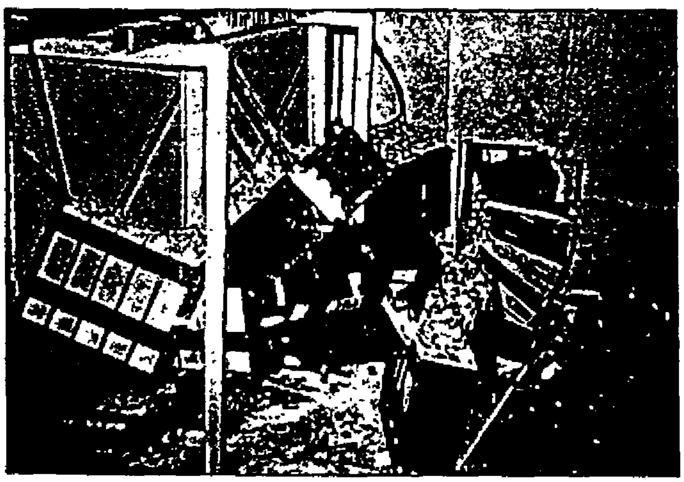
Motors may be damaged from voltage/phase fluctuation.
Provide monitoring and automatic shutdown for larger motors.

Photograph 3-65. Large pump motor burned out from voltage fluctuation at Baguio, Philippines booster pump station.

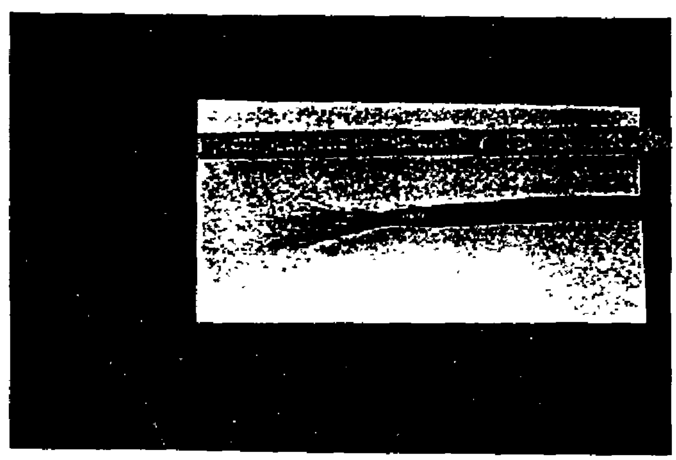
Batteries used for instrumentation backup and starting emergency generators may topple if unanchored. Secure them.



Photograph 3-66. Unanchored batteries topple.

Photograph 3-67. Battery rack with restraint design weathered Loma Prieta earthquake at Rinconada Water Treatment Plant.

Telemetry systems using dedicated/hardwired systems may have cables broken. Undedicated telephone line systems will not have phone line available. Use radio system with adequate backup power.

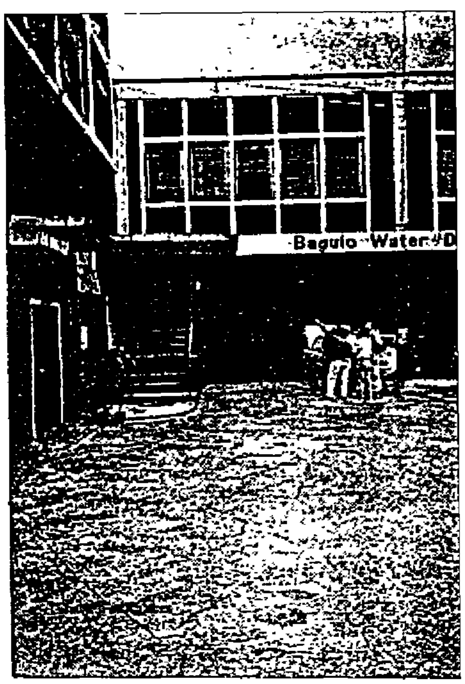


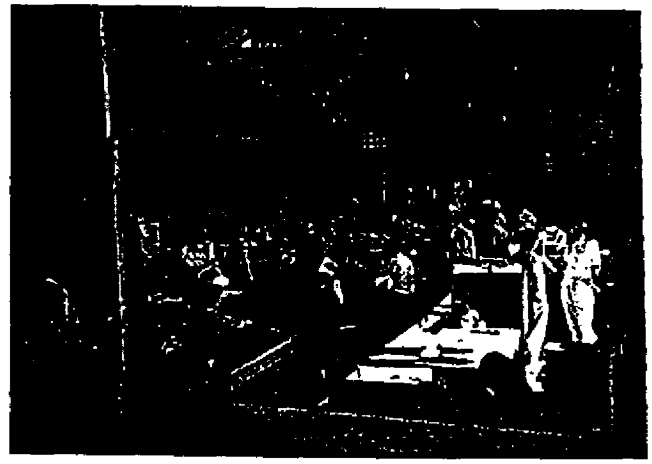
Photograph 3-68. Buried communication cable broken in earthquake.

