TITLE: **Northridge Earthquake: A Review of the Performance of Various Water Main and Service Line Materials**

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Northridge Earthquake: A Review of the Performance of Various Water Main and Service Line Materials

Keith A. Abercrombie

ABSTRACT

The 1994 Northridge Earthquake was a 6.7 magnitude event with an epicenter located approximately 10 miles south of the Valencia Water Company. At that time, Valencia Water Company served a population of 70,000 customers through 23,000 connections and its distribution system was comprised of 270 miles of AC, PVC, ductile iron and steel water main pipe materials with copper, PVC and HDPE services.

The Northridge earthquake was a blind thrust fault that caused significant damage to buried infrastructure. Prior to this event this type of earthquake was not deemed to be much of a threat.

The Northridge earthquake dewatered the Valencia water system in 30 minutes from 3 tank failures and hundreds of water main and service line breaks. This paper will review the performance of the various pipe materials during the earthquake as well as with the hundreds of aftershocks. Repair activities and construction challenges required to reinstate the water system as well as lessons learned which have been incorporated since the event will be presented. Valencia's emergency response and the methods of mitigation with these main and service failures on different materials will be reviewed. A comparison of various materials' performance and the operational considerations / pipe repair methods that were encountered have provided insights for future mitigation of risks in current pipe and service material decisions.

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VALENCIA WATER COMPANY

Valencia Water Company (Valencia) is a privately owned, public utility, regulated by the California Public Utilities Commission. Valencia was established in 1965 and currently has over 30,411 customer connections which serve a population of approximately 120,000, located in northern Los Angeles County along Interstate 5. If you're traveling south on I-5 you'll see a sign for the Magic Mountain Amusement Park, which will place you within Valencia's service area which encompasses over 30 square miles. Valencia, like much of southern California, has experienced relatively little growth over the past 5 years, but prior to that we were adding 1-2000 connections per year during the late 1990s to mid 2000s. Though Valencia was formed in 1965, its system is fairly new as demonstrated by our customer growth. For instance, in 1980 we had only 5000 connections. We have grown now to over 30,000. We provide potable water service to a mixed customer class consisting of residential, multi-family, public authority, commercial and industrial users. Our potable water comes from a combination of groundwater and purchased water. Groundwater is supplied by 21 company owned wells and purchased State Water Project water is received through 7 turnouts from our wholesaler, the Castaic Lake Water Agency. We typically provide our customers a 50/50 blend of groundwater and purchased water. Valencia's wells pump from two aquifers, the shallow Alluvium with well depths up to 200', and the deeper Saugus Formation with well depths up to 2100'. Valencia's annual production is approximately 30,000 acre-feet/year (9.7 Billion Gallons) and ranges from minimum daily production of 27.6 acre-feet (9.0MG) during winter months to 140.3 acre-feet (45.7MG) during peak summer periods. We also provide recycled water to a limited number of irrigation customers.

Valencia's water system is a tank-based system; meaning our sources of supply (groundwater and purchased water) are pumped into our pipeline grid and ultimately into tanks which provide the storage and pressure for our customers. Valencia's system is comprised of 25 tanks, ranging in size from 350,000 gallons to 5 million gallons. One tank is a buried pre-stressed concrete tank and the balance are above-ground welded steel tanks. These tanks serve 15 different pressure zones due to the varied topography within Valencia's service area and are supplied by 16 booster stations. Tank pad elevations range from 1275 to 1875 feet above sea level. Total tank storage is 55 Million Gallons.

Valencia's distribution system comprises over 360 miles of piping (not counting service laterals) ranging in size from 4 inches in diameter to 48 inches in diameter. Typical mainline materials are; PVC, ductile iron, steel, and asbestos-cement pipe. Approximately 64% of this piping is PVC, 31% is asbestos-cement, and the remaining 5% is a combination of steel and ductile iron. Valencia's service laterals are primarily 1 inch in diameter serving 5/8 inch or 3/4 inch meters (approximately 26,308 or 87%) and 2 inches in diameter serving irrigation and business customers (approximately 2531 or 8%). We have a number of larger services ranging in size from 4 inches in diameter to 12 inches in diameter (approximately 1572 or 5%). The predominant materials for our 1 inch service laterals are PVC and polyethylene (PE) with each representing approximately 50%. The predominant material for our 2 inch service laterals is PVC with a relatively small number (less than 200) of copper service laterals. Larger service laterals are typical of mainline materials.

