Vulnerability of Wastewater Treatment Plants and Wastewater Pumping stations to earthquakes

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Abstract

New Zealand is located in an earthquake prone part of the world. Earthquakes are the most common natural hazard in New Zealand with 10000 -15000 earthquakes report annually. Wastewater treatment plants in five earthquake prone areas in New Zealand were selected and their vulnerabilities to earthquakes were assessed. Earthquake vulnerability of 45 wastewater pumping stations in 3 earthquake prone cities in New Zealand has been assessed. The assessment revealed that the non-structural components are the most vulnerable parts in wastewater pumping stations. Structural vulnerability of some wastewater pumping stations is notable and require an immediate rehabilitation plan. The most vulnerable type of wastewater treatment plants in New Zealand are the simple upgraded wastewater treatment plants.

Keywords: earthquakes, vulnerability, wastewater treatment plant, wastewater pumping station
1. Introduction

In New Zealand the population is concentrated in urban areas (Statistic-NZ 2009). One of the public facilities which has a direct impact on communities is wastewater system (WWS). The malfunction of which, rapidly affects a large number of people. Wastewater systems in densely populated areas have been designated as a lifeline deserves particular attention due to their direct impact to community health.

The effect of earthquakes on wastewater systems both directly and indirectly influences human health and environment. Direct effects of earthquakes on wastewater systems are the damages which are caused directly due to ground shaking or ground movement. Direct damage can be defined as the immediate and onsite effect of an earthquake on different parts of a wastewater system (Heubach 2002). For instance, direct damage to treatment plants or wastewater pumping stations can be structural and non structural failures in different parts of the system (Heubach 2002). Indirect damage from an earthquake on wastewater systems can be caused by tsunami flood (Edwards 2005) or change of oceanographic characteristics near the wastewater treatment plant outlet (Morkoc, Tarzan et al. 2007)

2. Earthquake effects on wastewater systems

Earthquake effects on recently upgraded treatment plants during two main earthquakes in US and Taiwan show how the loss of power significantly affects wastewater systems particularly pumping stations (Lund, Cornell et al. 1998; Schiff, Abrahamson et al. 2000). However treatment plants that had been upgraded and constructed with new building codes withstood earthquakes well and only minor damages reported. San Jose wastewater treatment facilities and Watsonville primary wastewater treatment are two examples of earthquake resistant plants in the 1989 Loma Prieta earthquake (Lund, Cornell et al. 1998). No structural damage was reported for the Alvarado wastewater treatment plant, South Bay Side and Scott Valley wastewater treatment plants and Santa Cruz regional wastewater treatment plant (Lund, Cornell et al. 1998). Most of the wastewater treatment plants in the earthquake impacted areas during the 1989 earthquake had been upgraded before the earthquake with new buildings and structural codes (Lund, Cornell et al. 1998).

In the 1999 Chi-Chi earthquake Pali, Min-Shen and Ti-Hwaa wastewater treatment plants in the earthquake impact area operated without any interruption during the earthquake (Schiff, Abrahamson et al. 1999). The four existing wastewater treatment plants in Natou county performed well and just some pipelines inside the treatment plant site suffered damage. Just 8 out of 49 industrial treatment plants suffered minor damage during the 1999 Taiwan’s earthquake (Schiff, Abrahamson et al. 2000). During the 1999 Chi-Chi earthquake no wastewater pumping stations reported damage in the metropolitan Taipei area (Schiff, Abrahamson et al. 2000).

No damage was reported in the Hyperion Wastewater treatment plant in the 1994 Northridge earthquake, some minor cracking in the concrete was reported at the Simi Valley and Moorpark wastewater treatment plants (Schiff 1995). Schiff (1995) showed that the sewer system worked well
during the 1994 Northridge earthquake. Moehle (1995) explained how 54 wastewater pumping stations stopped working due to the commercial power outage, although standby generators and sewer bypass prevented sewage spilling. After the earthquake both Simi valley and Moorpark wastewater treatment plants suffered only minor cracks and continued operating with emergency generators (Moehle 1995).

