AmericanLifelinesAlliance

A public-private partnership to reduce risk to utility and transportation systems from natural hazards and manmade threats

Seismic Guidelines for Water Pipelines

March 2005

FEMA

National Institute of BUILDING SCIENCES

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Seismic Guidelines for Water Pipelines

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11.0 Service and Hydrant Laterals

Appurtenances are those ubiquitous components connected to pipelines that serve a variety of functions with the most common being customer service and fire hydrant lateral connections. Customer services and fire hydrant laterals respectively refer to the piping and associated hardware used to convey water from the distribution main to a customer's meter or fire hydrant. Other appurtenances include blow-offs, pressure relief valves, vacuum valves, air valves, test stations and the like. Traditionally, these are non-engineered for seismic conditions, and the hardware used is governed by ease of installation and maintenance economics.

Significant numbers of appurtenances have suffered damage during earthquakes. Post earthquake damage surveys that tracked service laterals damage revealed they constituted roughly 20% of all distribution system repairs in several surveys (Table 11-1 provides examples). Seismic failure of the appurtenance pressure boundary is more likely to lead to a leak rather that the more serious break that would necessitate immediate shutdown of the pipe until repairs are enacted. Nevertheless, all damaged appurtenances eventually will need to be repaired to restore the water system to its pre-earthquake condition, and this cost can be large considering that mobilization and excavation effort for a buried pipe repair is about the same as that to repair a buried service.

Because the large numbers of appurtenances and the fact those tend to be non-engineered for seismic conditions, this section presents seismic design considerations to mitigate appurtenance damage in earthquakes.

Earthquake	Numbers of Service Repairs	Numbers of Pipe Repairs	Service-to-Pipe Repair Ratio
1994 Northridge[1] (Toprak, 1998)	208	1,013[2]	1 to 5
1989 Loma Prieta East Bay Service Area (Eidinger, et al, 1995)	22	113	1 to 5
1971 San Fernando (NOAA, 1973)	557	856	1 to 2
Notes 1. Numbers of field repair records. 2. Includes repairs to hydrants.			

Table 11-1. Ratio of service to pipe repairs from earthquake damage surveys.

11.1 Typical Customer Service and Fire Hydrant Lateral

Figure 11-1 depict typical customer service installations defined as the piping connecting the water main to the customer meter. Isolation valves are located at the main and meter.

The valve at the main, commonly referred to as corporation stop or main cock, can be attached to the main in a variety of ways depending on main size and material type, and whether the connection is made when the main is in operation. Figure 11-2 shows typical connections. The corporation stop is the same in each case and is attached via a relatively weak threaded connection. Figure 11-3 depicts a typical fire hydrant lateral consisting of a tee connection at the main, valve and piping connecting to the hydrant. Cast-in-place concrete blocks can be placed around the pipe to act as thrust anchors and to protect the below ground piping from damage from vehicle collisions with the hydrant.

11.2 Seismic Hazards and Effects on Appurtenances

Three types of seismic hazards can affect appurtenances: ground vibratory motion, transient ground strain and permanent ground displacement. Figure 11-4 depicts an appurtenance consisting of an air valve located in a vault and associated piping connecting to a buried main to illustrate how the hazards can affect the installation.

Ground vibratory motion refers to the time-varying displacements that occur at the ground surface during an earthquake, typically characterized by the peak ground acceleration (PGA). Appurtenances suspended in air and attached to the ground will experience vibration due to support excitation. The air valve is suspended inside the vault and ground vibratory motion represents the hazard for components in the vault. Experience has shown that poorly supported appurtenances can suffer damage from earthquakes.

Wave propagation ground strains are produced in the soil from seismic wave passage, and are typically categorized according to peak ground velocity (PGV). These cause transient strains in embedded appurtenances as the component conforms to the soil. Such strains are relatively small and generally cannot cause appurtenance damage (by calculation) except when an appurtenance has been weakened such as from age or corrosion. Metallic piping embedded in soils outside the vault could be weakened by corrosion making it vulnerable to damage from transient ground strain.

Permanent ground deformations (PGD) are the movements of soil caused by seismic ground failure including liquefaction, landslides, lurching or surface faulting. These can be very damaging to buried components spanning between different soil masses moving relative to one another. Should an embedded appurtenance be anchored in each soil mass, it can be torn apart as the soil masses move. For example, if the soil mass at the vault moves relative to the main, the piping will be subject to applied deformations that could cause failure depending on the magnitude of the movement, soil strength, and pipe flexibility, strength and ductility.

11.3 Design For Inertial Seismic Motions

Past earthquakes have demonstrated that customer meters located in vaults generally are not vulnerable to damage from vibratory ground motions. Similarly, fire hydrants have not been damaged due to vibratory ground motions. However, past earthquakes have shown that other appurtenances can be susceptible to damage, especially components that are mounted in a relatively flexible manner (like inverted pendulums within or outside of a vault) and those that have non-ductile connections. Inverted pendulum assemblies seem to have been particularly prone to damage if the vertical riser pipe had suffered the effects of corrosion. An example is the air valve mounted on an aboveground large diameter pipeline as shown in Figure 11-5. The air value has the potential for dynamic amplification due to its support by piping acting as a flexible inverted pendulum (vertical cantilever). Also, the pipe connections in Figure 11-5 are threaded; threaded connections often have less capacity than the main pipe to accept bending moments; may not have been totally engaged during installation; may have suffered from aging/corrosion; and in general have low ductility (inability to accept local yielding for multiple cycles). Another example is the combination valve arrangement (Figure 11-6) having a vacuum release valve cantilevered above the pipe and an air valve cantilevered from the vacuum valve. The air valve is particularly vulnerable because the vibratory motions are amplified by the vacuum valve support structure (inverted pendulum).

