REVIEW OF PERFORMANCE OF GASKETED JOINTS OF BURIED CONCRETE AND STEEL PIPELINES IN CALIFORNIA AFTER RECENT SEISMIC EVENTS

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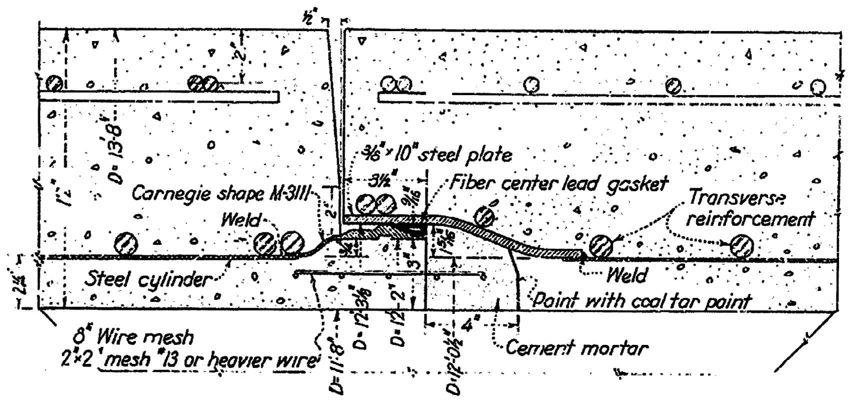
Abstract: The history of steel bell and spigot joints with fiber-center lead gasket for concrete pressure pipe in California dates back to 1933, and the modern joints with O-ring gaskets for concrete and steel pressure pipelines to 1940. The performance of these gasketed joints in the seismically active region of California has been excellent. There have been isolated occurrences of damage to both unrestrained gasketed joints and welded restrained joints. The damage generally occurred at the end of concrete encasements or at structures or near bends.

Several case studies will evaluate the effect of three large recent earthquakes on nearby pipelines. This paper will show that the empirical evidence suggests that gasketed joints of concrete pressure pipe and intermediate diameter steel pipe perform well in earthquakes and they should be considered for pipeline projects in seismically active regions. Recommendations will be made regarding measures that may reduce the risk of damage to pipelines using gasketed joints.

INTRODUCTION

There are four types of concrete pressure pipe which use gasketed joints. They are Reinforced Concrete Cylinder pipe (RCCP); Prestressed Concrete Cylinder pipe (PCCP); Reinforced Concrete non-cylinder pipe (RCP); and Bar-Wrapped Concrete Cylinder pipe (CCP). Welded steel pressure pipelines (WSP) usually utilize gasketed joints up to a diameter of 60 inches and use restrained welded joints for larger diameters.

A steel bell and special Carnegie shape spigot (M3111) with fiber-center lead gasket joint, shown in Figure 1, has been used in California since 1933 in many RCP and RCCP projects for pipe diameter up to 148 inches. Since 1940, the current steel bell and Carnegie spigot joint with O-ring gasket, shown in Figure 2 has been used for RCP, RCCP and PCCP for pipe diameters up to 201 inches. Also since 1940 RCP



LOCK JOINT FOR STEEL CYLINDER REINFORCEMENT

Figure 1. This joint can transmit the seismic axial thrust forces and also allows for a very limited joint extension to relieve the tensile seismic forces.

without a cylinder, two types of joints used are the concrete bell and spigot with confined O-ring, and concrete spigot to concrete spigot with a steel sleeve and two confined O-rings. For CCP and WSP, the gasketed joint in Figure 3 has been used since 1940; steel pipe also has other gasketed joint configurations shown in the AWWA M11 Manual.

