SURVEY OF EXISTING BURIED GAS PIPELINES AND THEIR SEISMIC RESISTANCE

Carl P. Aumen[I], Teoman Ariman[II], and Gregory Muleski[I]

ABSTRACT

Results of a recent survey on national gas pipelines systems in the U.S. and Canada are presented. Practically all the natural gas utilities and interstate gas transmission companies in the seismic zones 1, 2 and 3 in the U.S. and Canada were covered by the survey. A total of 455 survey forms were mailed to the companies listed in the Brown's Directory of North American Gas Companies. A total of 114 completed survey forms were returned and the information from them was utilized in the preparation of this paper.

INTRODUCTION

A survey of the characteristics of natural gas pipeline systems in the U.S. and Canada which may affect their seismic performance was conducted as part of an ongoing research project entitled, "Earthquake Response and Aseismic Design of Underground Pipelines," sponsored by the National Science Foundation. The main objectives of the survey were as follows:

1. To establish a data base on the types of gas pipelines that are in use, including materials, sizes, types of joints, depths of burial, backfill conditions, etc.
2. To determine perceptions of seismic risk among natural gas utility and interstate transmission companies.
3. To gather data on seismic performance of gas pipelines.

The survey was conducted by a questionnaire which was accompanied by a letter addressed to a high official of the utility or the interstate gas transmission company. A total of 455 survey forms were mailed between July 12 and August 19, 1978 to the companies with the use of the Brown's Directory of North American Gas Companies. All natural gas utilities and interstate gas transmission companies located in the seismic zones 1, 2 and 3 in the U.S. and Canada and listed in the Brown's Directory were covered by the survey. A total of 114 completed forms were returned and the information from them was utilized in the preparation of this paper. Due to space limitation only selected parts of the outcome of the survey are reported in the next section.

SURVEY RESULTS

Each selected question from the survey form and the corresponding reply are given in a tabulated form as follows:

1. Has a seismic risk study been conducted for the gas transmission or distribution systems?

Zone	Yes	No	Zone	Yes	No	Zone	Yes	No	Total	Yes	No
1	-	40	2	2	28	3	0	18		2	86

[I]Research Assistant, [II]Professor, Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, Indiana 46556, U.S.A.

2. What pipe material and type of joint material was used in older distribution pipelines?

Material	Joint or Joint Material
Cast Iron	AGA Cement and Yarn
	Lead and Yarn
	Caulked Bell and Spigot
	Inner-Tile
	Mechanical Joint
	Dresser Coupled
	Jute Yarn Caulked with Cement
Wrought Iron	Mechanical Joint
	Welded
	Dresser Coupled
Black Pipe	Welded and Threaded
	Threaded Coupling
Steel	Oxy-acetylene Welded
	Compression Coupling
	Welded
	Welded and Threaded
	Dresser Coupling

3. Which materials and joints are used in new transmission, distribution and service lines?

Line	Material	Joint
Transmission	Steel	Welded
Distribution	Steel	Welded
		Compression Coupling
		Mechanical Joint
	Plastic	Fusion
		Mechanical Joint
Service	Steel	Welded
		Compression Coupling
		Threaded Coupling
	Plastic	Fusion
		Compression Coupling
		Mechanical Joint

4. What are the best materials and joints for the seismic resistant design of gas pipelines?

Zone	1	2	3
Fused Plastic	10	3	1
Welded Steel	16	3	2

Specific Recommendations:

(1) Butt fused joints or restrained mechanical connectors and a polyethylene of high molecular weight should be utilized in plastic pipelines.

(2) Butt joints electrically welded together with a steel of Grade B should be used in steel pipelines.

5. What is the method of restraining tees, crosses, intersections end bends?

Zone	Concrete Anchors (Blocking)	Back-fill	Tamping	Welding	Casing	Wood Thrust Blocking	Straps or Reinf. Sleeve
1	10	2	2	4	1	1	13
2	3	3	-	3	1	-	-
3	2	2	1	1	-	-	-

Zone	Harnessed Joint on Comp. Couple	Mech. Joint	Anchor Flanges	Expansion Joint on Bridges	Kickers
1	1	2	1	-	-
2	-	-	2	1	1
3	-	1	-	-	-

6. Is separation or other relative movement between the restraints and pipe a significant problem?

Yes	No	Not Known
10	70	25

7. Are there any structures, such as compressor stations or storage facilities, which are massive and which may interact dynamically with the pipes during earthquakes and what are they?

Yes	No	Interacting Structures	Number	Aver. Distance Between
41	70	Pressure Control Stations	19	150 ft-90 miles
		Regulators	14	1-3 miles
		Storage Facility	4	30-190 feet
		Air Shaving Plant	4	3-8 miles

8. Are special pipe jointing procedures used where the pipe enters massive structures? If yes, what are they?

Zone 1

1. Welded steel in a steel casing
2. Welded steel with flexible loops, bends, etc.
3. Reinforced with weld saddles.
4. Use compression couplings adjacent to massive structures.
5. Use a heavier pipe wall thickness.
6. Use a corrugated type expansion joint.
7. Do not use cast iron to enter a structure.