Photograph 3-69. Microwave radio system remained operable following Erzincan, Turkey earthquake.

3.2.6 Buildings and Structures

The UBC focuses on keeping the building standing for life safety reasons following a DBE, and not building function. Building function may be critical to water system operation following an earthquake event. Evaluate buildings with post-earthquake function in mind. Buildings showing signs of distress following an earthquake can be condemned, with no entrance allowed.





Photographs 3-70 and 3-71. Condemned earthquake damaged water operations building forced staff to relocate recovery operation to shed following earthquake in Baguio, Philippines.

Pump station buildings are usually small symmetrical structures using a shear wall design. They typically perform well in earthquakes. Check to make sure that the walls are positively anchored to the floor, and the roof is positively anchored to the walls. Larger treatment plant buildings may use a variety of designs, some of which are vulnerable.

Unreinforced masonry (URM) buildings are the most vulnerable. The parapets on URM buildings are particularly vulnerable and should be braced or removed.

Photograph 3-72. Partially collapsed unreinforced masonry building

Non-ductile concrete frame buildings and tilt-up type buildings have not performed well in historic earthquakes. Tilt-up buildings constructed prior to the mid-1970s are particularly vulnerable. The roof/wall connection has failed in recent earthquakes.

Photograph 3-73. Non-ductile concrete column failure in San Fernando.

Braced steel frame, Butler type, are resistant to earthquakes. However, buildings are sometimes modified, weakening their seismic resistance. Do not remove bracing members; replace those that have been removed.

Photographs 3-74 and 3-75. Braced steel frame building had brace removed; building permanently twisted in Moin, Costa Rica.

Use FEMA Earthquake Hazard Reduction Series 41, *Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook*, for evaluation of existing buildings.

Pump station and water treatment plant buildings should be designed with seismic provisions of local or national building codes with post-earthquake system function in mind. Building design should satisfy the seismic requirements of the local building or national code, as a minimum.

3.2.7 Operational Flexibility and Redundancy

Seismic design should include provision to bypass plant treatment and to provide emergency chlorination in the event of damage caused by an earthquake

3.3 PIPELINES

3.3.1 Introduction

Historically, damage to pipelines in earthquakes has often resulted in overall water supply system failure. Pipeline failures result in rapid loss of water, draining reservoirs. When commercial power is out of service, reservoirs cannot be refilled, and the system can remain without water for days.

Photograph 3-76. Pipeline repair in Santa Cruz following Loma Prieta Earthquake.

Photograph 3-77. Areas mapped as being susceptible to liquefaction (shaded areas along river) suffered most of the pipeline damage in Santa Cruz in the Loma Prieta earthquake.

Pipeline failures are more likely to occur in areas where PGD from liquefaction takes place. Hazard mapping has become a critical tool for mitigation of the effects of earthquake pipeline damage.

Water system transmission and distribution pipelines are described below. They are typically buried 2.5 to 6 feet deep, depending on the area of the country where they are located. Transmission pipelines are sometimes laid abovegrade on pile supports.

Pipeline materials for most pipelines in place and currently used, and their respective AWWA Standards are shown in Table 3-1. Cast iron, riveted steel, and gas-welded steel do not have current AWWA standard designations, but have an extensive installed inventory.

TABLE 3-1

COMMONLY USED WATER PIPELINE MATERIALS, STANDARDS, AND VULNERABILITY TO GROUND DEFORMATION

Description	AWWA Standard	Joint Type	Vulnerability to Ground Deformation
Cast Iron	NA	Bell and Spigot, Leaded/Mortared	High
Cast Iron	NA	Bell and Spigot, Rubber Gasket	Moderate/High <18" diameter Moderate >= 18" diameter
Ductile Iron	C1xx Series	Bell and Spigot Rubber Gasket	Low - Restrained Joint Moderate - Unrestrained Joint
Steel	C2xx Series	Bell and Spigot Rubber Gasket	Low - Restrained Joint Moderate - Unrestrained Joint
Steel	C2xx Series	Arc Welded	Low
Steel	NA	Riveted	Low
Steel	NA	Gas Welded	Moderate/High
Concrete Cylinder	C300, C303	Bell and Spigot Gas Welded	Low/Moderate - Restrained Joint Moderate - Unrestrained Joint
Asbestos Cement	C4xx Series	Bell and Spigot Gas Welded	Moderate/High <12" diameter Moderate >= 12" diameter
Polyvinyl Chloride	C900, C905	Bell and Spigot Gas Welded	Low/Moderate - Restrained Joint Moderate - Unrestrained Joint
Polyethylene	C906	Welded	Low