The August 17, 1999 Marmara earthquake in Turkey is another example in which the wastewater treatment plants did not suffer any damage, although the power outage was the main concern (Scawthorn 2000).

During the 1987 Edgecombe earthquake in NZ, wastewater pumping stations with submersible pumps did not suffer damage (Pender 1987). The wastewater treatment plants in Whakatani and Edgecumbe stood well during the 1987 earthquake (Butcher 1998). The last notable earthquake in New Zealand (Gisborne) in 2007 caused minor damage to mechanical parts in some wastewater pumping stations (Rentoul 2008). The wastewater treatment plant and wastewater pumping stations continued working without major damages in the Ormond earthquake in 1993 (Read and Sritharan 1993).

Edward (2005) revealed that indirect damage from earthquakes can be flood damages created by tsunami waves. For instance, during the 2004 tsunami in Thailand treatment plants and pumping stations flooded and the whole wastewater system failed (Edwards 2005). Another example of an indirect impact of earthquake on wastewater system is the change of oceanographic characteristics near the wastewater treatment plant outlet. The ocean pollution in Izmit bay is an instance of earthquake indirect impact after the 1999 Turkey earthquake (Morkoc, Tarzan et al. 2007). In the 1931 Napier earthquake in New Zealand, the inner harbour floor uplifted and tidal current force decreased. Inadequate tidal current caused accumulation of the sewage solids near the harbour entrance. Consumption of contaminated shellfish caused some outbreak of typhoid after the 1931 Napier earthquake (NCC 2008).

The above case studies show that earthquakes caused minor damages to wastewater treatment plants and wastewater pumping stations. The main problem reported for treatment plants and pumping stations was power outage. In order to demonstrate the vulnerability of wastewater treatment plants and pumping stations to earthquakes in New Zealand, five wastewater treatment plants including 45 wastewater pumping stations were taken into account.

3. New Zealand treatment plants and earthquake vulnerability

Each city in New Zealand with a population greater than 30000 has at least one wastewater treatment plant, for instance Gisborn, Blenheim and Hutt City. Various types of wastewater treatment processes are used to treat collected wastewater. Wastewater treatment plants (WWTP) in New Zealand vary from simple treatment plants (Gisborne WWTP) to the most complicated treatment plants (Wellington and Auckland WWTP). According to this study WWTPs were classified into three main groups; advanced technology wastewater treatment plants (Wellington, Auckland and Hutt City), simple mille screening WWTP (Gisborne) and simple mille screening with ponds WWTP (Blenheim).
The oldest and largest WWTP in New Zealand is the Mangere WWTP in Auckland, which was established in 1972. The Mangere WWTP has been upgraded several times, the latest upgrading being done in 2003 (Watercare services limited 2008). The Wellington WWTP was built in 1998 and Hutt City WWTP was commissioned in 2001 (Capacity-Co. 2004). Blenheim treatment plant upgrading is under construction, whereas construction of Gisborne's treatment plant will be started in the near future (Gisborne-District-Council 2009). This study shows the major WWTPs in New Zealand were built recently and comply with the updated earthquake building codes.

Some regions' wastewater still relies on simple systems that filter and discharge the wastewater to nature, the sea or a stream. Gisborne’s wastewater millie-filtering station is an example of simple WWTP that only filters collected wastewater and releases it to the harbour (Zare 2008), although the design of a new treatment plant is in progress. The Napier wastewater treatment plant is another example of simple wastewater treatment plant (WWTP), which entails millie screening of the collected wastewater and pumping to Hawke Bay via 1600 metre of outfall marine pipeline (Christchurch City Council 2008).