Zone 2

1. Joints in accordance with regulations of the U.S. Department of Transportation, Office of Pipelines Safety Regulations.

Zone 3

1. Expansion joints.

9. Experience with respect to failure, leaks, earthquakes and displacements (settlement uplift).
Under normal operations, the failure of buried pipelines is most commonly associated with:

		Zone 1	Zone 2	Zone 3
a.	Joints	16	4	3
	Pipes	19	4	1
b.	Types of Pipes	Zone 1	Zone 2	Zone 3
	Cast Iron	10	2	1
	Old Steel	1	-	-
	Uncoated Pipe	3	1	1
	Plastic	1	-	-
c.	Types of Joints	Zone 1	Zone 2	Zone 3
	Bell and Spigot	8	1	1
	Old Lead Joints	1	-	-
	Mechanical Joints	2	-	-
	AGA	1	-	-
	Dress Couplings	4	-	1
	Threaded Joint	1	-	-
	Valve Flanges	1	-	-
	Pinholes in Welds	-	1	-

d. Particular Laying Condition

Zone 1 - Peat
In Shallow Cover
In Rock or Unstable Soil

Zone 2 - None

Zone 3 - None

e. Corrosion

Zone 1: 36
Zone 2: 5
Zone 3: 4

f. Ground Settlement

Zone	1	2	3
Yes	8	1	1
No	1	9	2

g. Soil Erosion

Zone	1	2	3
Yes	-	-	-
No	3	10	2

h. Pinhole leaks and/or Cracks in the Coating

Zone	1	2	3
Yes	18	2	3
No	1	9	1

i. Wrapping and/or Coating

Zone	1	2	3
Yes	12	1	1
No	1	10	2

10. Rank in order of seriousness the damage expected in an earthquake (6-most serious, 5-etc.) to the following:

(Average/Rank)	Zone 1	Zone 2	Zone 3
Distribution Lines	3.964	4.375	-
Transmission Lines	2.333	3.66	-
Connections in Distribution Lines	3.697	2.347	3.25
Connections in Transmission Lines	2.545	2.823	4.0
Regulators	3.45	4.25	4.375

(Average/Rank)	Zone 1	Zone 2	Zone 3
Valves	3.107	3.454	3.583
Couplings	1.880	2.141	3.875
Compressor Stations	3.361	3.684	3.300
Storage Facilities	3.875	3.250	2.750

11. Does the utility have experience of ground movement or earthquakes which prompts it to use or avoid a particular pipe size, pipe material or joint or joint material?

Zone	Yes	No
1	6	61
2	1	29
3	1	17

12. If the answer to 11 is yes, what size, materials, etc. have been performed well or badly?

Materials that have performed well:
Steel - welded joint sizes (5/8" - 53")
Plastic - compression weld, fusion sizes (2" - 6")

Materials that have performed poorly:		Number of Replies
Cast Iron	Bell & Spigot	30
	Mechanical	30 Sizes (2" - 8")
	AGA	1

13. What construction support does the utility expect to use to repair damage after an earthquake?

	Zone 1	Zone 2	Zone 3
Own Personnel	15	19	12
Contractors	14	16	8
Federal Government (i.e., Army Corps of Engineers)	0	2	1

14. If damage due to earthquake is extensive, what changes will be made in the system when it is restored?

Materials	Size	Type of Joint
From Cast Iron to Steel (3)	Heavier Wall (1) Increase in Diameter (2)	Welded (6) Expansion Joints at Critical Areas (1)
From Cast Iron to Plastic (5)	Increase in Diameter (3)	Heat Fusion (4)

In this table the numbers in parenthesis indicate the replies from gas companies to this question.

15. Are there known active faults within or near the system which are capable of producing strong ground shaking (Richter scale greater than 6)?

Zone 1	Zone 2	Zone 3
Yes: New Madrid (1)	Yes: New Madrid (5) Wasatch, Magna (1)	Yes: New Madrid (6) Newport/ Inglewood (1)
Zone 1	**Zone 2**	**Zone 3**
	Yes: 39 miles east of Montreal (1)	Yes: San Andreas (1)
No: (67)	No: (23)	No: (9)

16. Operational Procedures

16.1 What is the normal range pressure in the system (Operational/Surge)?

Normal Pressure Range:

Zone		Transmission	Distribution
Zone 1:	High	1440 psi	High 1080 psi
	Low	20 psi	Low 20 psi
	Pressure Differences		
	High	900 psi	High 630 psi
	Low	50 psi	Low 8 psi
Zone 2:	High	936 psi	High 270 psi
	Low	50 psi	Low 10 psi
	Pressure Differences		
	High	350 psi	High 90 psi
	Low	45 psi	Low 8 psi
Zone 3:	High	1400 psi	High 1100 psi
	Low	20 psi	Low 1 psi
	Pressure Differences		
	High	1250 psi	High 1090 psi
	Low	80 psi	Low 20 psi