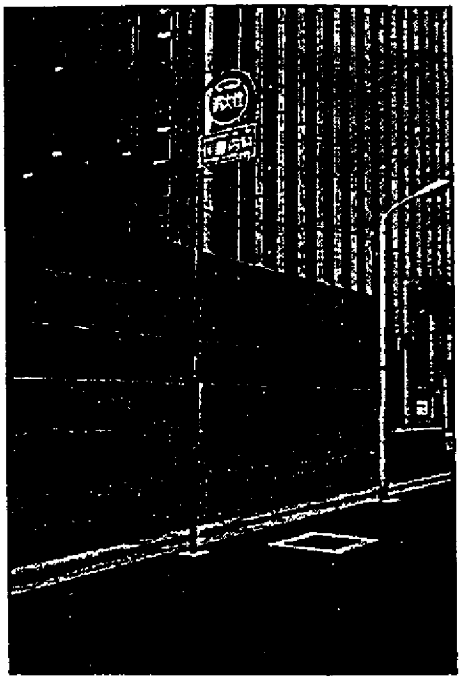
Note:

NA = Not applicable.

Pipelines may include appurtenances such as gate, butterfly, or vacuum/air release valves; hydrants; and blowoffs. Gate or butterfly valves are used to isolate pipeline segments. Vacuum/air release valves are used to release trapped air and to vent the lines to prevent vacuum formation. Hydrants are used to access water for fire suppression. Blowoffs are located at low points to permit removal of sediment and allow the pipeline to be emptied, resulting in unchecked flow and reservoir drainage. Use of belowgrade hydrants such as those used in Tokyo and London should be considered.

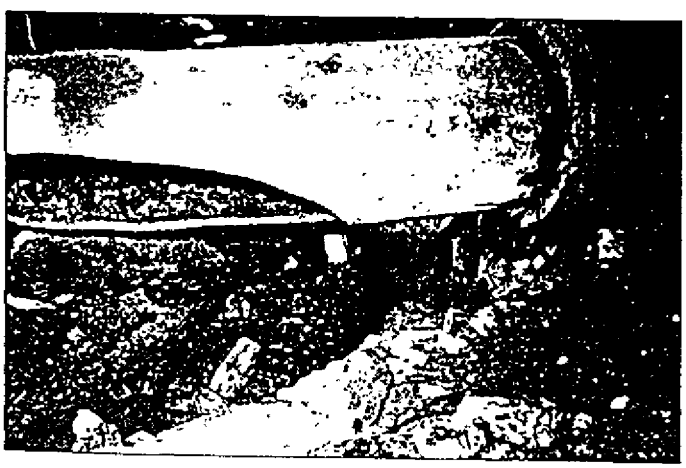
3.3.2 Damage Mechanisms

Pipeline damage mechanisms can be categorized to include wave propagation, PGD, and fault rupture. Each of these three mechanisms is described below. Hydrant damage is a special case. Hydrants have been broken by collapsing buildings,



Photograph 3-78. Sign on pole marks below grade fire hydrant in Tokyo, Japan.

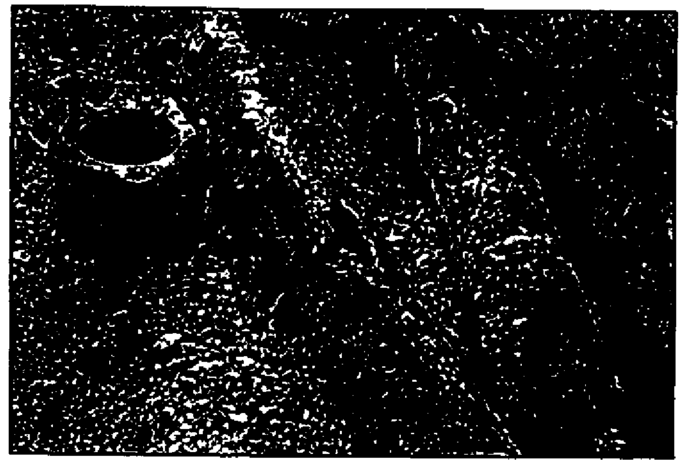
3.3.2.1 Wave Propagation. Pipelines fail from earthquake compression wave passage as a result of differential movement along the pipeline's longitudinal axis. Primary differential movement is in tension and compression. Damage is small compared to other failure mechanisms. Bending and/or joint rotation is insignificant. Differential movement between adjoining pipe sections can be calculated using the approach presented in *Pressure Pipeline Design for Water and Wastewater* (ASCE 1992). The maximum wave propagation velocity must be provided by a geotechnical engineer working with a seismologist.



Photograph 3-79 Broken 20-inch diameter pipeline in downtown Seattle following 1965 earthquake.