Under seismic events, two phenomena occur: (1) transient movement and deformation of the soil and (2) permanent ground displacement due to fault movement or large scale soil movement (O'Rourke and Liu 1999). Soil strains resulting from seismic waves induce stresses and deformations in the pipe barrel and pipe joints. The soil strain along the pipeline can be compressive or tensile or can cause curvature in the line. The curvature effect is usually small. The magnitude of tensile or compressive soil strain can be estimated conservatively as the ratio of peak

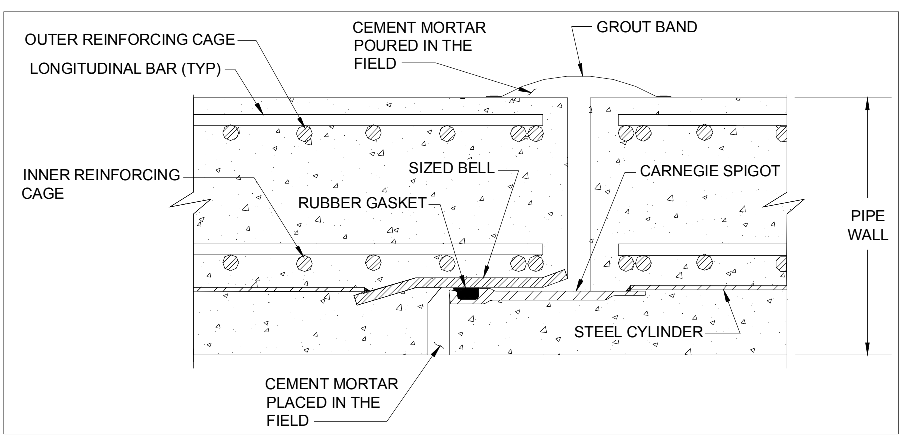


Figure 2. This standard joint can transmit the seismic axial compressive thrust forces and also allows for approximately 1/2 inch reserve joint extension, assuming that one inch joint extension will be used during installation, to relieve the tensile seismic forces.

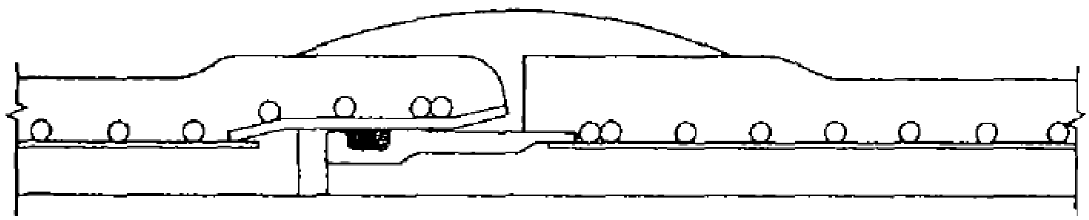


Figure 3. This joint can transmit the seismic axial compressive thrust forces and also allows for approximately 3/8 inch reserve joint extension, assuming that ¾ inch joint extension will be used during installation, to relieve the tensile seismic forces.

ground velocity and the apparent wave length in the plane of ground, usually taken at about 3000 fps (ASCE 4-98). Compressive strain in the soil introduce compressive stresses (and compressive forces in the pipe that is proportional to the soil strain and axial stiffness, EA) in the pipe and compression of the joints as the joints are not free to deform in compression. Large diameter concrete pressure pipe with gasketed bell and spigot joints can resist these movements because they have good compressive strength and beam strength. The tensile strain in the soil causes tensile strains in the pipeline. The joints allow small relative movements which relieves the tensile forces. When large ground displacements are anticipated, special designs including extended joints, short length pipe, restrained joints, and changes in alignment have been successfully used.

In general, pipe with gasketed joints can resist earthquake forces. There have been isolated occurrences of damage to unrestrained gasketed pipe joints and restrained welded joints. The damage generally occurred at the end of concrete encasements, near structures or near bends. The locations of damage generally occur where the pipe is restricted from moving or moves differently from the rest of the pipeline.

SEISMIC FORCE EFFECTS IN SPECIAL CASES

Effect of Joint Restraint: The joint restraints do not allow relative joint movement; therefore, tensile forces will be transmitted to the pipe and the joint, for which the pipeline must be designed.

Effect on Connection to a Large Structure: The motion of the soil is modified significantly near a large structure. The pipeline away from the structure moves with the soil and near the structure moves with the structure, resulting in significant relative motion for which the pipeline must be designed.

