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Seismic Vulnerability of the Water System in Mexico City

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Abstract. Cities must provide services and resources in optimal conditions for their inhabitants to live in harmony. The primal ones are the lifelines systems that furnish services such as water, energy, transportation, etc. If the territory is heavy populated these systems are composed by complex networks that comprise extended distances hence making them more vulnerable to many different kind of risks, particularly the natural ones. The water system is one of the most fundamental lifelines and it is often subjected to natural hazards, especially flooding and earthquakes. Mexico City, being one of the most populated cities in the world requires a colossal water network that is often subjected to seismic forces. Moreover, the complex soil conditions in the basin and the problem of regional subsidence, make the system more vulnerable. This paper presents a brief background of the water system in the city and its damage during the 1985 Michoacan Earthquake and the 2017 Puebla-Morelos Earthquake. It also compiles the measures taken after these earthquakes to restore the system. The extent of damage and the geotechnical conditions are described. The fundamental of seismic vulnerability and some countermeasures that can be implemented to turn the Mexico City water network into a more resilient system are discussed, as well the challenges that large urban water supply systems have to deal to overcome their vulnerability to seismic hazards and increase its resilience.

Keywords. Water system, earthquakes, resilience, vulnerability, hazards.

1. Introduction

Natural hazards, such as earthquakes, hurricanes, or floods, cause significant disruptions in urban environments that go beyond casualties and impairments to the infrastructure. Damage in lifelines decreases the ability of cities to recover, the quality of the affected people and delays the return to economic activities causing more loss. To avoid this scenario, lifelines should not only keep working but have a performance similar to the pre-disaster conditions; one of them is the water distribution system, which is required to carry out daily activities and is also useful to prevent other hazards triggered by the primal one, such as fires. As a large part of the water system is buried and widespread over the city, this system is more vulnerable to ground movement and therefore it is required to be resilient. The resilience of a system has four different dimensions, as defined by Bruneau et al. [1]: 1) robustness, the ability to sustain

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damage during a disruptive event; 2) rapidity, the rate of recovery; 3) redundancy, the capacity of the system elements to be substitutable; 4) resourcefulness, the ability to identify problems, establish priorities and assign resources for recovery. Considering these dimensions, the seismic resilience of a water system depends on the responsible organizations being able to manage the network and take actions to prevent and mitigate the damage; the users, being able to adjust to the reduced supply in case of disruptions; and finally, it also depends on the technical and economic resources available to make the system seismic resistant.

The water system of Mexico City comprises more than 26,000 km of pipes and 2,150 facilities forming a gigantic network that serves more than 20 millions of people and is laid over very compressible soils that also experience sinking in some areas. It has been affected by several earthquakes over the last century, being some of the greatest the 1985 Michoacan Earthquake and the 2017 Puebla-Morelos Earthquake.

In this paper, the authors provide a framework of the current state of the Mexico City water supply system and its vulnerability under ground motion hazards. First, the water system is described, followed by the system damage after the 1985 and 2017 earthquakes, and the emergency response of authorities in both cases. Finally, the paper presents the challenges an extensive water system has to deal with, and the countermeasures that can be implemented to reduce vulnerability and became more resilient.

2. Mexico City water supply system

In view that Mexico City and its metropolitan area have a population over 27 million that grows every year, water collection is a serious problem. The Valley of Mexico receives a daily flow rate of 77 m^3/s, out of which: 71% is extracted from subsurface strata, 21% from the Cutzamala system, 6% from the Lerma system and 2% is obtained from springs and surface runoff. About 13 m^3/s are used for irrigation, 9 m^3/s are used for industrial purposes, municipal services and shops; and the remaining flow is distributed through a pipeline network, barely fulfilling the water endowment recommended by the Pan American Health Organization, as a result of leaks in the pipeline network rated about 24.6 m^3/s [2].

The recharge of the aquifer is made through infiltration from Sierra de las Cruces (western area) and Sierra del Chichinautzin (southern area). The extraction of underground water is turning into a problem considering that water recharge in the aquifer is slower than the pumping flow, which causes regional subsidence and leads to several problems in buildings foundations and other civil works just like the buried waterworks, including sewerage system. However, still 44% of the supply comes from water wells.

