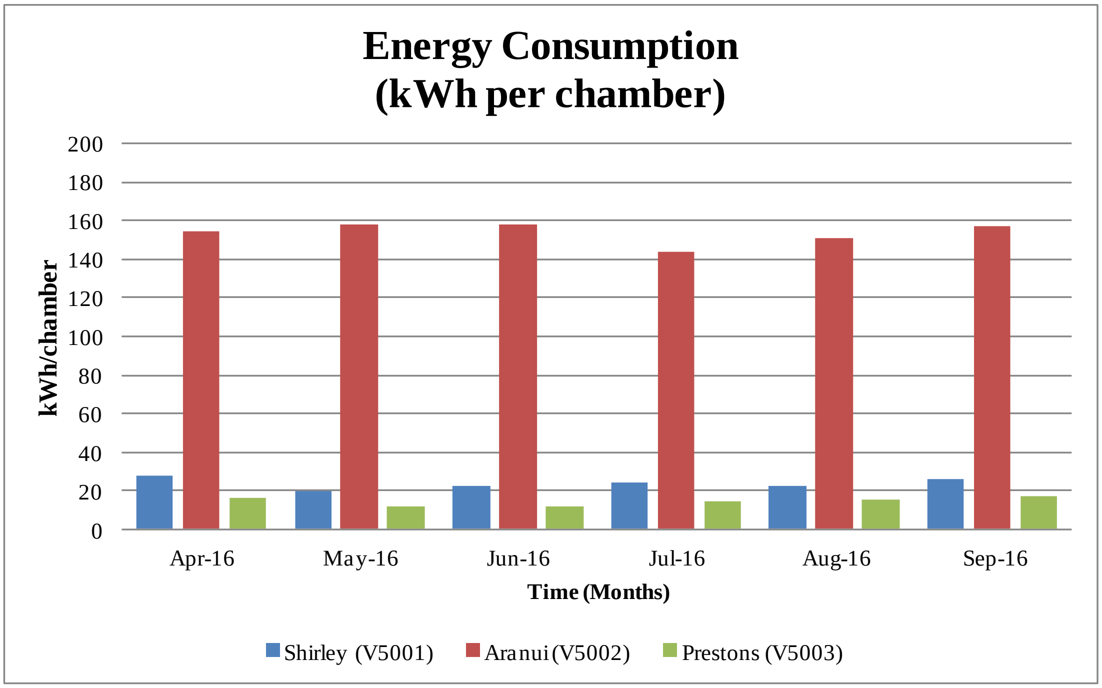

Fig.3: Energy consumption in different vacuum sewer areas

In Aranui, vacuum pumps were identified as operating for long hours causing energy costs to be significantly higher than the other areas. The energy cost for the Shirley vacuum network was also higher than the Prestons vacuum area. All the vacuum sewer systems are in the early stages of their lifespan which suggests that the cost of power for the chambers may increase over time as the efficiency of the valve decreases in the future. It has been observed that there is large variation in energy costs per valve based on the vacuum pump station electricity bill; this suggests that the valve system may not be operating efficiently. The monitoring system in the Prestons vacuum sewer area assisted the operators to identify faults easily in comparison to the Aranui and Shirley areas. It was observed during site visits that, in some cases, the chamber lid did not have a proper seal which meant water collected in the top part of the chamber with no discharge point. This has impacted the operation of vacuum sewer valves. A monitoring system is very important to identify faults and reduce unnecessary energy costs as it helps maintenance contractors to target faulty parts or chambers immediately.

IV. Modelling Vacuum Sewer

Modelling the operation of a vacuum sewer system in Christchurch posed a number of challenges for a hydraulic modeller as the pump station operational pattern was found to vary from one area to another. Two hydraulic modelling platforms (Infoworks ICM and MIKE URBAN) were investigated. Both hydraulic modelling tools have limitations to create the correct differential pressure in the vacuum sewer network to drive wastewater towards the terminal vacuum main pump station site.

A number of alternative methods were investigated for Christchurch's hydraulic model building works since the aforementioned systems were perceived to have limitations, and considering Christchurch's specific operational pattern of vacuum sewer units.

A) Vacuum sewer modelling approach 1

An individual vacuum sewer unit can be modelled using a storage tank or chamber with a small pump station in each chamber and a pressurised pipeline to the terminal vacuum pump station site. Figure 4 shows the modelling approach in diagrammatic form.

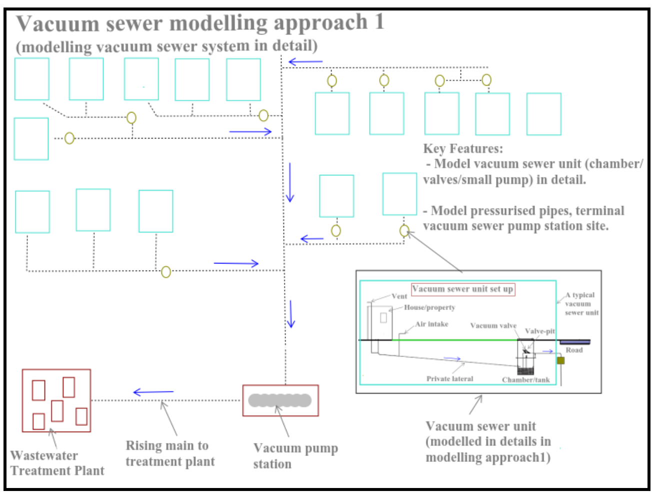

Fig.4: Vacuum sewer modelling: Approach 1

This method helps to model the network in detail but addition of design and operational information created instability in some part of the sewer model. In addition to this, adding a large number of pumps slowed the simulation process significantly. The simulation for Christchurch sewer network had increased by three times due to this detailed modelling approach. Though it is a detailed modelling approach, this approach had not been adopted for Christchurch's sewer model due to its limitations.