Wastewater treatment plants located in main cities in New Zealand usually include similar apparatus. Common features in the NZ's WWTPs include pumping stations, sedimentation tanks, reactors, clarifiers, micro-filtration units, ultra violet disinfection parts, storage buildings, labs, administration buildings, discharge pipelines and outlet point. Simple WWTPs are located in small cities and usually comprise simple filtration units and pumping stations. Different sources of wastewater in various cities lead to a variety of treatment processes, although normally treatment plants have the same main components with different capacities and layout. WWTPs in the earthquake prone areas are expected to withstand particular earthquakes and consequently, each part of the WWTP should resist earthquake forces. Each WWTP is a combination of various types of building and apparatus, which should operate simultaneously. If the administrative buildings and their facilities suffer an earthquake and are not to be used, the whole system will be affected. For instance, water system recovery was delayed in the 1985 Mexico City, 1991 Philippines, 1995 Kobe and 2001 Nisqually earthquakes because of the administrative building damage in the earthquakes (Heubach 2002). Each part of the treatment plant has the particular vulnerability and each part can be affected by an earthquake in different ways (Heubach 2002). For instance, Seiche should be considered in the sedimentation tanks and clarifier, all mechanical equipment housed in them should be designed to tolerate the wave effect caused by earthquakes (Heubach 2002). Clarifier structures usually are resistant to ground shaking or ground movement but sloshing can damage them, for instance sloshing damaged clarifiers in the 1989 Loma Prieta Earthquake (Heubach 2002).

Structural design codes for WWTP should conform with nationally recognized codes (Vesilind 2003). The local earthquake codes should be up to date with new design criteria and earthquake codes should cover all buildings and structures. In New Zealand most of the treatment plants have been renewed or constructed recently with new earthquake design codes.

WWTP vulnerability in NZ can be divided into vulnerability of recently upgraded or constructed modern treatment plants located in populated regions and the vulnerability of simple treatment plants in small cities. Power outage is the most notable susceptibility in the both types of wastewater
treatment plants. All visited wastewater treatment plants have a power generator in the case of an emergency outage, although in large scale earthquakes these would not be able to produce sufficient power to run all systems during the power recovery period. Power shortage could be a great concern in modern wastewater treatment plants in New Zealand. High demand for electricity in different sections of WWTPs particularly in UV disinfection units makes WWTPs in populated regions more vulnerable to a power outage in contrast with other smaller wastewater treatment plants. Power outage is the most significant vulnerability in NZ’s large cities WWTPs. Enormous amounts of untreated or partially treated wastewater can be discharged to nature due to a power outage. Environment pollution is the most probable consequence of continuous power shortage in WWTPs in New Zealand. NZ’s WWTP’s in comparison with the wastewater pumping stations and wastewater pipelines have the lowest vulnerability to earthquakes.

Earthquake vulnerability of simple WWTPs in New Zealand is equal to that of wastewater pumping stations. Screening units in simple WWTP’s were installed during the last two decades with new building codes and earthquake forces were taken into account in their design. The main issue in the simple treatment plants in New Zealand is the vulnerability of wastewater pumping stations.

4. Wastewater pumping stations vulnerability to earthquakes

Wastewater systems are designed to transmit wastewater by gravity force, as the most reliable and economical way of conveying fluids. Economical issues and technical difficulties are the main barriers to using gravity force. Burying pipe to gravity flow cost more than construct a wastewater pumping stations in terms of technical and environmental effects, especially in some soft soils. Due to these barriers, pumping stations are one of the main parts of each wastewater system, particularly in the wastewater reticulation systems. Pumping stations also are one of the main parts in the treatment plant and treated wastewater discharge stations. The main function of pumping stations in sewage reticulation is transmitting sewage to the upper level to carry by gravity. In some cases wastewater or treated wastewater is completely carried under pressure, which is powered by one or several pumping stations. The 18km pressure pipe in the Hutt City wastewater system is a good instance of the pressure system, which carries treated wastewater to the discharge point in Wellington harbour (Capacity-Co. 2008).