The distribution network is composed of 1,343 km of primary pipeline network; the diameters range of these pipes is from 0.5 m to 1.83 m, on the other hand, secondary pipeline network comprised 12,128 km of pipelines with lower diameters than 0.5 m, besides the system has 243 storage tanks. The outer area in the city counts with 348 km of primary pipeline network [3]. There are 976 wells, 69 springs, 267 pumping plants with capacity of 5,466 m^3/s and 51 treatment plants with capacity of 4,422 l/s. There are 731,420 km of aqueducts and transmission lines [4].

The main elements of the network are displayed in Figure 1 along with the sources from the north and southwest areas [4].

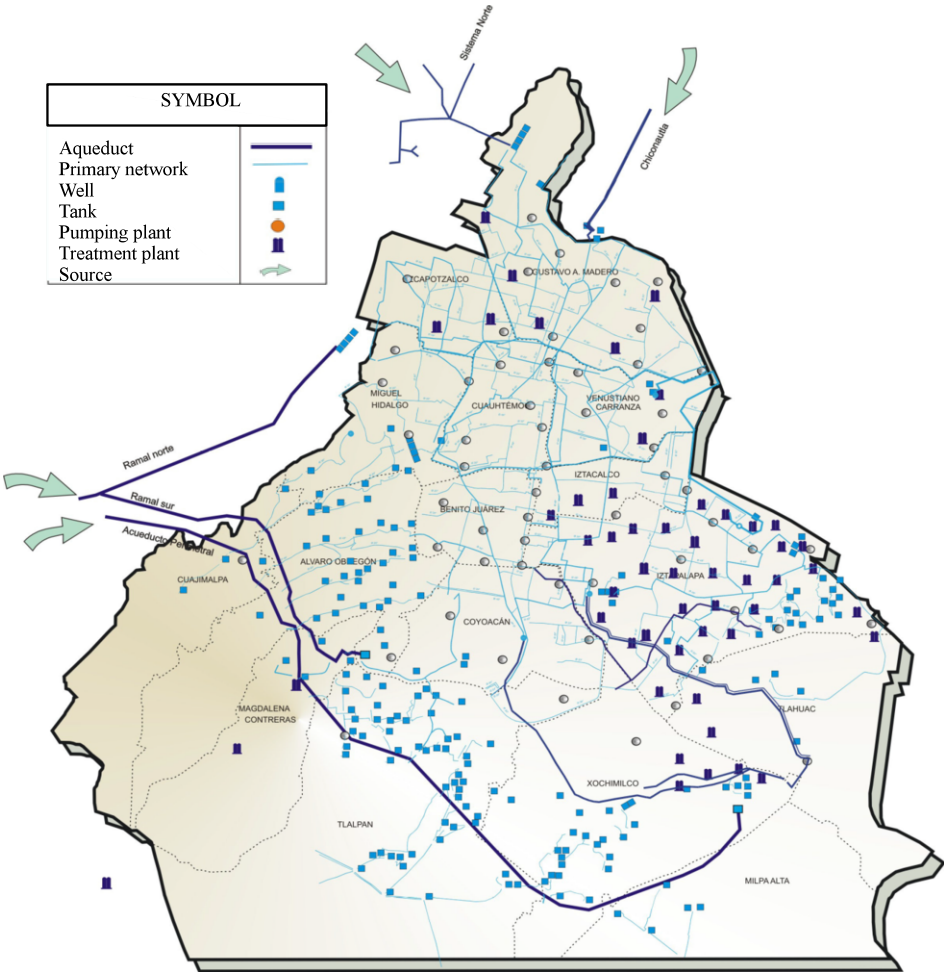

Figure 1. Water system in Mexico City [4].

3. 1985 Michoacan Earthquake

A M_w 8.1 subduction earthquake impacted the pacific coast of Mexico on September 19, 1985. The earthquake, being one of the largest in Mexico City, caused damage of three to four billion dollars and at least 5,000 casualties. The water supply system and other lifelines systems of Mexico City were also severely damaged during the earthquake. The aftermath of the earthquake left about 5.3 millions of people without water service, as a result of disruptions in transmission and distribution lines. Surprisingly, storage facilities, reservoirs and purification plants were undamaged and only few wells were affected. The southeastern aqueducts of the supply system were affected leading to a temporally cease of the regular 7.6 m/s flow being distributed.