It is clear that if the inverted pendulum assembly has been designed for seismic loading, then the performance will be adequate (barring corrosion or improper installation). Section 4 provides the level of ground motion that should be considered at such installations.

From field observation in past earthquakes (including San Simeon 2003, Loma Prieta 1989), it is apparent that "standard" installations of such assemblies have led to seismic inertial-induced damage on small diameter pipe (Figure 11-5 style installation) as well as on major transmission pipelines (Figure 11-6 style installation). Damage seems to be either very sporadic or non-existent when local PGA values are less than 0.15g, even for non-seismically designed installations. Accordingly, the Guidelines suggest that such installations need no special seismic design requirement in design at sites with PGA < 0.15g. As the extra cost to seismically design an assembly like those in Figures 11-5 or 11-6 should be in most cases very small, we suggest that a simple design check for the riser pipe (and its connections) should be done; with an allowance in pipe wall / connection styles for possible long term corrosion. To recognize that a standardized design will usually be desirable, a water utility would establish a suitable 475-year return period PGA motion for its entire service area, and then design all such inverted pendulum-type assemblies for 2.5 times the PGA. We recommend that no "response modifier" be used; instead, the entire assembly should be designed for the elastically-computed motions, while keeping maximum pipe component stresses below yield. Design recommendations follow.

PGA	Design Approach
0 to 0.15g	Standard installation
Over 0.15g	Design to elastic limits

Table 11-2. Recommended appurtenance design for vibratory ground motion.

11.4 Design For Wave Propagation Ground Strains (PGV)

Corrosion of metallic appurtenances can weaken them so that even the relatively small strains caused by seismic wave passage are sufficient to cause failure. Copper service laterals are an example where one west coast utility has altered its approach to better protect against corrosion. Originally, copper services were electrically insulated only at the customer meter but left electrically connected to metallic mains with the rationale that the main would protect the service because the pipe would act as the anode vis-à-vis the service acting as a cathode. At a later date, copper services were also electrically insulated at the corporation stop to reduce corrosion in metallic mains; but so isolating the service produced cases of copper service failures due to corrosion. This led to the current practice for new service installations of using plastic coated copper service hardware and connection with magnesium anode as illustrated in Figure 11-7. Costs associated with enhanced service corrosion protection were deemed worthwhile versus future maintenance costs associated with service replacement due to corrosion. Accordingly, good corrosion protection programs will mitigate damage to appurtenances from transient ground strains resulting from earthquake wave passage. Design recommendations follow.

PGV	Cost-Effective Design Approach
0 to 10 in/sec	Standard installation
Over 10 in/sec	Provide explicit corrosion protection to buried metallic appurtenances

Table 11-3. Recommended appurtenance design for transient ground strain caused by seismic wave passage

11.5 Design For Permanent Ground Displacement

Permanent ground displacement represents the most serious hazard for buried appurtenances. Figure 11-8 illustrates one typical mechanism. The appurtenance is located in an unstable soil mass that is subject to movement to the south, and connected to a north-south oriented water main that is anchored to another east-west oriented water main that is located in a stable soil mass. The relative motions cause stresses to develop in the appurtenance with the key location being at the attachment to the main (point A in Figure 11-8). In this example, the north-south run of main does not displace with the moving soil due to its being anchored in the stable soil mass to the north. Whether the appurtenance pressure boundary fails and a leak develops depends on the strength and flexibility of the attachment.

- Strength. A relatively strong attachment can allow the appurtenance to shear through the soil thus having no loss of the pressure boundary.

- Flexibility. A flexible attachment can accommodate the relative displacements with no failure of the pressure boundary. Flexibility can be provided by mechanical hardware and/or material ductility.

11.5.1 Customer Services

Main cocks, typically made of brass castings, are relatively weak and possess low ductility due to the threaded connection into the main. The strategy for PGD-tolerant design is to uncouple the main cock from the (moving) soil. This can be achieved by providing a soft void space around the main cock so that a modest amount of relative motions can be distributed over the relatively flexible and ductile service tubing. One such device is the "service boot" (Figure 11-9) that one west coast utility uses in areas of known ground movements having a history of main cock failures. Figure 11-10 shows a photo of the service boot components. Figure 11-11 shows another style of installation having copper tubing routed several directions creating a flexible "swing joint" near the main. This latter design is not expected to be as effective as the service boot. Design recommendations follow.

PGD	Cost-Effective Design Approach
0 to 2 inches	Standard installation
2 to 12 inches	Service boot
Over 12 inches	Case-specific custom design

Table 11-4. Recommended customer service designs for permanent ground displacement.

11.5.2 Fire Hydrant Laterals

Fire hydrant laterals are typically connected to the main with tee connections that possess significant strength and ductility (especially if the lateral branch pipe is welded steel). Therefore, the standard installation, having no special mechanical couplings to provide additional flexibility, is able to resist (probably modest) levels of PGD. However, it is clear that under excessive PGD, it is likely that failure of the lateral will occur at the main-to-branch attachment point. Table 11-5 provides design recommendations. The magnitude of PGD beyond which special flexible coupling devises are cost-effective is difficult to quantify. Life-cycle cost must be considered on a case-by-case basis. Dresser-type couplings have the potential for increased maintenance costs due to leakage over time (versus a continuous pipe). EBAA flextend (or equivalent) couplings are relatively expensive leading to high installation costs versus the low likelihood that seismic PGD will affect a particular hydrant installation. Hydrant installations having histories of actual failures due to PGDs are candidates for special coupling devices as these will likely experience additional PGDs in future earthquakes.

The Guidelines recommend one dresser-type coupling for PGDs up to 3 inches; and two dresser-type couplings for PGDs up to 12 inches. If the direction of the PGD is axial along the lateral (like a hydrant placed in a slide on the fill side of a road, while the pipe is in the stable cut side of the road), then the couplings should be restrained. Flextend-type couplings can be used for large PGDs. Other design strategies could be used for pipeline systems designed to be extremely reliable post-earthquake (such as dedicated fire-fighting systems).

