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LIFELINE PIPELINE RESTORATION AND SEISMIC MITIGATION

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SUMMARY

A number of methods are discussed which can be used for lifeline pipeline rehabilitation and improving the seismic performance of pipelines used for water, wastewater, natural gas, liquid fuel; and conduits used for electric power and communications cables. Many of these methods use the trenchless technology process which minimizes disruption to traffic, business and residents and also reducing the time of construction and costs.

INTRODUCTION

A lifeline pipeline can convey water, wastewater, storm drainage, natural gas and liquid fuels and a lifeline conduit can contain electric power and communication cables. Lifelines are those systems and facilities necessary for the functioning of an industrialized society and also necessary for emergency response and recovery after a natural disaster, such as an earthquake. The seismic hazards that may impact pipelines and conduits are faulting, shaking, liquefaction and landslides. Also they may be damaged by another lifeline system which is damaged and is co-located with the pipeline or conduit. Temporary repair of pipelines and conduits are necessary to restore utility service to medical facilities, police and fire stations, and emergency operating centers. Also necessary is water for public fire protection, natural gas for cooking and space heating and liquid fuel for operation of emergency equipment and lifeline facilities. Temporary repairs are made to prevent floods from broken water lines, fires and explosions from broken gas and fuel lines, and sewers and storm drains to prevent pollution and the spread of disease. Restoration of power and communications facilities are necessary for emergency response and recovery. Eventually pipelines and conduits are repaired to provide service to homes, business and industry.

Permanent pipeline replacement is made to increase seismic resistance, improve or increase flow or cable capacity, and minimize leaks of gas, fuel oil and water and wastewater. These leaks result in unaccounted for gas, fuel oil and water and result in loss of revenues. However, in some cases relocation is necessary because of interference with a new structure or other lifelines.

Difficulties in implementing seismic mitigation or rehabilitation of pipelines and conduits is normally financial, which requires management and sometimes public and political support. However, in some cases the lack of good information on the condition of pipes, and the operational restraints necessary to maintain service may impact the decision process. Financing the program may come from normal rates charged for the quantity of product used, emergency surcharges, taxes approved by the governing body, general obligation or revenue bonds, insurance, government grants or loans.
Repair, rehabilitation and seismic mitigation of lifeline pipelines can be divided into emergency, temporary and permanent installations.

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2. EMERGENCY SERVICE

Emergency supply of water can be provided by tank trailers, tank trucks, bottled water, side lining (temporary pipelines), portable hose, etc. Waste water pipeline damage can be bypassed by pumping from an upstream manhole to a downstream manhole. Gasoline and diesel fuel can be supplied by tanker trucks. Underground power and communication service can be provided by an overhead temporary pole wire or cable system.

3. TEMPORARY REPAIRS

Temporary repairs will permit quick restoration of service and can be done in a number of ways depending on the damage. Pressure pipeline repairs are treated in a different way than gravity pipelines. Water and wastewater line repairs can be done by redwood plugs which swells sealing off small holes, repair clamps and replacement of small section of pipe with new pipe especially when there is longitudinally cracking. Steel tendons or reinforcing rods can be wrapped around damaged concrete pipe or conduit and encased in concrete. Temporary pipelines can be placed above ground with temporary service connections to the users to be in operation until permanent repairs or replacement has been made. Gas and liquid fuels lines can use some of these methods; however, caution should be observed in the repair of high pressure lines. High pressure water, gas, liquid fuel pipe may be repaired using welded butt straps internally or externally to seal circumferentially cracked pipe. The above repairs may not all have seismic mitigation capabilities.

4. PERMANENT REPLACEMENT

Underground permanent replacement, if repair is not feasible, and seismic mitigation if desired, can be done by two methods, trench excavation or trenchless technology.

4.1 Trench Excavation

Replacement of pressure pipelines using trench excavation method, using welded steel pipe with welded joints and ductile iron pipe with rubber gasket joints has shown good performance in past earthquakes. These types of pipe can be joined by various types of mechanical couplings which provide flexibility during a seismic event. Trench excavation in an urban area with busy roadways causes disruption of traffic and disturbs the residents and businesses. The type of joints used in this pipe is important for good seismic performance. Joint types will be discussed later in this report.