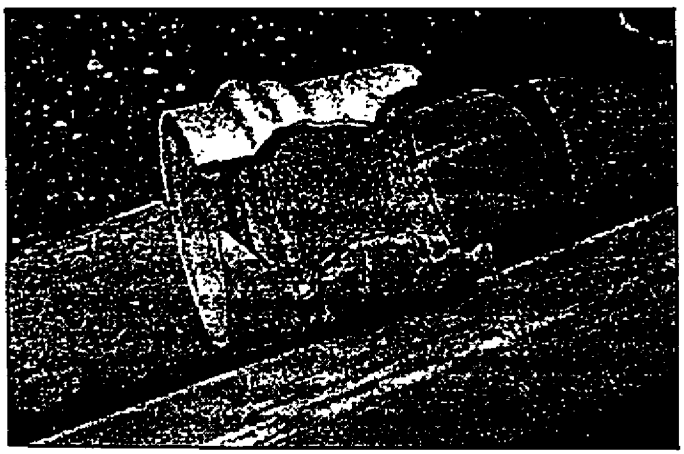
Continuous, welded steel or polyethylene pipe have adequate ductility to accommodate earthquake wave passage ground strains with no damage.

Corrosion can also lead to pipeline failure from wave propagation or PGD. Pipelines that have a high maintenance history from corrosion leaks should be evaluated. Provide pipe coatings or cathodic protection for corrosion control.

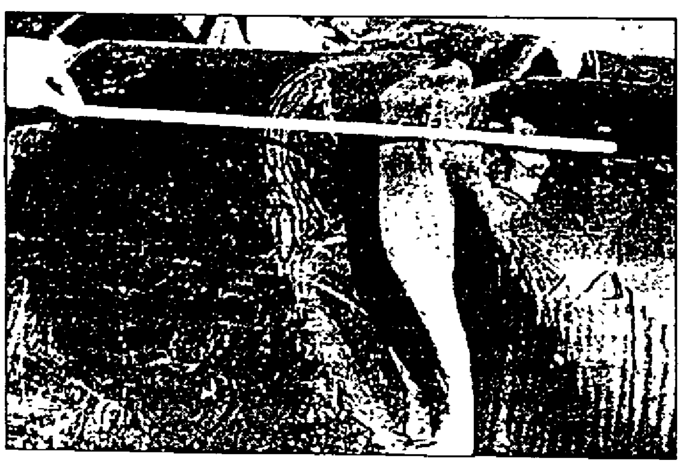


Photograph 3-80. Corroded pipe failed in Coalinga earthquake.

3.3.2.2 Permanent Ground Deformation. Pipelines move with the ground in liquefaction/lateral spread, differential settlement, cracking/lurching, and landslide. Pipelines fail in bending, shear, tension, and compression. This damage mechanism results in much higher unit length failure rates than from wave propagation. Partially empty pipelines, primarily gravity sewers, may float. Also, connections can shear off the pipe, and services break at their weak point.



Photographs 3-81 and 3-82. Lateral spreading shown by ground cracking PVC pipe joint compression failure in Agoo, Philippines.



Photograph 3-83. Steel pipeline failed in compression in San Fernando.

Photograph 3-84. Repair of failed asbestos cement pipe in Limon, Costa Rica.

Liquefaction hazard mapping is crucial to understand pipeline vulnerability within a water system, and design of new pipelines that may pass through liquefiable areas. PGD can be quantified using the Liquefaction Severity Index developed by Youd and Perkins (1987). PGD maps have been developed for some areas.

PGD may result in relative displacements along the pipe axis or in bending/shear perpendicular to the pipe axis. For bell and spigot pipe, longitudinal differential movement along the pipe axis should be accommodated in the pipe joint. In most cases, any single joint in extension or two adjacent joints in compression could accommodate 4 cm of movement without failing. Joint restraint should not be needed. Bending/shear should be accommodated using pipe ductility where the pipe length/diameter ratio is greater than 12. Where the length/diameter ratio is less than 12, joint rotation should relieve the strain. For this magnitude of joint rotation, currently used bell and spigot joints should accommodate the rotation without damage.

Based on the above assumptions, categories of pipeline vulnerability to PGD with failure PGD thresholds can be described below. The PGD thresholds shown in this listing are based on findings from recent earthquakes and are a suggested starting point for pipeline evaluation and design. Also, the geometry of the PGD will greatly impact pipeline damage. For example, deformation of 50 cm, evenly divided over 100 meters will have less impact than a 50 cm offset in one location. Vulnerabilities are summarized on Table 3-1.

- Low Vulnerability:
  - Welded steel (arc welded) or restrained joint segmented steel, polyethylene, or restrained joint ductile iron
  - Continuous/restrained joint pipe made with ductile materials
  - Can accommodate significant PGD (<50 cm).

- Moderate/Low Vulnerability:
  - Restrained joint PVC or restrained joint concrete cylinder pipe restrained joint pipe with non-ductile materials can accommodate some permanent ground deformation (<10 cm).