PGD	Cost-Effective Design Approach
0 to 2 inches	Standard installation
2 to 12 inches	Dresser-type coupling
Over 12 inches	EBAA flextend type coupling

Table 11-5. Recommended fire hydrant lateral designs for permanent ground displacement.

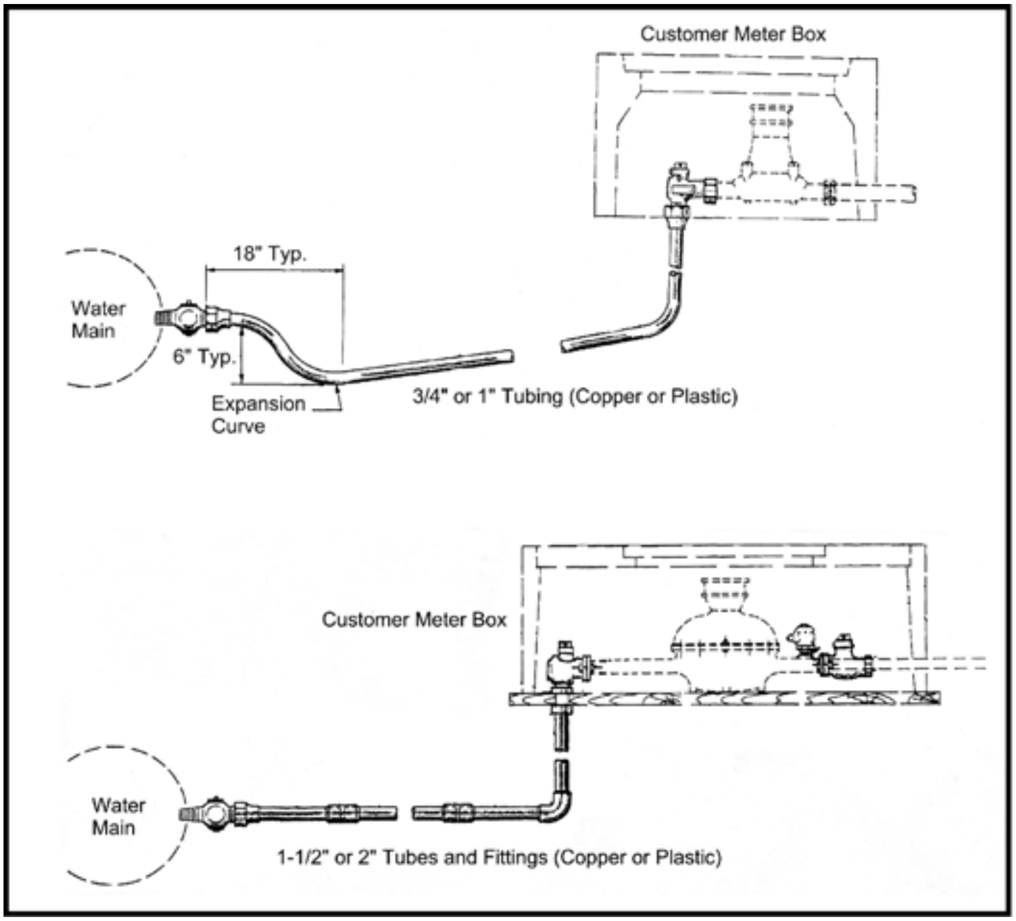

Figure 11-1. Elevation view of typical customer service installations

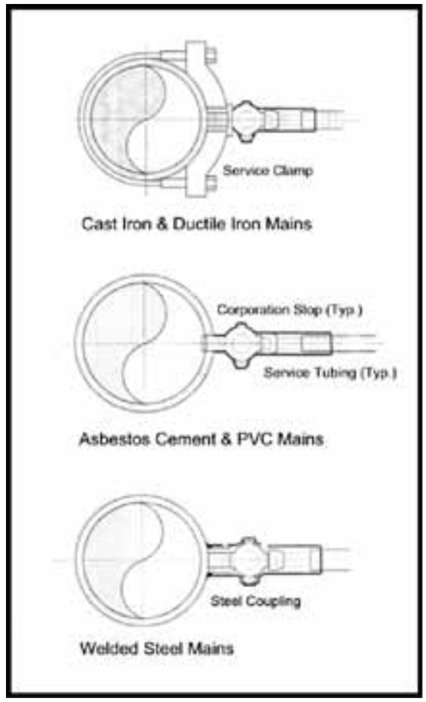

Figure 11-2. Elevation view of typical customer service connections to water main