The Mexican authorities had an emergency response plan in case of breakdown of the water supply system but the implementation was delayed because of complete destruction of the city central headquarters building. Nonetheless, the emergency

response plan was carried out relatively fast. A damage assessment was performed by Mexican authorities to identify which areas in the city were left without water service [5]. Some of the neighborhoods with water outages are listed in Table 1 and mapped in Figure 2, where it can be noticed that there are more neighborhoods without water in the northern and eastern zones of the city due to the failures in many aqueducts in the area.

The actions that authorities implemented were [5]:

1. Send water tank trucks: authorities sent these trucks and also portable tanks provided by the U.S. government to many zones with lack of water in order to prevent health public issues and panic among the people.
2. Repair the damaged hydraulic infrastructure: meanwhile water was being supplying by trucks the city water council was focused on repairing vital lines of the network, in this case, the southeastern aqueducts. By the end of October, the flow in those aqueducts were about 7.1 m^3/s. Flow had been practically restored, nonetheless repairs on local water networks took some more months.

Most of the repairs in the pipelines were related to problems in the joints of the pipes, fortunately the spare parts needed to repair the network were fabricated in the city so there were no logistic problems.

Table 1. Neighborhoods without water from different areas.

Benito Juarez	Xochimilco	Tlahuac	Iztapalapa	Cuauhtemoc
Narvarte	Sta. Cruz Acalpixca	Selene	Col. Iztapalapa	Centro
Alamos	U. Villa Xochimilco	Sta. Cecilia	Zona U. Ejidal	Algarin
	San Gregorio	Ampl. Selene	Juan Escutia	Asturias
		Sta. Catarina	Tepalcates	Morelos
		San Jose	Ejidos del Moral	DOctores
		Del Mar	Voceadores	Roma Norte
		Tlaltenco	Francis Villa	Roma Sur
		Sur Tlaltenco	Voceadores	Obrera
		Ojo de Agua	La Pena Sta. Cruz	Paulino Navarro
		Triangulo		Lagunilla

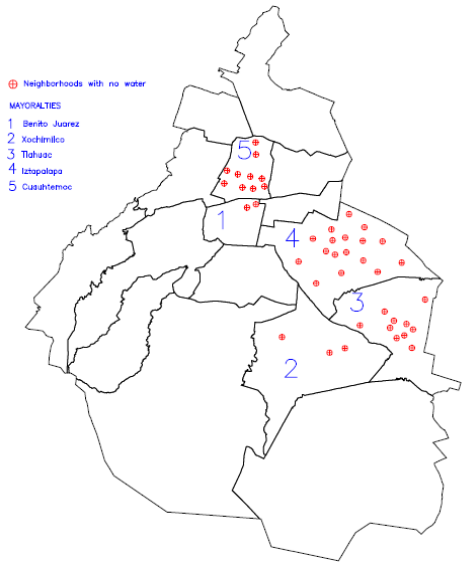

Figure 2. Location of some neighborhoods with no water in different mayoralties of the city.

4. 2017 Puebla-Morelos Earthquake

After the 1985 Michoacan Earthquake, authorities and stakeholders were concerned with modification on the building code to avoid similar situations in the future; nevertheless, regulations on buried pipelines were not meaningful concerning the seismic response.

The 2017 Puebla-Morelos Earthquake showed the vulnerability of some structures and systems in Mexico City (e.g., [6–8]). Even though seismic characteristics in the 1985 and 2017 events were not similar, several buildings collapsed, and failures in lifelines were also reported.

The water service was interrupted leaving 3.3 millions of people without water in Mexico City, and roughly six million in the adjoining states of Puebla and Morelos. In Mexico City, 2696 leakages in the distribution network were reported, affecting mostly the eastern area, in the zones of Iztapalapa and Tlahuac (Figure 3), that also regularly experience cracks, sinkholes and subsidence. Wells, storage and pumping facilities were affected and large-diameter pipes had more failures among pipelines [9].