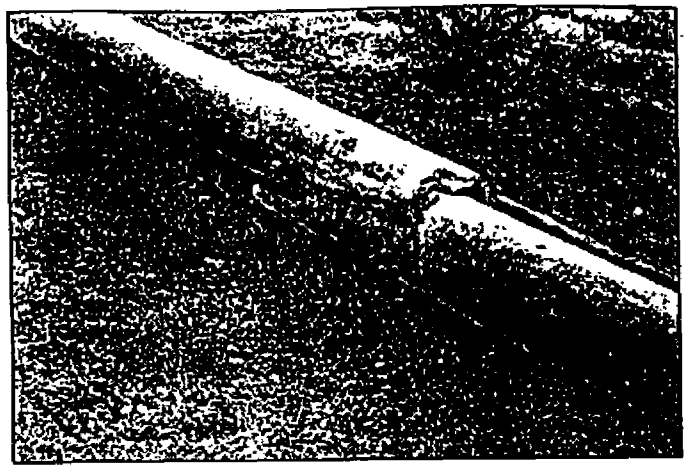
- Moderate Vulnerability:
  - Unrestrained joint ductile iron, PVC, concrete cylinder pipe, reinforced concrete, and segmented steel pipe
  - Unrestrained joint pipe constructed with ductile/semi-ductile, materials of length/diameter ratio <12 can accommodate ground deformation up to the bell and spigot insertion length allowance, and some pipe barrel bending (<4 cm).

DEFINE ACN BEND

- Moderate/High Vulnerability:
  - Asbestos cement, cast iron, vitrified clay, unreinforced concrete, welded steel (gas welded)
  - Cannot accommodate any ground deformation because pipe barrel will fail in bending
  - Can accommodate wave passage (<2 cm).

- High Vulnerability:
  - Cast iron or vitrified clay with rigid (mortared or leaded) joints
  - Cannot accommodate any PGD or wave passage (<1 cm).

3.3.2.3 Fault Rupture. Pipelines crossing faults will shear or be put in tension or compression when the fault moves. Pipelines experience the same type of soil movement when fault movement occurs as when ground deforms. Pipelines in the low vulnerability category, above, will perform the best when fault movement occurs.



Photograph 3-85. Asbestos cement pipe telescoped on itself when compressed by fault movement in Landers earthquake.

3.3.3 Pipe Design Considerations

Pipeline vulnerability to earthquakes is based on considerations discussed in this section.

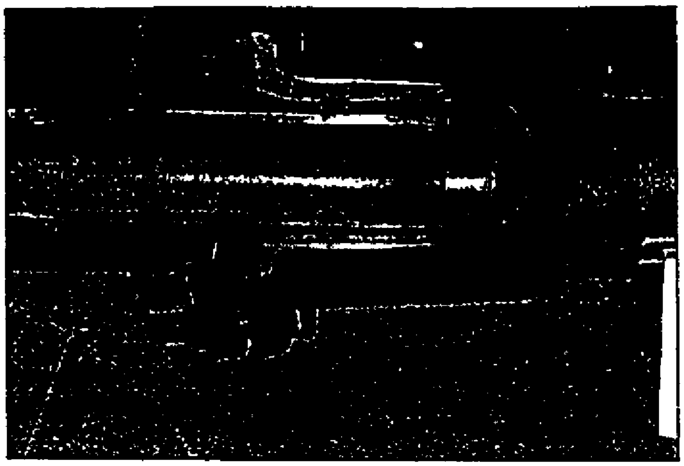
3.3.3.1 Strength and Ductility. Ductile, strong pipe is preferable to brittle weak pipe for seismic resistance.

Ductile iron, steel, concrete cylinder pipe, and reinforced concrete pipe composite sections all have high yield strengths. Polyvinyl chloride (PVC) have moderate yield strengths. Polyethylene has a relatively low yield strength.

Ductile iron, steel, and polyethylene are very ductile, and will deform considerably before they break. PVC is moderately ductile. Mortar lined and/or coated steel pipe has steel cylinder that is ductile. Concrete cylinder pipe has a steel cylinder and reinforcing that is ductile. Ductile iron pipe often has a mortar lining. When the pipe yields, the mortar will crack and spall. This disrupts the corrosion protective coating, and will allow the stee' to begin to corrode. Corrosion problems could become a problem in the future. Plastic/ductile pipe and lining/coating systems should continue to resist corrosion if the pipe yields.

3.3.3.2 Joint Type. Ductile pipe systems with continuous welded or segmented restrained joints will accommodate ground movement with minimal damage. Segmented (i.e., bell and spigot) joints with rubber gaskets will allow joint flexibility, but will easily pull apart. Segmented pipe with leaded or mortared joints become rigid and will not allow joint movement, increasing pipe strain and ultimate failure.

Modern bell and spigot pipe design employs elastomeric gaskets to seal pipe jo..ts. Bell and spigot joints with elastomenc gaskets can remain flexible in extension, compression, and rotation, depending on the installation practice. Available flexibility is typically shown in the pipe material standards or can be supplied by the manufacturer. Smaller diameter pipe allows greater joint rotation than larger diameter pipe. Special pipe bells can be manufactured to allow greater extension, compression, and rotation. Standard ductile bells can be machined to allow greater rotation. Shorter pipe sections with a greater number of joints increase the available curvature of the pipe system.



Photograph 3-86. Japanese earthquake resistant pipe joint design allows flexibility in extension, compression, and rotation.