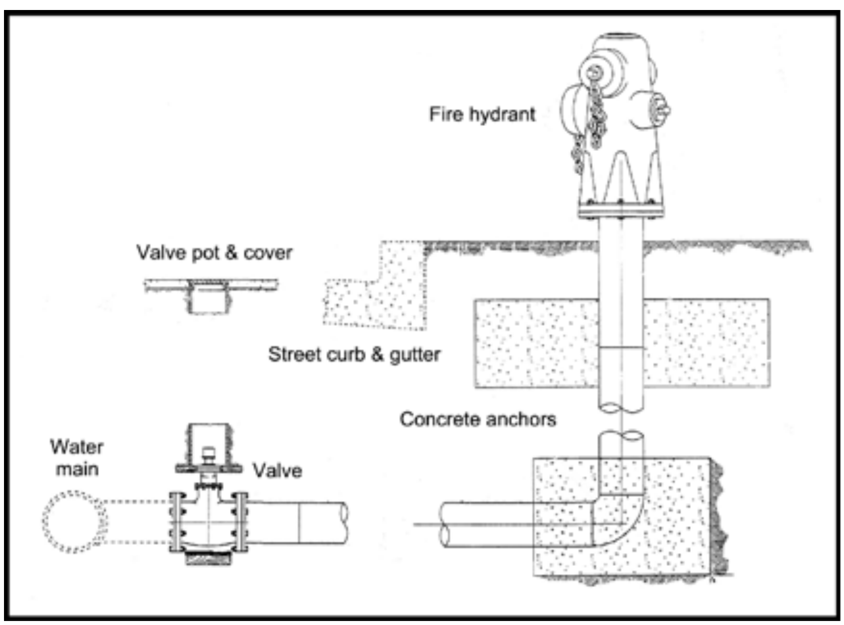

Figure 11-3. Elevation view of a fire hydrant installation

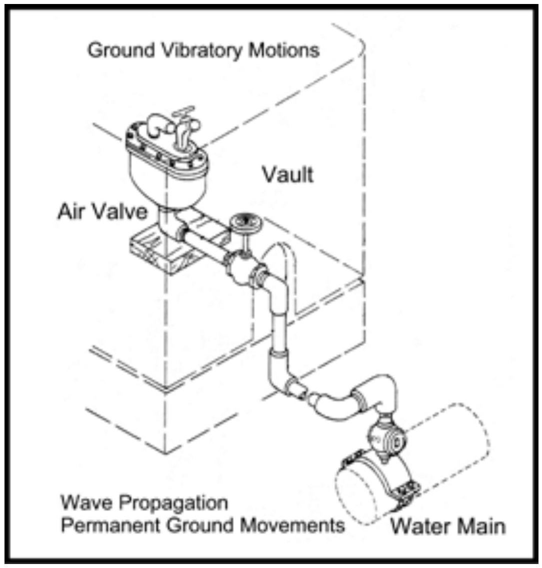

Figure 11-4. Example air valve installation to illustrate seismic hazards. Buried portion vulnerable to seismic wave propagation and permanent ground movements, and portion suspended inside vault vulnerable to vibratory ground motions