NORTHRIDGE EARTHQUAKE

At 4:30 a.m. on January 17, 1994 a 6.7 magnitude earthquake struck, with epicenter near Northridge, CA, (later determined to be closer to Reseda, CA) approximately 10-15 miles southwest of Valencia's service area. The earthquake struck on what seismologists refer to as a blind thrust fault. Interestingly, at the time, this type of fault was not believed to be a significant threat from a damage point of view. Obviously, the resulting damage from this earthquake changed the way seismologists view blind thrust faults. My understanding is that some of the strongest ground motions ever recorded in an urban area in North America were measured with this event, and vertical movement of up to 20 inches was recorded in certain locations. The earthquake caused loss of life and significant property damage with estimates of $20B.

SYSTEM PERFORMANCE AND REPAIR ACTIVITIES

Valencia's service area was hit hard by this earthquake. We lost 3 tanks completely, had 3 others that with significant but repairable damage and suffered hundreds of mainline breaks and hundreds of service lateral failures. Our entire system was dewatered within 30 minutes due to the significant number of pipeline breaks.

Most of our employees had reported to work within 30 minutes of the earthquake, and we set about trying to ascertain the extent of our damage. We had no electricity, no phone communications, therefore no functioning Supervisory Control and Data Acquisition (SCADA) system. Field crews began the task of traveling to each tank, well, turnout and booster station. At times, messages such as "the tanks aren't here anymore" would come over the radio. Other crews began the task of trying to identify obvious pipeline failure locations with initial focus on returning water service to the local hospital. Most of our significant 'above-ground' issues were identified within a matter of hours such as destroyed tanks or collapsed walls at well sites. Some indications of below ground pipeline failures were obvious due to cavities in tank access roads or public roadways while other below ground failures were less obvious.

Electrical service was restored to portions of our service area within 12 hours with all electrical service restored in 24 hours. At that point we could begin the task of evaluating the condition of our pumping equipment (wells and booster stations). Fortunately most of these facilities were operable, suffering from only minor damage such as wall failure or piping breaks within the facilities. Now that we had the ability to put water into our system, the long (almost never-ending it seemed) process of re-pressurizing the system could begin. This task became a process of pressurizing the system from the wellhead and discovering a pipeline break; making repairs to that break; disinfecting the pipeline and re-pressurizing the system from the wellhead and discovering yet another break farther down the line, and repeating the process over and over again.

The majority of our pipeline breaks were experienced with our asbestos-cement pipe. These breaks were generally beam breaks or collar breaks. While we have much less steel or ductile iron in our system, we had a number of failures with these types of materials as well. Steel pipe failed at weld-joints at angle points but also at on straight runs. Several instances of ductile iron failure appeared to be caused by the pipes separating at the joints (push-on type fittings). Connections going across bridges oftentimes failed at the abutments. I recall one instance a few days after the earthquake when we experienced a 5.1 magnitude aftershock. At the time, we were making repairs to a 27" mainline near a bridge abutment. The joints were butted together and being readied for welding when the aftershock struck. The two ends of the pipe separated by 2-5 inches before they came crashing back together smashing both ends. Finally, PVC pipe which accounts for over 60% of our system performed much better. We experienced no mainline breaks on PVC piping.

Service lateral failures typically occurred at the connection point with the mainline or at the meter box location. Both PVC and PE laterals performed similarly, with most breaks at the connection points. Within four days of the earthquake, Valencia had restored service to 75% of its customers. Progress continued but the remaining customers out of service were not all fully back in service until 13 days after the earthquake. Our boil water notice was lifted a week after that, 19 days after the earthquake. Though service was restored, repairs would continue for 1 ½ to 2 years after the earthquake. Due to the necessity of returning service to customers as quickly as possible, some repairs were made without the proper materials or coating systems. These would need to be repaired yet again in the future. Also, the destruction of 3 tanks and damage to 3 other tanks required us to make temporary connections between zones to allow for the repairs and reconstruction of the tanks. These temporary inter-connections would need to be removed once the tanks had been repaired and replaced.