It is common pipe installation practice to push the pipe spigot "home" into the bell when installing the pipe. This eliminates pipe flexibility in compression. Ductile iron pipe is shipped from the factory with a ring painted on the spigot end to indicate when it has been pushed into the bell the correct amount, leaving a small gap between the end of the spigot and the bell. If the painted ring limit was observed during installation, pipe would have some flexibility in compression.

Usually, steel and concrete cylinder pipe bell and spigot joints are mortared after they are joined to protect the steel bell and spigot from corrosion. This makes the joint rigid. An alternative should be considered to control corrosion but leave the joint flexible.

Most steel and polyethylene pipe has welded joints, and rely on ductility of the pipe barrel to accommodate movement.

3.3.3.3 Pipe Strength/Stiffness/Diameter. Even non-ductile pipe will resist earthquake damage if it is strong enough to resist failure in bending, tension, and compression. Pipe with a length to diameter ratio less than 12 (for cast iron) will be ~~stronger in~~ bending and is recommended. Joint restraint must be provided to resist significant ground movement resulting in joint separation.

Long pipe sections are subjected to greater bending stresses than short sections. Bending stresses are relieved at pipe joints. Pipelines designed with shorter nominal pipe lengths are subjected to lower levels of bending stress. Large diameter pipe sections are stronger in bending than small diameter pipe sections.

3.3.3.4 Joint Restraints. Pipe joint restraint is a significant consideration in pipeline response to earthquakes because it allows transfer of loads and displacement across joints. Restrained joints are also commonly used to resist hydraulic thrust loads, eliminating the need for thrust blocks. Welded joints, used for polyethylene pipe and sometimes for steel pipe, are inherently restrained. There a four considerations for better joint restraint design discussed below.

- Maintain joint flexibility in extension, compression, and rotation. If a restraint system is used to resist thrust loads, it cannot be installed to provide further extension. It still may be designed to allow compression or rotation. If the system uses rods restraining the bell and spigot, and they are not used for hydraulic thrust restraint, the rods should be left slack to allow joint extension and rotation. The allowable slack should be limited so that they will tighten and not allow joint separation to the extent that the joint seal would be broken when ground deformation occurs. Joint restraint systems built into the joint/gasket will not allow any extension. This places all the tensile strain on the pipe and is not preferred.

  Joint restraint systems are preferred that could allow further joint compression after installation. Some restraints using restraining bolts across the joint (i.e., friction, welded attachment, and grooved) and wedge designs allow compression by allowing the bolt connection to go slack (assuming the spigot has not been pushed home). Some restraint designs do not allow compression and are not preferred.

  Redistribute loads evenly across restraint system after joint has moved after the original installation. Most restraint systems will impart point loads on the restraint system if the joints are moved (rotated) after installation. They have caused restraint system failure. Joint restraint systems allowing load redistribution are preferred. Continuous welded pipe systems offer the advantage of providing even load distribution across the pipe and joint.

  Transfer a high percentage of the pipe barrel load carrying capacity. During an earthquake it may become important to be able to transfer large longitudinal loads through the joint to accommodate significant differential movement in a pipeline. This would allow the pipe system strain to be limited by distributing the relative displacement over a long "unanchored" length. A maximum unanchored length of approximately 600 feet can be developed. This requires that the restraint system would be designed to transfer loads to overcome pipe/soil friction loads developed in 600 feet of pipe (ASCE 1984).

- Not affect the pipe integrity when installed. It is important not to damage the pipe integrity when installing the restraint system. Bolt-on straps that develop strength through friction should not damage the pipe. Welding restraining rings or lugs to the pipe may weaken the pipe wall. Grooving the pipe weakens the pipe in tension reducing it to the strength of the cross section where it is grooved. Set screws place point loads on the pipe walls that have broken cast iron pipe, but may be more acceptable for use with ductile pipe materials. Wedge systems seem to limit degradation of pipe integrity. Factory manufactured spigot attachments do not damage the pipe integrity, but limit flexibility in cutting required pipe lengths during field installation.

3.3.3.5 Pipe Fittings and Appurtenances. Fittings and valves installed in pipelines are often constructed of different materials than the pipelines. For example, many fittings (i.e., bends, tees, and crosses) for small diameter ductile iron, PVC, (AWWA C900) and polyethylene are constructed from cast iron. Cast iron is brittle and will fail more easily than ductile iron. Fittings should be required to be as strong and as ductile as the pipe material. The application of the relatively new AWWA C153, Standard for Ductile Iron Compact Fittings is increasing, replacing use of cast iron fittings. Ductile iron or steel valve bodies should be used in lieu of cast iron.

Photograph 3-87. Cast iron valve body broken in pipeline in San Fernando.

3.3.4 Pipeline Earthquake Design and Mitigation Recommendations

This section provides recommendations for seismic design of new pipelines, and seismic mitigation of existing pipelines. The focus is on pipelines in areas susceptibility to liquefaction. Fault crossing design is also discussed.