5. Wastewater pumping stations in New Zealand

Three earthquake-prone cities in New Zealand were selected to investigate their WWPSs vulnerability to earthquakes. Approximately, half of the wastewater pumping stations (WWPS) were visited and inspected in each city. WWPSs' vulnerability to earthquakes in each city was classified and investigated. Gisborne and Hutt City in the North Island and Blenheim in the South Island are three earthquake-prone regions, which were selected to investigate their WWPSs vulnerability. The following observations are the result of the site visiting, technical interviewing and data analysing which were done in 2008 by the author.
New Zealand's wastewater pumping stations are classified into two main groups: drywell WWPTs and wet-well WWPSs. Pumps in dry well WWPTs are located in the separate underground structures, whereas in wet-well WWPSs submersible pumps are installed inside the reservoir. Usually wastewater pumping stations which were built before 1966 are drywell pumping stations. For instance, all 8 wastewater pumping stations built before 1966 are dry-well WWPSs in Gisborne (Gisborne District Council 2008). WWPSs earthquake vulnerability was divided into two main groups: structural vulnerability and non structural vulnerability. To evaluate WWPSs structural vulnerability, WWPSs were split into two main sets, WWPSs with above ground building and WWPSs without above ground building.

Buildings of WWPSs mounted on top of the underground structures (usually in dry-well WWPSs) house all electronic equipment including control boards, telecommunication and data transferring devices. The WWPS building also is the access point to the dry well for maintenance. During the cities' development remote controlling and telecommunication devices were installed in WWPSs and mounted on the building walls. All relevant data requires for WWPSs monitoring including wastewater level, working hours of each pump, discharge rate and security signal continuously records and transfers to control room. SCADA according to collected data controls the whole wastewater system. Failure of any installed instrument inside the building makes the WWPS useless and failure of each WWPS directly affects whole wastewater reticulation system. In addition to this, the WWPS’s building is the access point to the underground structure which includes pumps, valves and piping. The building collapse not only affects whole systems function but also hinders a repair process of affected WWPSs. Building vulnerability in the wastewater pumping stations was taken into account as a main susceptible factor.

Various parameters were taken into consideration to demonstrate earthquake vulnerability of WWPSs’ building. Building characteristics (such as age, type) include geological and geotechnical characteristics (such as soil type, liquefaction susceptibility) were applied to reveal the WWPSs’ building vulnerability to earthquakes (See (Building Act 2004 ; Standards New Zealand 2004; NZSEE 2006). The latest earthquake vulnerability assessment of buildings in NZ has been applied to accurate initial assessment(NZSEE 2006). Building age is one of the main factors, which shows a building vulnerability to an earthquake (NZSEE 2006). Various building codes have been developed in New Zealand to satisfy required standards during the urban area development. The first building code was established in 1935 and renewed several times to decrease its deficiencies (Beattie and Thurston 2006). Beattie showed the first earthquake building code with sound engineering approach was established in 1976. Consequently, buildings built prior 1976 may have vulnerability to earthquakes.

Figure 3 illustrates WWPSs age among three earthquake-prone cities (Hutt City, Gisborne and Blenheim). As figure 3 shows the oldest WWPSs belong to Blenheim wastewater system, although the percentage of the new WWPSs also belongs to Blenheim. This shows the development of Blenheim city and replacing of aged WWPS’s. About 60% of Hutt City wastewater pumping stations were built during 1935 and 1976, followed by 40% of Gisborne WWPSs. Finally, it should be summarized that in three selected cities in New Zealand more than 40% of all wastewater pumping stations were built before 1976, which means at least 40% of wastewater pumping stations buildings should be accurately evaluated for earthquake vulnerability.
Another factor which affects earthquake vulnerability of building is material types used in building. For instance, masonry buildings are the most common building types in WWPSs although, some concrete buildings are also available in NZ's WWPSs. Roofs in the WWPSs' buildings usually are concrete slab, wood frame with ceramic tiles or steel frames with steel sheets on the top. The WWPSs' building height varies between 2 and 2.50 meters except main WWPSs. Another factor which affects vulnerability of wastewater pumping station buildings is the irregularity in the building plans. Most WWPSs' buildings in this study have the almost regular plans (rectangular plan) but with different plan types. For Instance, Gisborne's WWPSs have different types of the plans compared with Blenheim and Hutt City WWPSs. Circular and hexagonal plans are common in the Gisborne's wastewater reticulation. The WWPSs' building except some trunk WWPSs in Hutt City and main WWPSs in two other cities have small area and building area in common WWPSs varies between 6 to 25 square meters. WWPSs in Gisborne and Hutt City have greater building area compared with Blenheim WWPSs. Recent field studies by the author showed that superficial physical condition of all assessed WWPSs were fine and no sign of deterioration or crack on above ground structures was visually detectable. However, concrete deterioration in the wet well structures was seen in some WWPSs. Detailed tests and analysis should be done to show accurately the vulnerability of building structures.