Effect of Bends: Near bends the pipe cannot move with the ground because the soil cannot resist the large axial forces that develop in the pipe without significant deformation relative to the soil. The deformation of the pipe, which requires harnessed joints, reduces the axial force but increases the bending moment of the pipeline for which the pipeline must be designed (ASCE 1984, Kan and Zarghamee 2002).

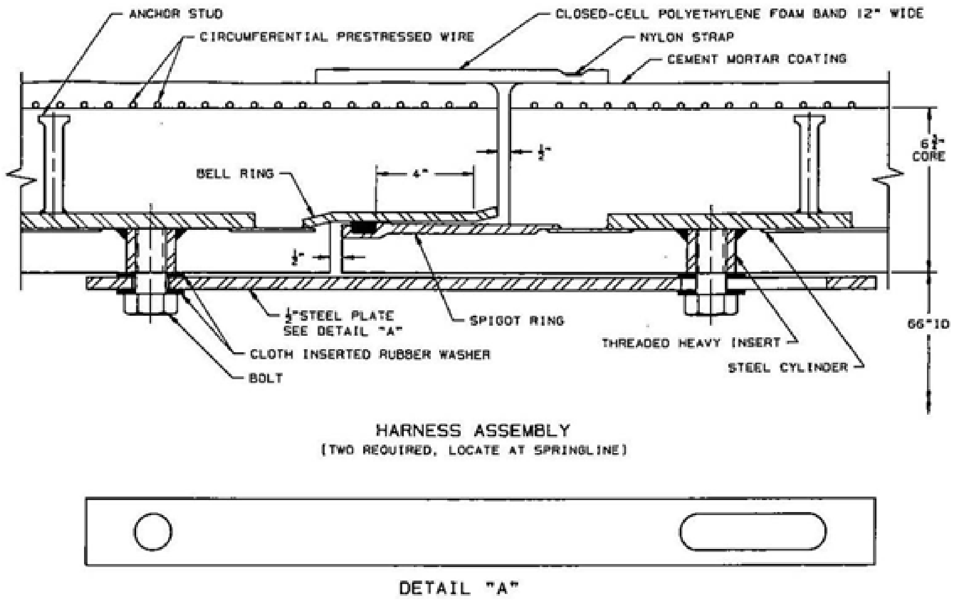


Figure 4. Special Gasketed Joint with Internal Harnesses which will allow a 4- inch joint extension for two parallel 66-inch PCCP lines crossing the Calaveras Fault. The same joint can be used without the harnesses as an extended joint for anticipated large /seismic deformations.

Effect of Change in Axial Stiffness: When the axial stiffness of the pipe changes, such as in an encasement of a section of a pipeline, the large axial force developed in the stiffer pipe will be applied to less stiff pipe. If the relative motion is not allowed at the joint, the less stiff pipe must be designed for the force.

INSPECTION RESULTS OF TWO PARALLEL 66-INCH DIAMETER PCCP PIPELINES AFTER 1989 LOMA PRIETA 6.9 EARTHQUAKE

The Calaveras Fault in Northern California is a major branch of the San Andreas Fault. The U.S Bureau of Reclamation's (USBR) San Felipe project in Northern California, which was completed in 1986, conveys water through approximately 50 miles of concrete pressure pipelines into four Counties in Northern California. The pipelines consisted of 18 miles of 42-inch, 54-inch and 60-inch diameter CCP, 22 miles of 96 inch-diameter PCCP and 8 miles of 120-inch-diameter PCCP. At the Calaveras Fault crossing, the 96 inch diameter Santa Clara Conduit branched into two 66-inch diameter PCCP parallel lines with a special joint design. These lines begin at a wye fitting near an Inlet Structure. The 66" diameter lines are 2600 ft long and join together again at a wye fitting near an Outlet Structure. One 96 inch-diameter flexible coupling was installed before the Inlet Structure and one was installed after the Outlet Structure. It appears that due to the gradual settlement of the Inlet Structure the 96-inch diameter flexible coupling outside the structure was leaking slightly and it was repaired on a few occasions before the earthquake. There was also a small leak at one of the 66" diameter joints between the steel to PCCP adapter outside the Inlet Structure which was repaired before the earthquake occurred. The 66"pipe was constructed using a special joint with two internal harnesses at springline, shown in Figure 4, which can withstand 4 inch joint movement. The design concept was based