3.3.4.1 New Pipelines. Use any modern bell and spigot or continuous pipe to accommodate earthquake wave passage.

In areas susceptible to liquefaction:

- Avoid liquefiable area - relocate or go below (directional drilling).
- Use ductile, flexible pipe systems such as restrained joint ductile iron, welded steel, or polyethylene. Design the pipeline structure to accommodate expected loading from permanent ground deformation.
- Provide special connection designs that will accommodate longitudinal pipe movement without failure.
- Use restrained joints rather than thrust blocks to resist thrust. Thrust blocks may move if liquefaction occurs.
- Minimize soil loadings (see fault crossing recommendations below).
- Provide system operational flexibility and redundancy.
- Build in emergency response capability - isolation valves around vulnerable area.
- Stabilize soils using methods such as vibroflotation, stone columns, or grouting. (This is typically very expensive.)

3.3.4.2 Existing Systems. Focus on the most vulnerable system elements.

- Upgrade vulnerable, critical segments in accordance with new design recommendations.
- Implement prioritized upgrade/replacement program based on earthquake hazards, pipe system, and criticality as part of comprehensive plan.
- Install system operational flexibility and redundancy.
- Install emergency response capability - isolation valves.

3.3.4.3 General Design for Fault Crossing. Minimize the required displacement and/or load carrying requirements of the pipe system (ASCE 1984).

- Minimize the pipe diameter to minimize the soil/pipe interface to reduce soil friction loads. At the same time, consider the impact of the diameter reduction on the hydraulic design.

- Minimize the friction coefficient between the pipe and soil by using appropriate pipe coatings or wrapping. Polyethylene wrapping is commonly used for corrosion protection for ductile iron pipe and should be used to reduce pipe/soil friction loads. Minimize burial depth and backfill weight.

- Install abovegrade. This is the best from a soil loading perspective, but will likely not be acceptable for other reasons.

- Locate the pipe in a sacrificial tunnel or culvert, or design the pipe to accommodate design loads from fault movement within the zone.

- Do not use anchorage such as thrust blocks, bends, or connections within a distance of 600 feet of a fault zone. Special connection designs are required to accommodate movement along the unanchored length.

- Provide system redundancy whenever possible; several smaller pipes should be used in lieu of one large pipe.

3.4 STORAGE TANKS AND RESERVOIRS

3.4.1 Description

This section includes water storage tanks and reservoirs. A description of typical reservoirs follows in this introduction along with a description of failure consequences.

Storage tanks and reservoirs provide system storage typically ranging from one to three days of average system demand. They provide storage to accommodate diurnal flows and for fire protection.

Storage tanks and reservoirs described herein include lined in-ground ~~lined~~ reservoirs, cast-in-place and post-tensioned concrete tanks, at-grade steel tanks, steel standpipes, steel elevated tanks, and wood stave tanks.

In-ground reservoirs are often earthen structures with concrete lining and concrete, wood, or sheet metal column supported roofs.

Cast-in-place concrete tanks are usually in-ground or at-grade. Post-tensioned tanks are usually in-ground or at-grade, and have their primary reinforcing provided by wire wrapping or post-tensioning tendons. Both types usually have column supported roofs.

At-grade steel tanks and standpipes usually sit on a ring wall or mat foundation. Tanks with larger height to diameter ratios are often anchored to the ring-wall. Their steel roofs are either supported off the side or use column supports, depending on the tank diameter. Elevated tanks can either be supported on a single pedestal or multi-leg cross-braced frame.

Wood tanks are constructed with vertical wood staves wrapped with hoops or bands.

3.4.2 Failure Consequences

Storage tanks and reservoirs play a vital role in post-earthquake system operation. The system is usually dependent on the stored water for fire suppression. Transmission systems are not usually sized to deliver adequate fire flows.

Seismic evaluation of tanks, like other system components, should consider consequences of failure. As stored water in tanks is crucial for fire flows, their functionality may become critical. Also, tank collapse, unlike most other water system structures, may become a life safety threat. A tank failure consequence evaluation should also consider the number of tanks and/or supplies serving a pressure zone, and the relative capacity of each as shown in Figure 3-1. A larger tank providing the sole storage for a pressure zone is more critical than one of several smaller tanks serving a zone.

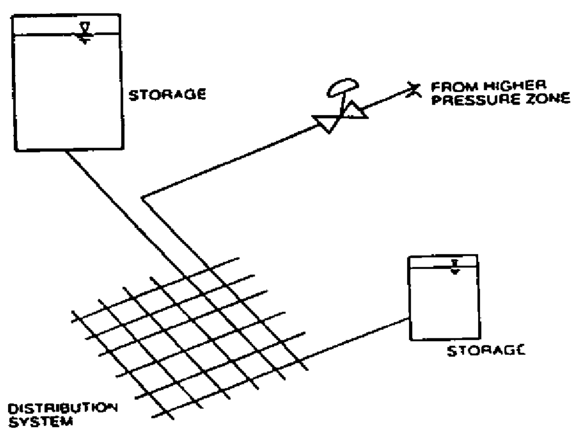


Figure 3-1. Evaluation of storage/feeds to a pressure zone consider number, capacity, and location within the zone.