4.2 Trenchless Technology

Trenchless replacement pipe installation has increased in popularity in urban areas, because of its lessened impact on traffic, residents and businesses. The pipe or conduit rehabilitation has some value towards seismic mitigation; however, it cannot be specifically quantified. Also important is the fact generally new pipe occupies the existing space among other substructures in a somewhat crowded area with other utilities. Also trenchless technology can reduce the cost, time of construction and minimize impact on the ground surface environment. All of the methods require a drained pipe to implement.

Bore hole, jacked casing, pipe insertion, slip lining, cement mortar lining and pipe bursting are several types of construction used in trenchless technology. Where there is an existing pipe an inspection of the pipe is made to determine its internal condition. Self propelled television camera can be used to inspect the interior of the pipe for smaller diameter pipes or conduits (Figure 1). The real time image can be viewed on a television monitor and a tape can be prepared for future use (Figure 2). Sharp angle points and some types of valves may have to be removed to permit the television camera to passed through the pipe. Large diameter pipes can be inspected by personnel physically traveling through the pipe. Trenchless technology usually requires two access pits (entrance and exit); one at each end of the pipe to be installed or rehabilitated, except for the bore hole and jacked casing methods.

4.2.1 Bore Hole

Bore hole method is where a horizontal hole is made in the soil by a rotating auger or hydraulic water pressure which erodes the soil creating a round hole and subsequently a pipe is inserted in the that hole. This method is generally used for short distances under roadways, sidewalks, freeways and railroads and for smaller diameter of pipes.

4.2.2 Jacked Casing

Jacked casing method is again for short distance, for larger diameter pipe and is a mining operation. Generally hand excavation is done in the soil within a jacked steel or concrete pipe casing. The protective casing is jacked into the excavation by hydraulic jacks as the excavation progresses. The permanent pipe is installed into the casing and the annular space between the casing and the permanent pipe is filled with cement grout.

4.2.3 Cement Mortar Lining

The rehabilitation of existing water mains by cleaning and cement mortar lining permanently improves the hydraulic capacity, seals joints and pinhole leaks and improves water quality by minimizing taste and odor problems associated with unlined pipe. Temporary bypass lines are first laid above ground to maintain customer water service prior to the cleaning and lining operation. After inspection and the pipeline is cleaned, using a scrapper and squeegee cleaning device; a cement-mortar is premixed above ground and pumped to the lining machine through high-pressure rubber hoses inside the pipe. The cement mortar lining machine consists of a rapidly spinning dispensing head that centrifugally applies a uniform coating of cement, sand and water to the pipe wall as the lining machine is winched through the pipe (Figure 3). As the cement-mortar is applied, a flexible conical troweling device follows behind to produce a smooth hydraulically efficient surface. In large diameter pipes the smoothing of the cement-mortar is done with rotating trowels instead conical troweling device. Cement-mortar lining is generally not considered a seismic improvement; however, the fact the fact that old valves, fittings and service connections are upgraded during rehabilitation, it provides some seismic improvement. In the 1994 Northridge earthquake, field personnel observed old cast iron and steel pipe which had been cement mortar lined in place appeared to have a lower frequency of leaks; however, this has not been scientifically documented

4.2.4 Pipe Insertion

Pipe insertion method is done in existing larger diameter pipes, where retaining the diameter for flow capacity is not critical. The existing pipe requires inspection, cleaning and the removal of valves and sharp bends. Prefabricated welded steel pipe is installed within the annular space of the old pipe and joints are welded. The annular space between the old pipe and the new pipe is filled with cement grout.

4.2.5 Slip Lining

Slip lining method using high density polyethylene (HDPE) pipe is done on existing pipe in both the small and large sizes mainly for gas, water and wastewater lines. The British gas industry has been the pioneer since the 1970’s, in using slip lining technologies to rehabilitate gas mains. Later wastewater agencies started using the slip lining method for sewer mains. Gas mains rehabilitated with HDPE pipe performed well in the 1994 Northridge earthquake. The use of HDPE pipe for water service has lagged due to the approval process for the material to be used in potable water systems.