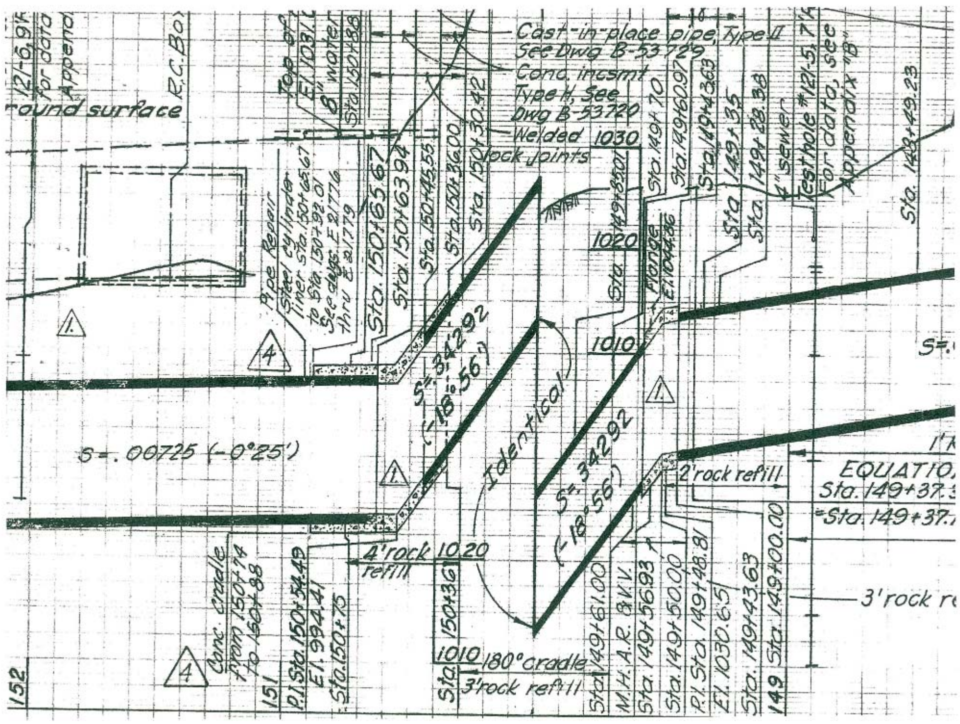


Figure 5. Sepulveda feeder partial profile at the concrete encasement and joint repair at the end of the encasement.

upon a crossing angle of approximately 49º which will result in joint tension (i.e. the joint will only open or deflect if the fault moves).

One of the 66-inch diameter lines was drained after the 1989 earthquake. The inspection revealed that only one joint has moved and opened up approximately ½ in. This movement was not at the center of the fault but it was near the Outlet Structure; No joint movements were observed near the Inlet Structure.

INSPECTION RESULTS 150-INCH AND 54-INCH DIAMETER PCCP PIPELINES AFTER 1994 NORTHRIDGE 6.7 EARTHQUAKE

The Metropolitan Water District of Southern California (MWD) is the largest Water Agency in Southern California. MWD has approximately 400 miles of four types of concrete pressure pipe (RCP, RCCP, PCCP and CCP) in their conveyance system with pipe diameters ranging from 39 inches up to 201 inches and installed between 1934 and 1985. The Sepulveda Feeder a 150- inch- diameter PCCP pipeline, installed in 1968, and the West Valley Feeder No. 1 a 54-inch-diameter PCCP pipeline, installed in 1962 are part of the MWD water conveyance system. Two instances of