3.4.3 Response of Tank Contents

Water in tanks responds differently than a rigid mass. Housner modeled a portion of the water to respond as if it were rigidly attached to the tank wall imparting impulsive loading, and a portion of the water ~~to~~ responding as if were attached to the tank wall with springs resulting in convective loading. The resulting loading is actually less than if it all responded as a rigid mass. The convective portion of the water is sometimes identified as the sloshing water. Figure 3-2 shows a tank model.

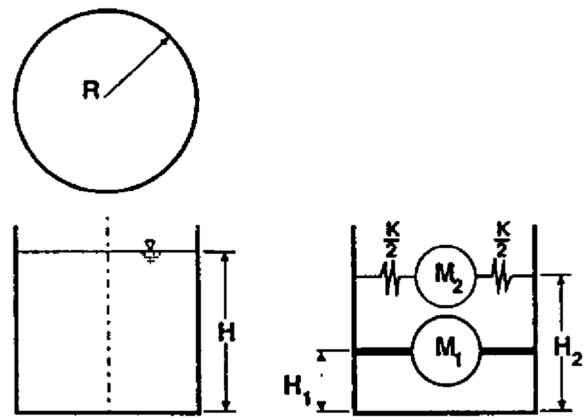


Figure 3-2. Schematic of tank model for earthquake response. Mass M_1 imparts impulsive loads and mass M_2 impacts convective loads on the tank. H = height; R = radius; K is a spring constant.

The relative portion of water responding in the impulsive and convective modes, respectively, changes depending on tank geometry. The smaller the tank diameter to height ratio (i.e., tall, slender tanks), the more water acts in the impulsive mode. The larger the diameter/height ratio (i.e., large, low tanks), the more water acts in the convective or sloshing mode. We expect more sloshing to occur in large/low tanks. The relative portions of water acting in each mode are shown in Figure 3-3 (AWWA, 1984).

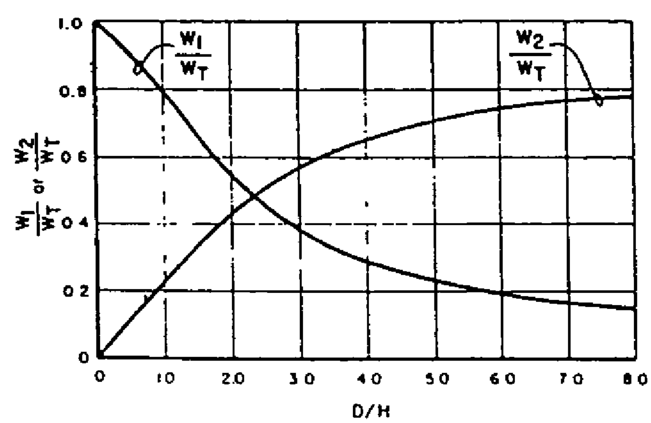


Figure 3-3. Tank model weight (W) distribution between impulsive and convective loads is a function of tank diameter (D) and height (H).

Sloshing liquid should be taken into account in tank design, in that it may impart loads to the tank roof. The roof may or may not be designed to resist these loads. To mitigate this type of damage, provide adequate tank freeboard to accommodate sloshing (Kennedy/Jenks/Chilton 1990a). Empirical evidence and recent dynamic analyses have indicated actual slosh wave heights may exceed calculated heights by a factor of up to 1.8.

3.4.4 History of Steel Tank Design Standards

A standard for steel tank design was first established in the Journal of the American Water Works Association in 1935, but with no seismic provisions.

Housner conducted dynamic analyses of tank sloshing in the late 1950s and early 1960s for the nuclear power industry.

Prior to the 1979 version of the AWWA Standard for Welded Steel Tanks for Water Storage (AWWA D100-79) seismic design was taken into account by the purchaser specifying static lateral loads. AWWA D100-79 included optional provisions for seismic design in Appendix A. Those provisions were added to the body of the standard in 1984, mandatory for UBC seismic zone 4, and optional for seismic zones 1, 2, and 3. An update of the 1984 standard is expected out in 1993.

In 1991, the UBC included requirements for tank design that, in some instances, are more stringent than the AWWA standard.

3.4.5 Damage Mechanisms and Mitigation Alternatives

3.4.5.1 General Damage Mechanisms. Failure mechanisms in this subsection are applicable to all the types of tanks described.

Rigid piping connections are vulnerable if the tank moves or if differential movement occurs between the tank and the surrounding ground/buried pipe. Tanks can either be anchored or pipe flexibility added. Unanchored and inadequately anchored steel tanks may rock. If the connection to the tank is on the side, provide flexibility in the connection using two restrained flexible joints in series, or proprietary flexible piping systems.