B) Vacuum sewer modelling approach 2

Instead of adding vacuum chambers and individual vacuum sewer units, as shown in Figure 5, an appropriate wastewater profile can be added for each vacuum sewer unit.

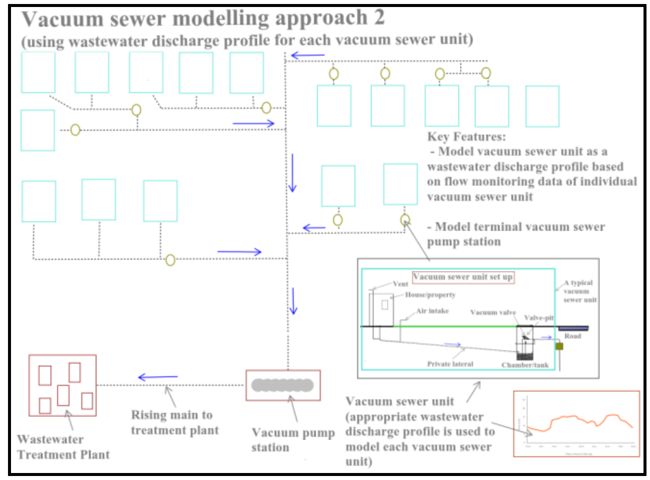

Fig.5: Vacuum sewer modelling: Approach 2

This methodology helps to reduce simulation runtime and the method models the network in sufficient detail without any major model instability issues. A wastewater profile can be created based on control and monitoring data for individual vacuum sewer units. This method is suitable for Prestons vacuum sewer area as each vacuum sewer unit is monitored in Prestons whereas the method cannot be applied to Aranui and Shirley.

C) Vacuum sewer modelling approach 3

If there is no valve monitoring data for individual vacuum sewer units, as shown in Figure 6, a generic flow profile can be added based on the flow data of the terminal vacuum pump station site (V5001, V5002, and V5003). This method is considered the easiest way to model a vacuum sewer system.

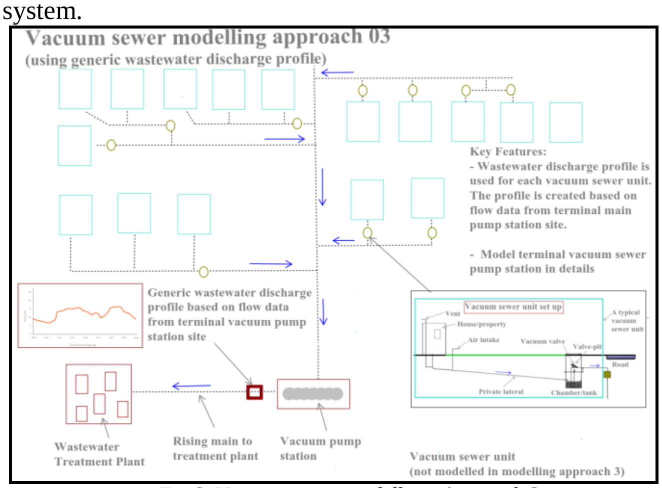

Fig.6: Vacuum sewer modelling: Approach 3

In the Christchurch sewer hydraulic model, wastewater flow profiles were generated for each vacuum sewer unit based on the flow data of terminal pump station site. The wastewater flow profiles were added in each vacuum sewer unit. In some cases, further adjustments were made based on network knowledge and the operational pattern of industrial and commercial sites. This method ensured acceptable model simulation runtimes; further, the network was modelled in appropriate detail acceptable to the stakeholders.

V. CONCLUSIONS

The vacuum system has valve chambers which control the sewer flow to the pump stations. If the operation of these valves is not monitored, it makes it difficult for the operations and maintenance team to troubleshoot faults. In Shirley and Aranui, there is no system in place to record valve behaviour in order to assist the engineers to carry out asset analysis. The monitoring system at Prestons was found to be very useful to find faulty valves easily. The information was also collected and recorded locally in the control panel. In summary, there are operational and cost benefits to installing a monitoring system across a vacuum sewer network.

Modelling vacuum sewer systems in a hydraulic modelling platform poses a number of challenges. A number of alternative methods were identified and investigated as part of this research study. A detailed modelling approach can be taken if the network is simple and model simulation runtime is not very important to the modeller. Alternatively, appropriate wastewater discharge profiles can be added to replicate the operation of vacuum sewer systems.

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Author Profile

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