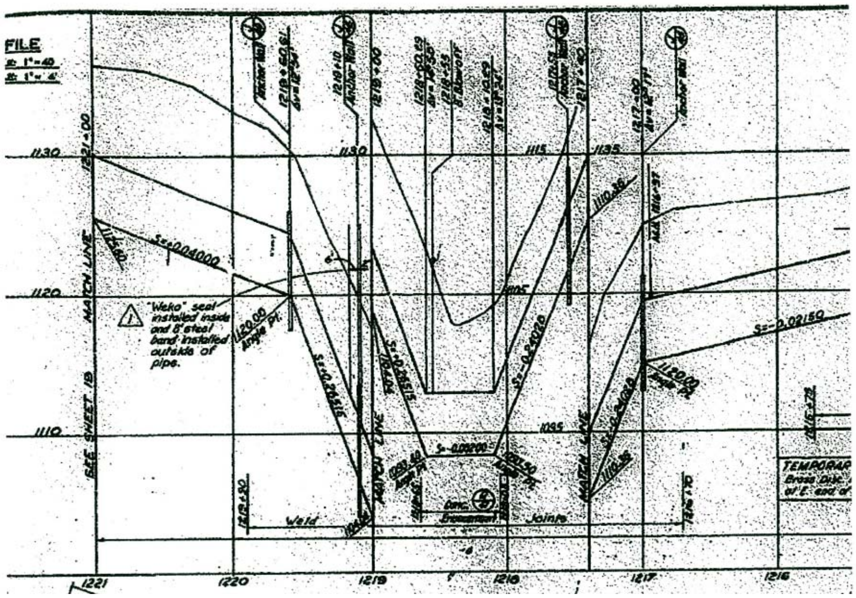


Figure 6. West Valley Feeder crossing profile showing the encasement at the bottom and joint damage.

damage in those two pipelines after the 1994 Northridge earthquake with a magnitude of 6.7 will be discussed.

Damage and Repair of a 150-inch- Diameter PCCP Pipe Section in the Sepulveda Feeder

After the earthquake, a leak was discovered in the 150- inch- diameter Sepulveda Feeder at the end of a reinforced-concrete encasement as shown in Figure 5. This figure depicts the localized profile of the damaged area and the permanent repair notes. The encasement was designed for 30 feet of cover and ended initially at station 150+65.67 at the bell end of a pipe section. The joints were welded from station 150+36.00 to station 150+ 65.67. The next pipe after the encasement was between station 150+65.67 and station 150+76.15. The joint at station 150+76.15 was a gasketed joint, and the joint at 150+ 65.67 was a welded joint. An internal inspection found a minor leak in that area and it was thought initially that the gasketed joint at station 150+ 76.15 was leaking. However it was discovered during the permanent repair that the leak was coming from a tear in the steel cylinder at springline near the welded joint at station 150+ 65.67. The cylinder was probably damaged because the encasement will not move as readily as the pipe. As a result the cylinder was damaged due to compression failure. In 1998, a new steel liner was installed between station 150+65.67 and station 150+92.01 (McReynolds,1999); in addition a 180º concrete cradle or cap was placed between station 150+74 and 150+88.

Damage and Repair of a 54-inch- diameter PCCP Pipe Section at a Crossing in the West Valley Feeder

Figure 7. Extensive Damage (right picture) to the Mexicali-to-Tijuana Highway at kilometer 20 at the Laguna Salada Fault Crossing. The Fault line can be observed in the left picture.

After the Northridge earthquake a leak was discovered in West Valley Feeder No. 1, near a joint in an inverted siphon with restrained joints (see Figure 6). The slope angle at the longer side is 15º and 105 feet long, and the slope angle at the shorter side is 13.5º and 53 ft long. The length of the crossing at the bottom, which was encased in concrete, was 60 ft. The joints at the bottom and on both slopes were welded for a total length of 320 feet. The pipe had several cutoff walls to protect it from erosion. The 54- inch PCCP pipeline was damaged near one of the cut off walls. The pipes movement was restricted by the cutoff wall and encasement, resulting in large difference in deformations of the pipe and the soil, which contributed to failure. A temporary repair was made by installing a "Weko" seal inside the pipe and installing an 8-ft-long steel band on the outside the pipe. This portion of the pipeline was relocated and replaced a few years later.