Wastewater pumping stations' wells in New Zealand are usually made by precast concrete or cast in place concrete. However, in some cases the reservoir well is made by fibreglass tank. Early wastewater pumping stations were made by in place concrete. Concrete well deterioration was not obvious in the majority of cases at least above the reservoir water level. Further structural evaluation accompanied with some material tests are required to accurately evaluate underground ground structure vulnerability to ground shaking.

Figure 3: Date of construction in three cities' wastewater pumping stations
6. Initial assessment of Hutt City WWPS

Initial assessment procedure recommended by NZSEE (2006) was applied to disclose the Hutt City WWPSs' building vulnerability to earthquakes. NZSEE (2006) recommends if calculated percentage of the New Building Standard (NBS) for each particular building be less than two thirds of the NBS then the building is vulnerable to earthquakes. Although the NZ Building Act (2004) declares if calculated %NBS be less than one third of the new building standard then the building is an earthquake prone building.

Geological characteristics of each WWPS in Hutt City including soil types were extracted from the Dellow and Dissen 1992 (Dellow 1992) and (Van Dissen 1992)). The Hutt City WWPSs GIS data base was applied to find location and age of each WWPS in the Hutt City wastewater system. Liquefaction vulnerability map of Hutt City was applied to modify calculated %NBS for the initial assessment (MWH 2005).

WWPSs structure assessment by the author revealed that WWPSs which were built during 1960-1964 are the most earthquake vulnerable WWPSs in the Hutt City wastewater system. All the WWPSs which were constructed between 1960-1964 are vulnerable to earthquakes by NZSEE (2006) and just one of them satisfies building act code 2004. All WWPSs were built before 1960 meet the NZ building act (2004) except one, although none of them satisfy NZSEE (2006). Construction of the WWPSs on the liquefiable soil during 1960-1964 is the main factor affected vulnerability of WWPSs in this period. Considering NZSEE (2006), 35 % of whole WWPSs in Hutt City should be rehabilitated structurally, while 15 % of whole WWPSs in Hutt City should be strengthened for earthquake according to building act (2004). This shows significant differences even between two NZ standards' references, which may deserve investment. Considering WWPSs as the necessary buildings may issue a great concern for any specific region. Consequently, the NZSEE 2006 recommendation seems more reliable and appropriate.

7. Non structural vulnerability of WWPS

Non structural vulnerability in the NZ's WWPSs was categorized into two main types including, vulnerability of electrical and electronic equipment and mechanical component vulnerability. Regional and common WWPSs transmit collected wastewater of each region to main collectors or trunks pipeline. These pumping stations usually house two pumps, two check valves, two control valves, flow-meter, pipes and fitting, control panels, data transmitting and telecommunication instruments. Alongside the mechanical and electrical instruments, each pumping station consists of a reservoir to collect and pump wastewater to the designated point. Under-ground structures in pumping stations usually consist of two wells (dry and wet wells) or one wet well. Wastewater discharges to the wet well and pumps to the designated point. Dry well in dry-well WWPSs houses fixed pumps, valves, pipes, fitting and access point. In the new pumping stations which usually are wet-well WWPSs, there is no dry well. Consequently, pumps and piping directly are installed in the wet well. Fixed pumps in dry-well WWPSs replace with submersible pumps in wet-well WWPSs and are directly installed in the wet-well.
Vulnerability of the electrical and electronic equipment in WWPSs should be taken into account as the monitoring and controlling devices, which control the system. This type of vulnerability is divided into two main groups of WWPSs: WWPSs with building and WWPSs without building. Wet-well WWPSs which electrical and electronic equipment is installed in the control panel outside the WWPSs' buildings are much less vulnerable to earthquakes compared with dry-well WWPSs. Wet-well WWPSs house all electrical and electronic equipment in a steel box mounted on the concrete pad near the underground structure, whereas electrical and electronics panels in dry-well WWPSs are simply mounted on the building walls without adequate fixing supporters. WWPSs with building cover about half of the WWPSs in all three cities and inadequate fixing of electrical and electronic equipments is the similarity in all of them. Even if building walls be able to stand earthquake shaking, toppling and falling of inadequately mounted equipment could cause whole failure in WWPSs during a strong earthquake.