Television inspection is done on the pipe to identify unknown obstructions (valves, bends or connections). The sharp bends and valves are removed and then the pipe is cleaned. The HDPE pipe is laid out along a roadway (Figure 4) , joints are fused together under high temperature and pressure (Figure 5). The HDPE pipe is pulled through the existing host pipe. Connections are made to existing pipe by a specially fabricated bolted flanged connection. The HDPE pipe can either be smaller than the existing pipe or through a special process (pipe bursting to be discussed later) maintain the same inside or increase the inside diameter the host pipe.

4.2.6 Pipe Bursting

The Pipe Bursting Process simultaneously breaks the old pipe pushing it into the surrounding soil while the new pipe is pulled into place. Again this is done after a television inspection and removal of gate valves and sharp bends and the cleaning of the pipe. The HDPE pipe is laid out along a roadway, joints are fused together under high temperature and pressure as in the slip lining process. An expander on the pipe bursting tool increases the diameter of the hole. The pneumatic tool is guided through the old pipe by a cable, pulled from the pipe’s opposite end. An internal reciprocating piston breaks the pipe and supplies the force for most of the forward motion (Figure 6). The HDPE pipe is attached and immediately follows the expander tool into the existing host pipe. A large capacity portable compressor is used to drive the pneumatic tool (Figure 7). Sometimes an extension in front of the expander tool, called a schnoze, is used to help guide the expander tool in the host pipe. Connections are made to existing pipe by a specially fabricated bolted flanged connection. The new pipe is a high density polyethylene (HDPE) material which can be up to 50-mm (2-in) thick depending on system pressure. Even with the same diameter this new pipe reduces the hydraulic friction and automatically increases the flow capacity. Also this process provides an opportunity to increase the pipe diameter up to 25% in diameter to further increase the capacity of the pipe or conduit.

While most pipe bursting jobs use the pneumatic type of bursting tools there are other types. There is static bursting which pulls a splitting head into the host pipe and fractures the host pipe by the constant pulling by the chain or cable attached to the splitting head. The other method used is the hydraulic actuated bursting head to fracture the pipe. A cable attached to the front of the bursting head pulls the devise through the pipe. Again the new HDPE is immediately pulled through the expanded pipe. These systems can be used for water, wastewater, storm drainage and gas systems, as well as upgrading telephone and power circular conduits.

4.2.7 Other Lining Systems

There are several methods available for gravity and pressure pipe systems which are trade names of the Insituform Technologies, Inc.

The **Paltem System** uses a continuous woven polyester hose with an elastomer coating and can be used in pipelines up to 1000-mm (40-in) in diameter and through bends up to 90 degrees. The uncoated side of the liner is covered with an epoxy resin. Compressed air or water pressure is then used to invert (turn inside out) and propel the liner through the pipe from the access pit. This is called the inversion process. Heat or ambient temperature is used to cure the epoxy resin and adhere the liner to the inside of the pipe. The ends of the liner are then cut off and the end seals are installed before the line is placed back into service.

Pressure **Pipe Liner** is like the Paltem System for structurally sound pipe system. The system uses a reinforced felt tube and modified resin system. It can be installed in diameters 200- to 1200-mm (8- to 48-in) in diameter and uses the same inversion process as the Paltem.

The **Thermopipe System** is used for rehabilitating small distribution mains, 100- to 200- mm (4- to 8-in), and has a long term hydraulic pressure rating of 1000 kPa (150 psi). The system is polyethylene tube reinforced woven polyester fiber and is factory folded in a “C” shape. It is then wound onto a reel which enables it to be transported to a job site. The liner is winched into the pipe and is re-rounded using steam and air pressure, so that it closely fits the existing inside diameter of the pipe. End seals are installed before the line is placed back into service. It can

be used to rehabilitate pipes of all common materials and can be used through slight bends.

5. JOINT SYSTEM

The joint system is critical in the seismic performance of segmented piping systems. Butt welded joints have shown better performance in past earthquakes than bell and spigot welded joints. One of the better joint systems is one that permits both transverse and longitudinal movement of the joints for water, wastewater and industrial pipelines. This type of joint is available in sizes up to 1500-mm (60-in) in diameter, and is about 30% more expensive than conventional pipe joints (Figure 8). It performed very well in the 1995 Kobe earthquake. This joint is normally used for inlet/outlet connection to tanks and reservoirs, and at large service connections, but it may be used at other critical locations, such as, fault crossings.