INSPECTION RESULTS OF 60-INCH DIAMETER WSP AND PCP PIPELINES AFTER 2010 NORTHERN BAJA 7.2 EARTHQUAKE

The Rio Colorado Project included 13.5 miles of 60 inch diameter welded steel pipe with double gasketed joints as shown in Figure 8. The new pipeline is parallel to the Mexicali-Tijuana highway, installed within 50 feet from the highway, and crosses the Laguna Salada Fault in Northern Baja. The new pipeline has been operating since September 2009. Also parallel to the highway near the fault is another existing 60-inch-diameter prestressed concrete pipeline with gasketed joints.

Inspection of both 60-inch-diameter pipelines by the owner and the installation contractor verified that no damage has occurred to either pipelines at or in the vicinity of the Laguna Salada Fault, despite severe damage to the highway as shown in Figure 7. The owner requested that the contractor conduct potholing at several locations over the 60-inch-diameter steel and 60-inch-diameter prestressed concrete pipelines for verification that no damage has occurred, and a report was also written.

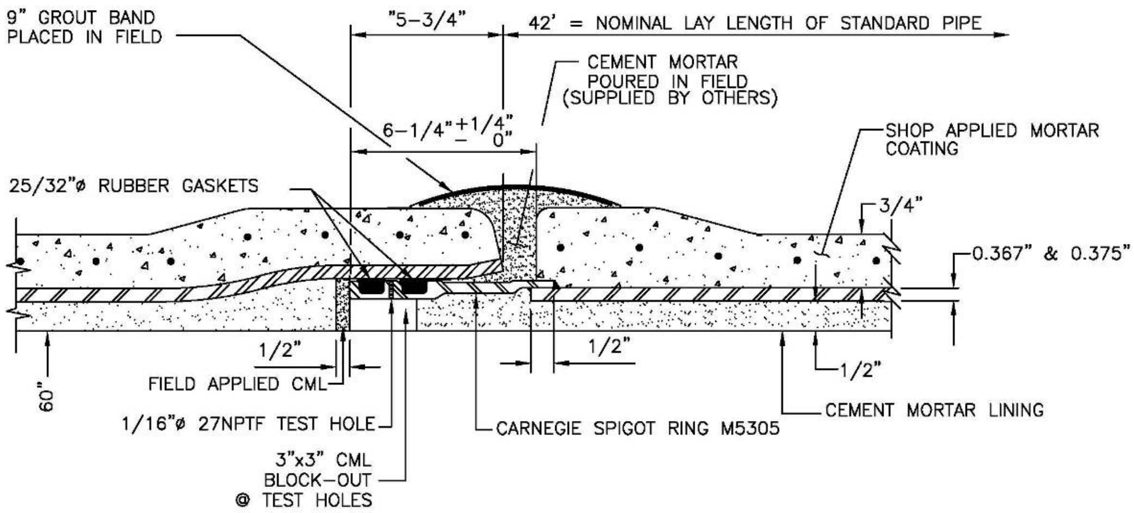


Figure 8. This joint allows for a total joint extension of 2 inches including an installation allowance of 1 inch. If the inside far gasket is scarified an additional joint extension of 1 ½ inch can be tolerated

LESSONS LEARNED AND RECOMMENDATIONS

At Concrete Encasements.

The following provisions are recommended:

- Avoid using restrained welded joints at end of encasements. When welded joints are utilized use thicker cylinders in the pipe in order to resist the compressive and the tensile forces and use a transitional concrete cradle between the encasement and the first unrestrained gasketed joint.
- If encasements are required, consider providing two flexible couplings or special joints to accommodate the differential movement.
- Use thicker cylinders in the pipe at inverted siphon crossings, with concrete encasement at the bottom and welded joints, in order to resist the compressive and the tensile forces.

At Fault Crossings

The following provisions are recommended when large seismic deformations are anticipated:

- Consider using flexible joints similar to Figure 4 without the harnesses, or use double gasketed joints similar to Figures 8 and 9. Also use shorter pipe lengths.
- Cross the fault so that the movement puts the flexible joints in tension.
- At fault crossings, a seismic analysis by a qualified consultant should be conducted to evaluate the seismic stresses and deformations in the pipe wall and joints.