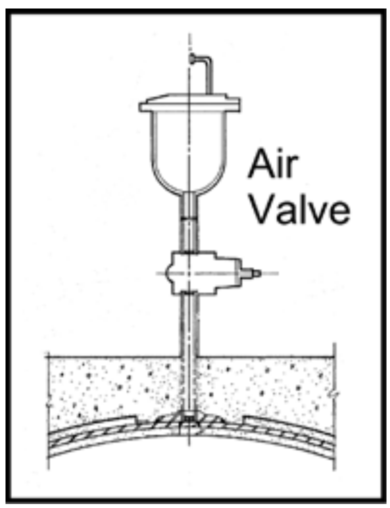

Figure 11-5. Elevation view of 1-inch air valve installation on pipeline

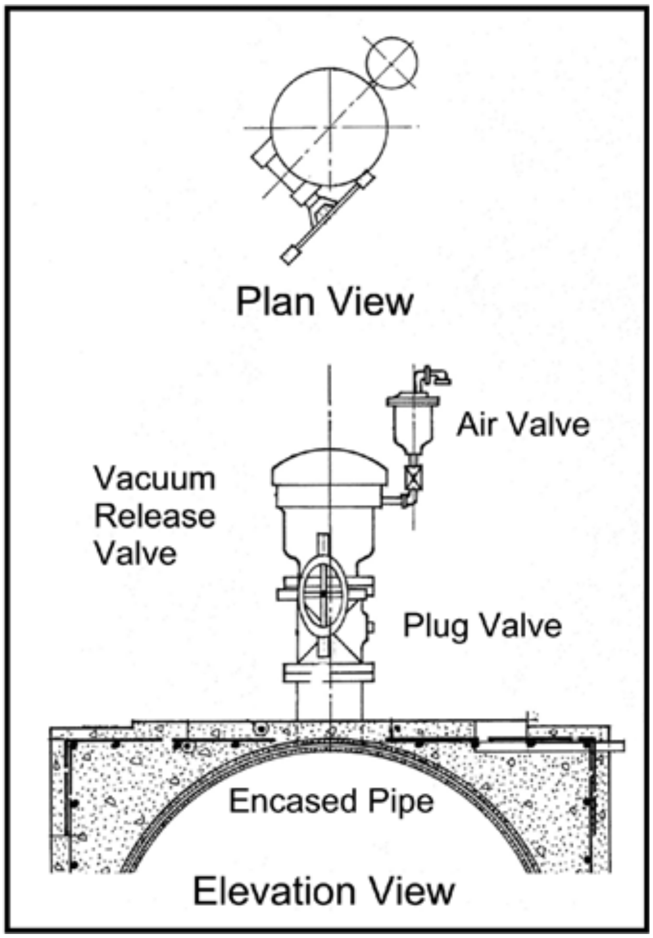

Figure 11-6. Combination valve installation on pipeline

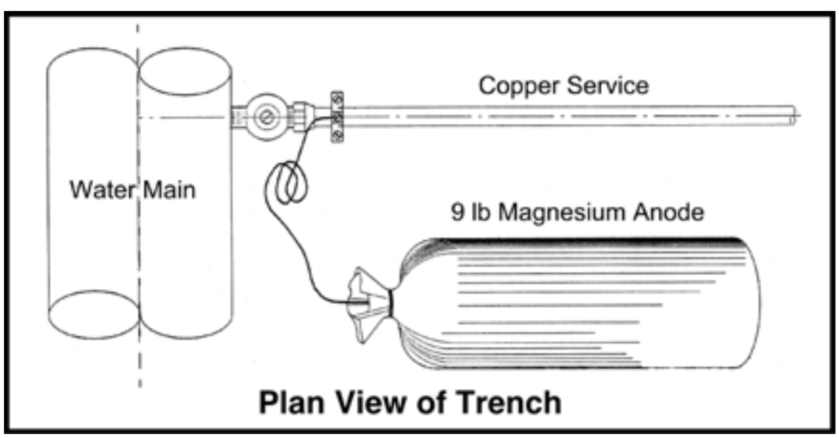

Figure 11-7. Corrosion protection of metallic customer service

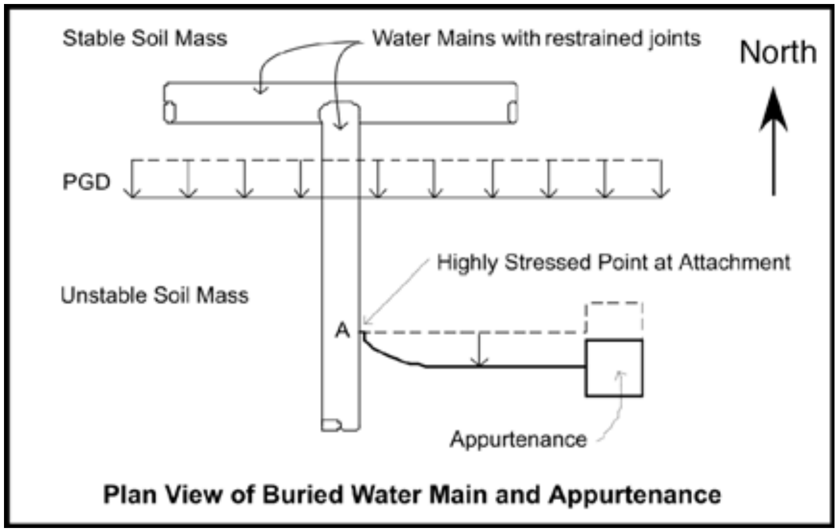

Figure 11-8. Example of PGD mechanism affecting appurtenance

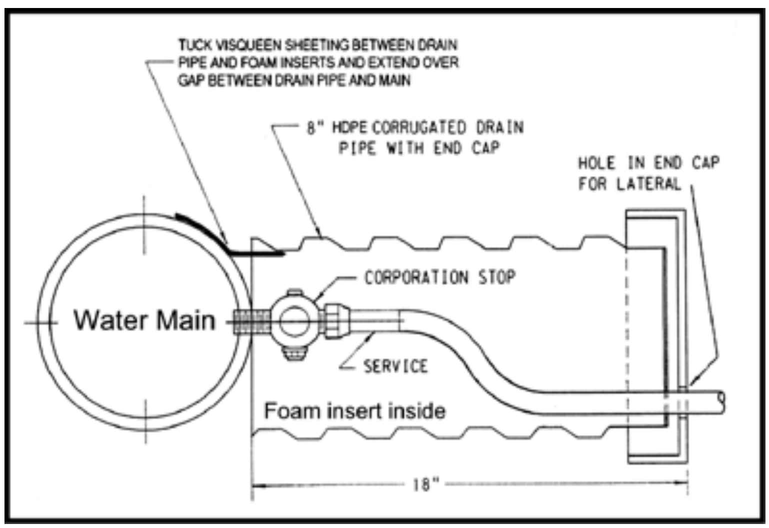

Figure 11-9. Side view of service boot.

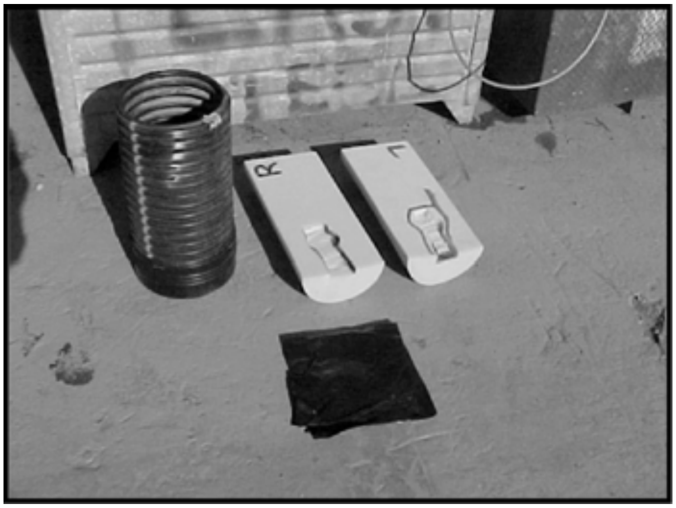

Figure 11-10. Photo of service boot components: HDPE drain pipe and end cap (upper left), two foam inserts (upper right), and visqueen sheeting (foreground)