The butt welded joint system avoids the eccentricity of the conventional bell and spigot joints. Butt welded joints on gas lines performed well in the 1994 Northridge earthquake. Studies at the Cornell University, New York are being performed to improve the performance of the bell and spigot joint, by changing the configuration of the bell and spigot or by applying a reinforcing plastic wrap around the joint. The ductile iron seismic joint (S1 and S2) with rubber gaskets used in Japan performed very well in the 1995 Kobe earthquake.

6. CONCLUSIONS

Implementation of seismic mitigation program should be done after completion of a seismic vulnerability analysis of the entire utility system. The mitigation program also requires an updated and practiced emergency response and

recovery plan. Pipeline utilities in areas of seismic activity should maintain an inventory or locate, list and continuously update emergency resources of temporary bypass piping, pipe, fittings, repair clamps, equipment and construction industry specialized trained personnel.

The previous discussion provides alternatives for lifeline pipeline restoration and seismic mitigation. The seismic mitigation has not been quantified and will vary depending on the materials and type of joints used.

1. The direct replacement of pipelines and conduits with seismic resistant materials will provide the best seismic performance. For water, liquid fuel, and natural gas systems welded steel pipe with butt welded joints has performed well in past earthquakes. Ductile iron pipe with rubber gasket joints with a seismic restrained joint performed well in the 1995 Kobe earthquake for water systems. Also polyethylene pipe for natural gas distribution has done well. Most of these replacements are done using the open trench technology.

2. Various forms of trenchless technology have an advantage over open trench technology.

a. The placement of newer seismic resistant materials within an existing pipe or opening below ground will improve the seismic performance depending on the materials and type of joints used.

b. Minimizes disruption to traffic, business, and residents by eliminating the open trench and in some cases the excavated earth spoil deposited on the street, and the ground surface environment.

c. The replacement pipe or conduit occupies the same space in the street, especially valuable in urban areas where there is competition for space with other underground utilities.

d. Maintains a stable foundation for facilities which place heavy loads on the ground surface, such as, railroads, trucks, etc.

e. Requires minimum waste disposal of excavated soil and broken street pavement

f. The cost of installation is generally less than open trench technology depending on the method used and for cement mortar lining could be as low as 1/3 the cost of open trench methods depending on the condition of the host pipe.

g. The time of construction may also be reduced.

h. In sensitive environmental areas the impact on the environment is minimal.

7. REFERENCES

American Society of Civil Engineers, *Pipelines in the Constructed Environment,* Proceedings of the 1998 Pipeline Division Conference, August 23-28, 1998, San Diego, California, Edited by Joseph P. Castronovo and James A. Clark, Reston, VA, 1998

Insituform Technologies, Inc., *Technical Bulletins*, Chesterfield, MO, 1998

Personal contact with Estela Bueno and Michael Grahek, Los Angeles Department of Water and Power; Rob Lauterborn and George Mallakis, J. Fletcher Creamer and Son, Inc.; Collins K. Orton, TT Technologies, Inc.; and Byron Weinstein, Civil Engineer. 1998-99

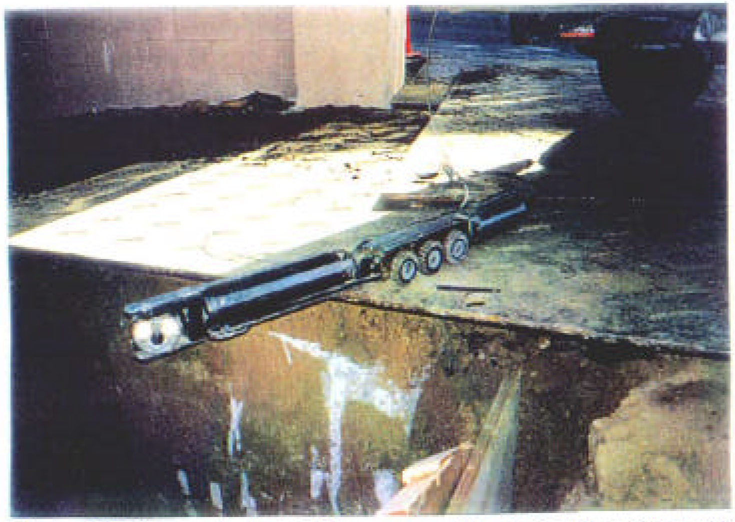

Figure 1-Self propelled television camera with rotating lights (L. Lund)