LESSONS LEARNED

The 1994 Northridge earthquake was an experience that we could have done without. It did however; provide us with a great learning experience. We learned how our system would perform in such an event, how our employees would perform, and what some of the challenges would be for us to restore service.

The largest single assets that we lost were the three water tanks. Two of these were bolted steel tanks. None of our tanks at the time had flexible expansion joint connections between the tank and the piping feeding the tank. Our design standards have since changed to move away from bolted steel tanks to welded steel tanks and we now install flexible expansion joint connections at all tanks. We have also retrofitted all of our existing tanks with flexible connections. Furthermore, because of the numerous system pipeline breaks, we observed all of our tanks draining even in the case where the tank itself wasn't damaged. To mitigate this loss of water and to allow for quicker service restoration, we have installed seismic sensors with shut off valves on many of our tanks since the 1994 earthquake.

Pipelines and service laterals represented the most significant challenge for us in restoring service, both in terms of expense and time. We are keenly aware of the high number of breaks at bridge crossings and have moved to install flexible expansion joint devices at many of these locations, especially on main transmission lines. PVC pipe which again represents the majority of our system performed extremely well during this earthquake. I'll leave the engineering discussion to the engineers on why this may be, but from our observations, flexibility and insertion length play key roles. Service laterals generally survived, but problems when they did occur were usually at the connections to the mainlines or to the meters. We haven't found nor implemented any significantly new measures to address service laterals. We have increased our inventory of repair parts, from service lateral size fittings to repair couplings for larger mainlines, with particular focus on pipeline sizes that are not standard or where parts are oftentimes hard to get. Another lesson that we learned years after the earthquake concerns the linings in steel pipes. We've had a number of leaks on steel mainlines that we believe was caused by the lining being damaged during the earthquake, resulting in accelerated corrosion and the ultimate failure of the pipe. We noticed our first instance of this approximately 10 years after the earthquake.

We have also made a number of improvements to our SCADA system as a result of the earthquake. We have switched to Radio based systems versus phone line systems for many of our facilities. We have increased the redundancy of communications schemes to allow for system control from multiple locations and have installed battery backup systems are key remote locations. We have added to our generator fleet to allow for quicker recovery in the absence of electricity service. We have created a mobile Emergency Operations Trailer which serves as a self-contained unit for responding to mainline breaks or other system emergencies. We have also constructed and put into service a remote self-contained Emergency Operations Center in order to allow for both Office/Customer Service Operations as well as Field Operations.

In order to 'harden' our ability to provide water to the local hospital, we have made a number of system changes to be able to have access to redundant sources of supply, some of which can be delivered via gravity without the need for electricity. Another difficulty that became apparent in the earthquake was that one of our primary tank farms was located on the west side of the I-5 freeway while the bulk of the sources of supply and customers (including the hospital) were on the east side. Many of the pipelines crossing the freeway on overpasses broke which severely limited our ability to restore service quickly. We took two significant steps to mitigate this issue. We installed a new east/west transmission line under the freeway within a bore and we also created a new pressure zone to serve an area including the hospital for which we constructed a new buried pre-stressed concrete tank. Both of these measures should increase our ability to maintain service or restore service more quickly for this critical customer. We have also made additional connections to other local water purveyors to be able to take water from or provide water to them in the event of any emergency.

And finally, though our personnel performed very well during the 1994 Northridge earthquake, this event stressed the importance of continued training. We have worked to increase training both in terms of material covered as well as frequency, specifically focusing on significant outages like an earthquake which will strain all aspects of the company. We have increased our on-hand supplies of food and water and have increased our participation in training with other first responders in the community. These measures all combined should enable us to respond quickly and appropriately to the next emergency.