Mechanical equipment, including pumps, piping and fitting are the main parts in each WWPS and their vulnerability can instantly affect whole system function. Earthquake vulnerability in mechanical parts is divided to the pumps' vulnerability and the piping system vulnerability. Ground shaking effect of an earthquake can be controlled by vibration isolators in fixed pumps, which they did not be installed in all visited WWPSs in the three case studies. Submersible pumps tolerate the earthquake effects better than fixed pumps and submersible pumps are less vulnerable in earthquakes (Heubach 2002; Rentoul 2008). Check and control valves, particularly heavy ones should be fixed properly to the basement of the underground structures in WWPSs. Steel strips and proper stands should be applied to fix valves and pipes in pumping stations. According to site visiting of more than 45 wastewater pumping stations in New Zealand, except two main pumping stations had not proper fixing strips the mechanical parts. Almost all WWPSs built after 1995 are wet-well WWPSs, consequently they do not have structural vulnerability and non structural components are expected to stand earthquakes. According to the earthquake effects in wastewater systems in the previous earthquake scenarios, recently constructed WWPSs even those built as a dry-well WWPS should stand well during an earthquake.

Joints and fitting are usually the most vulnerable parts in the WWPSs’ piping system which even in moderate earthquake can be affected. For instance, the only problem reported in the WWPSs after the 2007 Gisborne earthquake was joints' leakages in a few WWPSs. Joints should tolerate shaking and displacement caused by earthquakes. In earthquake prone areas usually flexible joints installed to connect fittings, valves and pumps to pipes in order to tolerate shaking and displacement caused by earthquakes. Observations of WWPSs and some potable water pumping stations in the three earthquake prone cities in New Zealand revealed fixed joints are the predominant type of joints. Only in 2 main WWPSs flexible joints were used to cope with longitudinal pipe movement. This type of joint facilitates installation and maintenance.

Existence of deteriorated and fragile pipes in the under-ground structures of WWPSs is another sort of vulnerability, which resulted in less strength in earthquakes. Flowmeters have been installed in some WWPSs to monitoring wastewater flow. Consequently, the old piping system has been renewed with the new ones. The most popular pipe type, especially in the WWPSs built before 1995 is the cast iron pipe which compared with new pipe types is much more brittle and sensitive to shaking.
8. Conclusion

Wastewater treatment plants in the populated cities in New Zealand by themselves are not vulnerable to earthquakes. Power outage after major earthquakes is the most significant vulnerability in the updated wastewater treatment plants. For instance, UV disinfection units require high demand of power, which will not be satisfied by an emergency power generator, on the other hand, the treatment plants' power generators are not able to supply power for a long recovery period. Power shortage directly impacts on the whole treatment process and decreases the quality of treated wastewater. Earthquake vulnerability of the simple wastewater treatment plants is relevant to the WWPS vulnerability, which is located beside the treatment unit (usually filtration unit).

WWPSs' earthquake vulnerability in New Zealand has the direct correlation with the structural and non-structural vulnerabilities. Non structural earthquake vulnerability is one of the predominant hazards in major earthquakes, especially in mechanical parts (piping and joints), electronic and electrical boards in dry-well wastewater pumping stations. Earthquake vulnerability of WWPSs’ buildings, particularly those were built before 1976 is also prominent. Similar to wastewater treatment plants, most of the WWPSs also can severely be affected by a power outage, due to lack of the power generators.

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