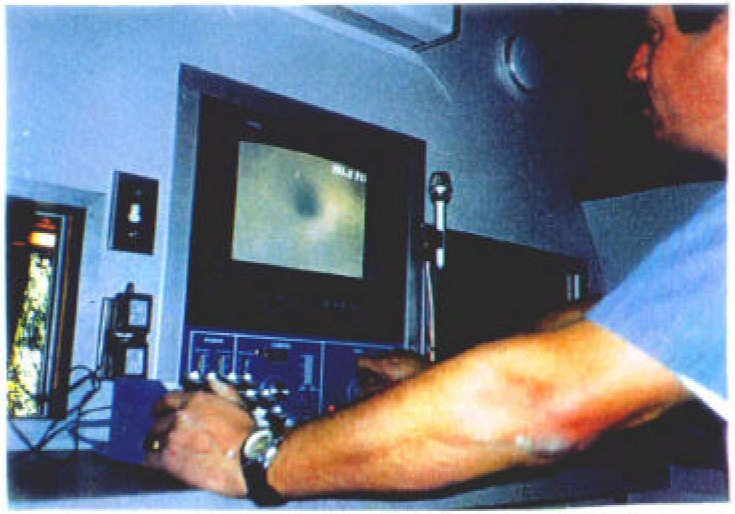

Figure 2-Pipe inspection television monitor. (L. Lund)

Figure 3-Cement mortar lining machine, trowel, and pipe cleaning tool. (L. Lund)

Figure 4-500 mm OD x 50 mm (20-in OD x 2-in) HDPE pipe laid on roadway prior to insertion into 300 mm (12-in) cast iron pipe. (L. Lund

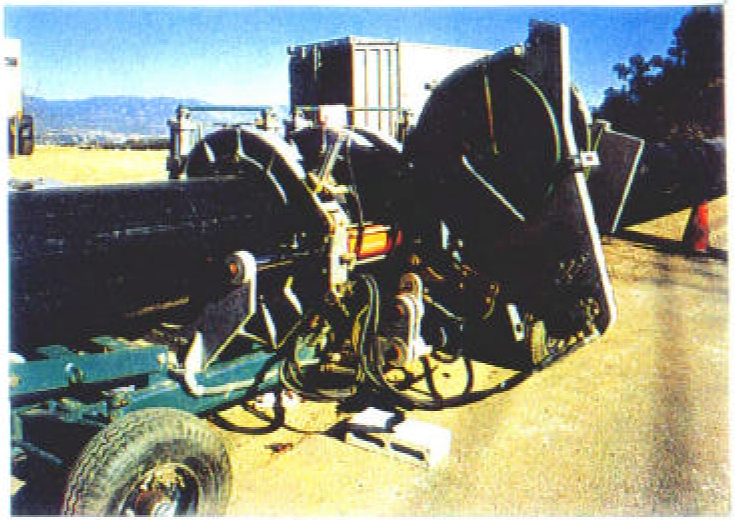

Figure 5-High pressure and high temperature HDPE 500 mm joint making machine (L. Lund)

Figure 6-Pipe bursting tool assembly (pneumatic pipe bursting tool, expander cone and guiding schnoze) (L. Lund)

Figure 7-Compressor equipment for pipe bursting tool. (L. Lund)

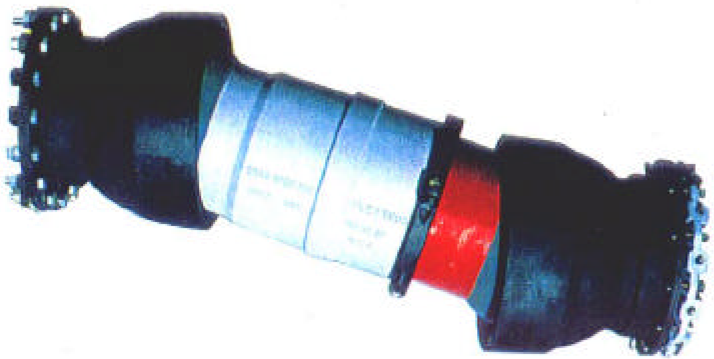

Figure 8 - Longitudinal and transverse movement joint (EBAA, Inc.)