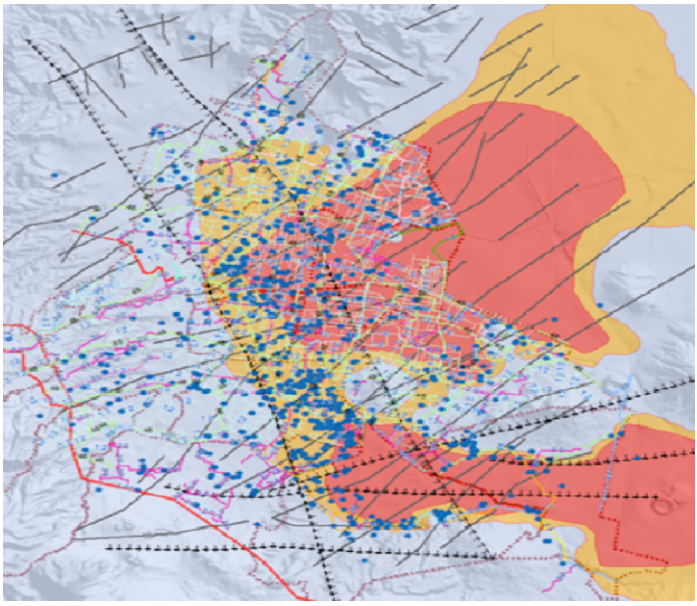

Figure 3. Blue points represent failure points in the city [10].

After the installment of the Emergency Committee and dispatch of Civil Protection, firefighters and Public Security, the actions towards restoration started. The Water System of Mexico City (SACMEX) in collaboration with the National Water Commission (CONAGUA) carried out restoration activities. Water tank trucks were sent to Tlalpan, Xochimilco, Tlahuac, Iztapalapa. About 18 million cubic meters were delivered in different parts of the city as well as 2,620,000 liters were delivered in other counties (La Paz and Nezahualcoyotl) that belong to the State of Mexico.

In Tlahuac, located in the southeastern area, the Health Ministry of Mexico City (Sedesa) carried out 45 field visits in the Tempiluli neighborhood in which they noticed several waterlogging on the streets, presence of harmful fauna and rankness, as well as

settlements and seepage, strong signals of breakages and leakages in the sewer pipelines. They carried out the following countermeasures [11]:

1. Give jars of colloidal silver to the residents.
2. Deliver of calcium hypochlorite pills: chlorination of different water storage (water tank trucks, local cisterns, head pressure tanks).
3. Repair of 17 wells.

Service reconnection, considering leaks repair, took around 100 days, including leaks that were reported days after the earthquake (Figure 4). The performance of the network was reduced to 70% immediately after the earthquake and then restored to a 0.25% per day rate [9]. This exhibits a robust service with a relatively fair speed of recovery.

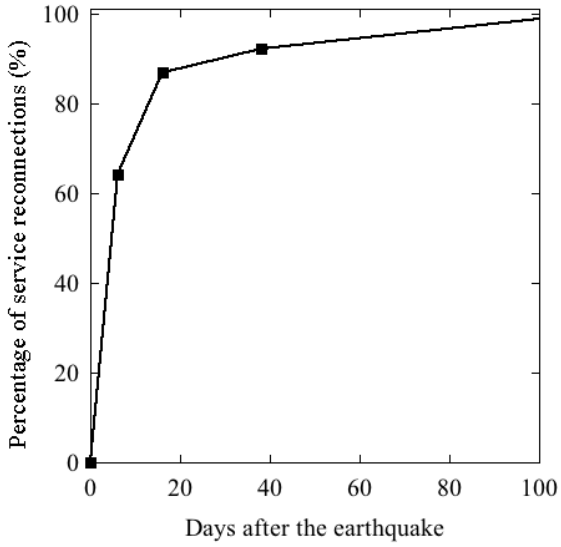

Figure 4. Service reconnection after the earthquake.

5. Observations and recommendations

The infrastructure of Mexico City is 55 years old in average, including asbestos-cement, steel and PVC pipelines, therefore most of the planning of SACMEX is directed to partial rehabilitation of the infrastructure. Authorities in charge of water distribution must consider the construction and design quality not only in water systems, but also in the city infrastructure as a whole.

Some of the strategies and information necessary to increase the resilience based on technology, social, economic and organization levels are:

1. Updated maps of distribution and transmission lines of the network, including depth of buried pipes, materials and age.
2. Emergency plans based on a decision-support system that includes data from previous earthquakes that also consider changes in demand in different earthquake scenarios.
3. Updated risk maps including the recently published map of cracks in Mexico City [12].

4. Development of fragility curves for the specific conditions of Mexico City
5. Social campaigns to educate the community regarding water consumption in emergency conditions

As part of the recommendations, it is necessary to modify current regulations focused on seismic performance of the water network system, as many countries with important seismic sources have done such as New Zealand, Japan and U.S. Insurance of hydraulic infrastructure can also encourage well-construction procedures to be followed rigorously to prevent faults to the insurance clauses contract [13].

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