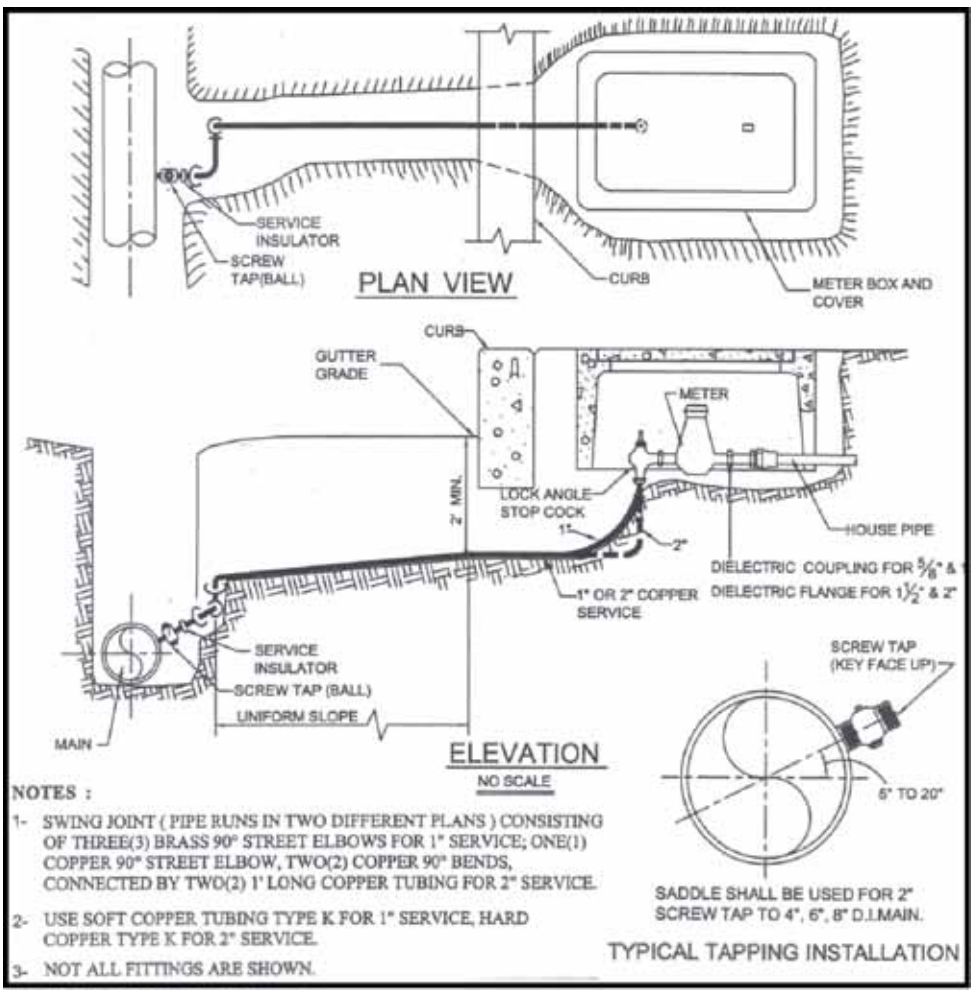

Figure 11-11. Service Lateral Installation to Address PGDs

12.0 Other Components

12.1 EBAA Iron Ball Joints at Fault Crossings

As outlined in other places in these Guidelines, EBAA "flextend" assemblies can be used to provide for a limited (usually around 12 inches) amount of pipeline movement. These assemblies have often been used to allow for limited wall uplift of water tanks without overstressing attached side-entry pipes.

In concept, these assemblies can also be installed in buried pipes to accommodate localized settlements, landslide and fault offset movements. However, when the amount of PGD to be accommodated starts becoming large (say 40 to 100 inches for fault offset); and the location of the PGD becomes uncertain (say at a fault crossing, where the actual rupture might be distributed over some uncertain location within a wide zone), then it is recommended that the FEM (Section 7.4) be performed to ensure that the pipe and EBAA flextend assemblies are not overloaded.

In the following example, the use of EBAA flextend assemblies were considered for a 42-inch diameter pipeline that was to be installed across a fault:

- The pipe is a 42-inch diameter butt welded pipe with wall thickness of 0.5 inches in the vicinity of the fault.

- Two 42-inch diameter ball joints are placed in the pipe. There is 27 feet separation distance between the centerlines of the two ball joints.

- One expansion joint is placed in the pipe, at a location between the two ball joints.

An analysis of the type outlined in Section 7.4 was performed, assuming transverse fault offset of 31 inches occurs midway between the two ball joints. The key results are as follows.

- One ball joint undergoes an angular rotation of 4.8 degrees; the other ball joint undergoes a rotation of 7.8 degrees.

- The expansion coupling undergoes an extension of about 4.3 inches.

- The ball joints carry low moment (under 5,000 kip-inches, due to friction), and 178 kips (tension).

- The expansion coupling carries low axial force (under 1 kip, by friction) and low moment (under 4,000 kip-inches).

- The 42-inch x 0.5 inch thick welded steel pipe near the assembly has maximum strains of ±0.07% (+22 ksi, -20 ksi). These strains (stresses) are low enough to preclude wrinkling.

Observations. The design with ball joints and expansion couplings will work for the assumed fault offset, provided:

- The fault offset occurs between the two ball joints.

- The fault offset does not exceed a certain amount. The maximum fault offset prior to pipeline failure is the amount of offset needed to cause one (or both) of the ball joints to reach their rotation capacity, or to cause the expansion joint to fail, or to overload the pipeline. At this time, EBAA –Iron does not manufacture a 42-inch diameter ball joint. However, the 36-inch diameter ball joint can withstand about 15 degrees offset; and a recent 48-inch diameter product can withstand about a 11 degree offset. (Note: actual degrees offset may vary somewhat, and would be verified in actual design). Assuming that a 36-inch diameter ball joint is used, and providing that the maximum ball rotation is 11 degrees (modest amount of conservatism), then the ball joints, if spaced at 27 foot intervals, could take a maximum of about (11/7.8) * 31 = 44 inches of fault offset.

- Once one ball joint reaches its rotation limit, it will either lock up and transfer moment to the opposing ball joint, or it will break. At this time, there is no experimental data to show what happens if the ball joint is rotated beyond its stop capacity; therefore, one might assume that it would fail. It might be prudent to include such a test as part of the procurement process. It is understood that EBAA tests these assemblies to resist internal pressure, and not mechanical loading due to excessive rotation of the ball joints (or elongation / compression of the expansion joints).

- This example shows an unequal amount of ball joint rotation for the two ball joints. This demonstrates that the effects of transverse fault offset, plus nearby pipe bends as is the case for this example, can tend to promote unequal accommodation of the fault offset by the two ball joints.

- The expansion joint is predicted to take 4.3 inches extension, for a 31 inch fault offset. It is relatively straight forward to design an expansion joint to take 4.3 inches of expansion. EBAA-Iron provides a device that takes 10 inches.