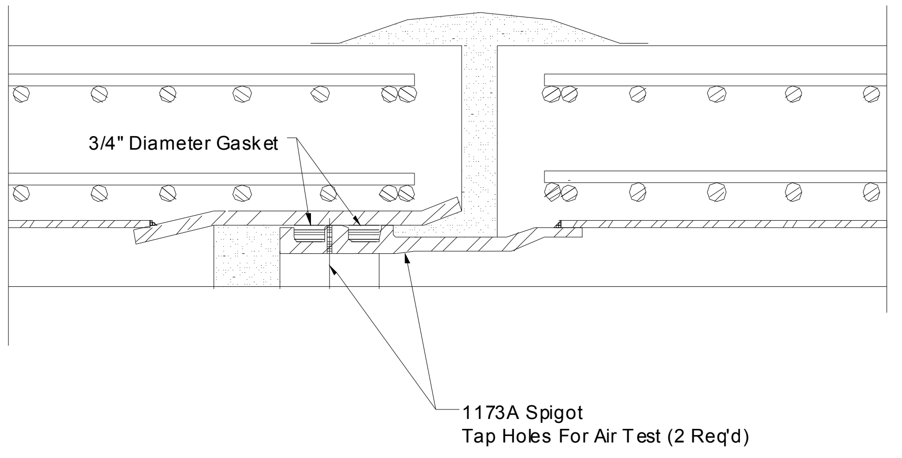


Figure 9. This joint allows for a total joint extension of 2 inches including an installation allowance of 1 inch. If the inside far gasket is scarified an additional joint extension of 1 ½ inch can be tolerated.

INHERENT-STRENGTH AND DESIGN RECOMMENDATIONS FOR CONCRETE AND STEEL PRESSURE PIPE SUBJECTED TO SEISMIC LOADS

RCP and RCCP

- Use a minimum wall thickness of D/12 where D is the nominal pipe diameter. This will provide additional axial thrust capacity to resist axial compressive stresses and deformations. The additional wall thickness will also help resist beam bending
- Use grout bands with closed cell polyethylene backing at joints. Standard joints can transmit axial compressive thrust across the joint and can move to relieve the tensile seismic forces. Based on tests and field observations, joint grout bands with closed cell polyethylene backing can bridge cracks in the joint grout up to ½ inch.
- Design of the pipe to resist seismically induced forces should be performed for load combinations and load factors of the current codes. In designing the pipe according to AWWA M9, capacities may be increased to account for the inherent safety factors. This means that the pipe has excess capacity to resist seismically induced transverse thrust and moment.

PCCP

- Design of the pipe according to AWWA C304, which is based on limit states-design, in the circumferential direction and according to AWWA M9 in the longitudinal direction, includes inherent safety factors. The inherent safety factors provide excess capacity for seismic load resistance.
- Use grout bands similar RCP and RCCP.

CCP and WSP

- The maximum ring deflection after installation for CCP and WSP is usually limited to D/40 % and 2%, respectively. The actual safe deflection limits are approximately 50% more which can be utilized to resist seismic loads.
- CCP and WSP must be designed for both strength and buckling resistance resulting from compression wave.
- Use grout bands similar RCP and RCCP.

CONCLUSIONS AND RECOMMEDATIONS

- The overall performance of unrestrained gasketed joints for buried concrete and steel pipelines subjected to seismic events has been excellent. There have been isolated occurrences of damage to unrestrained and restrained joints. The damage generally occurred at the end of concrete encasements or connection to large structures, or near bends.
- The use of concrete encasement should be avoided unless provisions are made to accommodate differential movement or the pipe strengthened to resist induced forces.
- Restrained welded joints at end of encasements should be avoided unless absolutely required. If required use thicker cylinder to safely resist seismic forces. Additionally considerations should be given to use a transitional concrete cradle until the first flexible joint; or a few unrestrained joints with long extension capability that can accommodate the total expected motion.
- The design capacities calculated for concrete and steel pressure pipelines according to M9, AWWA C304, and M 11 procedures normally provide excess capacity which can be used to resist seismic forces.

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