- The EBAA-Iron catalog shows maximum allowable lateral offset of 17 inches for a 30-inch diameter double-ball-and-single-expansion assembly, with 5.25 feet centerline to centerline, ball joint spacing. For the example application, it is assumed that additional spool pieces of straight pipe are inserted between the two ball joints, to make up a 27-foot long, centerline to centerline, ball joint spacing.

- By inserting additional straight pipe between the two ball joints, larger fault offsets can be accommodated. However, the pipe between the ball joints can be exposed to high bending moments due to imposed soil loading, if the pipe is buried. It is unknown if EBAA has tested their expansion joint assemblies to take concurrent bending moments. High transverse loading will tend to ovalize the pipe, possibly leading to leaks through the packing of the expansion joints.

- For above ground applications (or below ground applications where the entire ball joint – expansion joint system is enclosed in a vault or similar empty annular space), there is no lateral load applied to the pipe between the ball joints, and the expansion joint will not be exposed to simultaneous axial expansion plus high bending. For a below ground application where the ball and expansion joints are buried in soil, bending moment on the pipe between the rotation joints cannot be avoided; the wider the spacing of the ball joints, the higher the moment on the pipe between the ball joints. For design, the trade-off between ball joint spacing and the design of the pipe between the ball joints must be considered.

- If the fault offset can take place anywhere in a wide fault zone, then it may be necessary to include many ball joints and expansion joints through the fault zone. If the spacing between the ball joints is too wide, and if the soil is stiff, and the coefficient of friction between the pipe and the soil is high (like it normally is) then fault offset may break the pipe between the ball joints. If the spacing between the ball joints is very narrow, then the cost to install may be very high. If the amount of offset is large (say more than 50 inches) with a knife-edge movement, and if the pipe is large (say diameter over 48 inches), then it might be impractical to design a ball-joint-expansion joint type of assembly that can provide adequate margin; or possibly only at a cost higher than that for butt welded steel pipe. These issues should be considered in the actual design process.

If the hazard requires design for a large amount of fault offset (say 5 to 15 feet or more), it would seem apparent that a simple "two ball joints and an expansion coupling" type of assembly will not provide reliable performance. If one considers a series of such assemblies, higher offset can likely be accommodated, but careful design is suggested (reliance on catalog parts alone might not provide suitable assurance). A sufficient number of rotating parts and expansion sleeves may be adequate; but alternate systems (butt welded steel pipe) might provide more capacity, less chance of leak / maintenance issues over the service life, at possibly similar or lower installation costs.

12.2 Equipment Criteria

While these Guidelines are specifically focused on pipes, there are a variety of other components that are part of the entire pipeline system. The following paragraphs provide (limited) guidance on recommended seismic practices for these items. These items are commonly found at large valve vaults, especially those with motor-operated or hydraulically-operated valves, pressure and flow instruments, and SCADA telemetry systems.

- Valves in Vaults
  - In general, the valves are seismically rugged.
  - Actuator and yoke should be supported by the pipe and neither should be independently braced to the structure or supported by the structure unless the pipe is also braced immediately adjacent to the valve to a common structure.
  - Sufficient slack and flexibility is provided to tubing, conduits, or piping which supply air, fluid or power needed to operate the valve.
  - Valves operators should not be near surrounding structures or components that could impact the valve during seismic excitation.
  - The valve body should be strong enough to transmit the axial forces in the pipe. This might be an issue only if the valve is located quite near the source of PGD and the pipe exposed to the PGD outside the vault is connected to the valve inside the vault by continuous (welded or bolted) connections.
- Motor Control Centers (for motor operated valves)
  - Must be floor mounted NEMA type enclosure.
  - Anchorage must be evaluated for seismic loads. At least two anchor bolts should be used per Motor Control Center section.
  - Anchorage of the Motor Control Center must be attached to the base structural members (not sheet metal).
  - Avoid excessive eccentricities when mounting internal components.
  - Do not mount components directly to sheet metal; instead, mount them to the structural frame metal. Otherwise, the sheet metal may vibrate and induce high seismic loads to the components; if the components are not qualified for these loads, they may fail to perform their function.
- Control Panels and Instrument Racks
  - Anchorage must be evaluated for seismic loads.
  - Can be wall-mounted.
  - All door latches must be secured with locking devices.
  - Wire harnesses or standoffs should be installed on cable bundles to preclude large deformation of bundles.
- Batteries and Battery Racks
  - Battery cells can be lead-calcium, weighing 450 lbs. or less.
  - Batteries should be supported on two-step or single tier racks which have x-bracing or other suitable bracing.
  - Batteries should be restrained by side and end rails.

  - Provide snug fitting crush-resistant spacers between cells.
  - Racks must be anchored, and anchorage evaluated for seismic loads.
  - Small gel-type batteries located inside control panels, and commonly used for SCADA-backup power, should be restrained.

- Above Ground Equipment Piping
  - Provide sufficient flexibility at equipment connections and nozzles.
  - Assure flexibility of pipe routed between buildings or across expansion joints.
  - Assure that pipe has sufficient space to displace during seismic excitation without impacting other components or structures.

- Emergency Generators
  - Emergency generators should be anchored directly to the structural floor, or mounted on a skid which is directly anchored to the structural floor. Vibration isolators should not be used unless confirmed by analysis or test (avoid qualification by vendor catalog assertion only unless proper test and qualification data supports the vendor catalog assertion). Components (batteries, day tanks, mufflers, electric panels, etc.) should all be seismically designed. Propane tanks should be anchored. Emergency generators should not rely on piped natural gas.

- Vibration Isolated Equipment
  - Equipment (generators, air compressors and other rotating equipment) mounted on vibration isolators are vulnerable to damage in earthquakes. Vibration isolators for equipment essential to functionality of the facility should not be used. "Snubbed" vibration isolators should only be used if the "snubbing" devices are approved by the engineer as meeting the strength and operational requirements.

- Equipment Anchorage
  - Equipment anchorage is an important consideration in the design to assure functionality. A majority of equipment failures due to seismic loads can be traced to anchorage failure. Below is a brief discussion regarding equipment anchors and situations to avoid during installation.
    - <u>Expansion anchors.</u> The wedge type (or torque controlled expansion anchor) has been widely tested and has reasonably consistent capacity when properly installed in sound concrete. Other types of non-expanding anchors such as lead cinch anchors, plastic inserts, and lag screw shield are not as reliable and should not be used. Proper bolt embedment-length should be assured. Inadequate embedment may result from use of shims or high grout pads. Bolt spacing of about ten diameters is required to gain full capacity. Comparable spacing is required between bolts and free concrete edges. Expansion anchors should not be used for vibrating

equipment as they may rattle loose and provide no tensile capacity. All expansion anchors should be stamped with a letter on the exposed head, which relates to its full length; the lettering system should be shown on the drawings.

- Epoxy anchor bolts. Epoxy anchorage systems may be used for new construction in areas with limited edge distances or limited embedment depths, or in other areas, subject to the environmental limitations on epoxy systems. Inadequate embedment may result from use of shims or high grout pads. Bolt spacing of about ten diameters is required to gain full capacity. Comparable spacing is required between bolts and free concrete edges. Epoxy anchors should not be used for vibrating equipment. All epoxy anchors should be stamped with a letter on the exposed head, which relates to its full length; the lettering system should be shown on the drawings.

- Cast-in-Place Anchors. Properly installed, deeply embedded cast-in-place headed studs and j-bolts are desirable since the failure mode is ductile (steel governs). Properly installed undercut anchors with long embedment lengths behave essentially like cast-in-place bolts and are similarly desirable. Care should be taken to extend anchors through grout to provide required embedment in the concrete below. Bolt spacing and edge distance requirements are the same as for expansion anchors.

- Welded Anchors. Well designed and detailed welded connections to embedded plates or structural steel provide high capacity anchorage. There are some precautions: Avoid welding to light gage steel members if possible. Line welds have minimal resistance to bending moments applied about the axis of the weld. Puddle welds and plug welds used to fill bolt holes in equipment bases have relatively low capacity. Welded anchors in damp areas or harsh environments should be checked periodically for corrosion.

- The minimum design forces for anchorage and bracing of equipment and non-structural components and for structural design of these components should be as follows:

$$F_p = Z * I * C_p * C_f * C_g * W_p$$

where

ZI = the combined free field peak ground acceleration (should be taken for a 475-year return period motion) times an importance factor. For components that are considered critical for immediate post-earthquake operation, ZI should use I=1.5; or base Z using the 2,475 year motion for the site and I=1.0; whichever is larger. Or, base ZI on the 84th percentile motion for the site for the design-basis earthquake.

C_p = a factor to account for in-structure amplification, and some amount of ductility capacity of the component. For components mounted at grade or below, generally set this factor to 1.0. For components mounted at second floor or higher locations in a structure, consider local building amplification. No ductility should be considered for drilled-in or epoxy anchors. Adjusting Cp downwards for ductility is not advised for any component required for immediate post-earthquake operation.

C_f = Flexibility coefficient as follows:

- 1.0 for rigid components, rigidly mounted and braced to the supporting structure or foundation. A component installation is considered rigid if the first mode natural period of vibration of the mounted assembly is 0.06 seconds or less.
- 2.0 for flexible components, or rigid components flexibly mounted such that the first mode natural period of vibration is greater than 0.06 seconds.

C_g = Grade mounting coefficient as follows:

- 1.0 for components mounted at or above grade.
- 0.67 for components mounted below grade.

- The effects of vertical ground motion should be evaluated together with the effects of horizontal ground motion and design should be for either of the following load cases:

  $$F_e = F_h$$

  or

  $$F_e = \sqrt{F_h^2 + F_v^2}$$

  whichever produces the most severe effects, prior to combination with other loads required by the building code.

- A minimum factor of safety of four (against average test failure capacity) should be used for expansion or epoxy anchors used for equipment anchorage. This factor of safety can be reduced to 2 if the anchors can be shown to be at least 97% reliable at that load level.
- Earthquake restraints for above ground small bore piping, raceway and conduit systems, as determined by typical building codes, are oriented to reducing life safety risk, by limiting the falling potential for these items. Post earthquake functionality of these systems is not assured by following the UBC or IBC codes, and in some cases, the UBC- or IBC-mandated support systems may increase the potential for functional failures. Restraint systems other than that required by the UBC or IBC codes may be used, if justified by the engineer.

The following equipment can be considered as structurally and reasonably functionally rugged, and need be designed only for the minimum anchorage forces and the other recommendations in these Guidelines and other applicable documents:

- Valves
- Engines
- Motors
- Generators
- Turbines
- Hydraulic and Pneumatic Operators (limited yoke length)
- Motor Operators (limited yoke length)
- Compressors
- Transformers with anchored internal coils

The following equipment can be considered as structurally rugged, and need be designed for the minimum anchorage forces and the other recommendations in these Guidelines and other applicable documents. In addition, if post-earthquake operability of the equipment is critical, functional seismic qualification should be addressed by a knowledgeable engineer. Functional seismic qualification may be based on test or experience with similar equipment.

- Air handling equipment and fans (except for those with vibration isolators)
- Low and Medium Voltage Switchgear (< 13.8 kV)
- Instrumentation Cabinets
- Distribution Panels
- Battery Chargers
- Motor Control Centers
- Instrument Racks
- Batteries
- Inverters
- Chillers

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