16.2 What is the usual depth of burial of gas pipelines?

Transmission Lines			
Zone Burial Depth	1	2	3
Average	37"	39.5"	40"
High	48"	60"	48"
Low	29"	30"	30"
Distribution Lines			
Zone Burial Depth	1	2	3
Average	31.25"	35.5"	34.5"
High	48"	60"	48"
Low	24"	24"	24"
Service Lines			
Zone Burial Depth	1	2	3
Average	22.5"	29.5"	24.5"
High	42"	60"	24"
Low	12"	18"	24"

SUMMARY

a. Results shows that steel is practically the only material utilized in transmission lines of natural gas and interstate transmission companies in all three seismic zones. Steel is also used a great deal in distribution lines. However, the survey indicated that in the older lines of the late 1800s and early 1900s, cast iron was the commonly used material. Due to the pin-hole fracture and resulting gas leakage problems which were associated with the brittle nature of cast iron pipes, steel, ductile iron and plastic apparently replaced the use of cast iron for distribution lines.

It is also seen that particularly for the pipes with a diameter range of 1/2" - 2", the utilization of plastic is increasing substantially. This situation is due to a number of better features of plastic pipes in comparison to the metal ones. Among them are their lightweight, ease of handling and corrosion-free nature, etc. However, relatively low ultimate strength of plastics limits the use of plastic pipes to about 6" in diameter in natural gas piping systems.

b. Only 4 percent of the respondents, including both large and small gas utilities and transmission companies, have conducted seismic risk analysis of their systems. These surveys have apparently not resulted in a common course of action by the utilities to upgrade their systems for earthquakes.

c. Only 7 of 107 respondents, about 7 percent, did have experience of earthquakes. These respondents indicated that steel pipes with welded joints and plastic pipes joined with heat fusion performed well. However, cast iron pipes with bell and spigot and/or mechanical joints performed poorly.

d. Respondents in the Zone 1 believe that distribution lines are the most vulnerable parts of a pipeline system in the event of an earthquake. Joints and storage facilities are considered to be the second and third most vulnerable components, respectively.

e. Survey results also indicated that the seismic resistance of the piping system could be increased by replacing cast iron pipes with welded steel or with plastic joined with heat fusion, for large or small diameters respectively. Other changes would be the increase in diameter and wall thickness and some critical areas, the utilization of expansion joints.

f. It appears that about 22 percent of the respondents carry liability insurance covering possible damage following an earthquake. Furthermore, either their own personnel or contractors are planned to be used by utilities to repair damage after an earthquake.

g. In Zone 3, 50 percent of the respondents reported that there exists at least one active fault within or near their utility system. In Zones 2 and 1 the percentage as expected decreases to 23 and 1 percent respectively.

CONCLUDING REMARKS

a. Responses to this survey and private communications and interviews with selected utilities indicate that a large number of natural gas utilities and transmission companies, particularly the ones located in the seismically most active areas (Zone 3), appeared to be receptive to the concept of seismic resistant design of buried pipelines. However, to date, the ASME Pressure Vessels and Piping Code and the Department of Transportation Regulations do not address this important issue [1-3].

b. The results also showed that damage to buried pipelines has not yet been correlated with intensity and frequency content of earthquakes or any other practically useful measure of ground shaking.

c. Very few utilities, particularly in the Western United States, perceive that seismic risk is important enough to justify changes in the material, coupling and in backfill procedure for newly installed pipes; or even to replace some old cast iron pipes with welded steel and/or plastic-heat fusion pipes. They also pay insurance premiums for possible damage due to possible fire, explosions and two of the utilities have been evaluating seismic risk to their systems. However, the cost effectiveness of these steps is not known and there is no common course of action for upgrading the seismic performance of systems.

d. In spite of the wide range of pipe and joint materials, pressures, soil and backfill conditions and other factors, as one of the important outcomes of this survey, it appears that a series of representative piping systems can be modelled with reasonable accuracy for the analysis of the earthquake response of buried pipelines [4]. This would include welded or mechanically joined steel transmission and distribution lines and plastic-heat fusion service and small size distribution lines covered by 3 to 4 feet of tamped, native backfill.

ACKNOWLEDGMENT

This paper is a partial outcome of the research program entitled, "Earthquake Response and Aseismic Design of Underground Piping Systems," sponsored by the Earthquake Hazards Mitigation Program of the National Science Foundation under the Grant No. ENV-77-23236. The authors acknowledge the financial support and deeply appreciate the continuous encouragement and advice of Dr. S.C. Liu, Program Manager, during the course of this investigation.

REFERENCES

1. Ariman, T. and Muleski, G.E., 1979, "A Review of the Response of Buried Pipelines under Seismic Excitations," Lifeline Earthquake Engineering-Buried Pipelines, Seismic Risk and Instrumentation." Edited by T. Ariman, S.C. Liu and R.E. Nickell, ASME PVP-34, pp. 1-30.

2. Safety Standards Parts 191 and 192 Title 79 - Transportation of Natural and Other Gas by Pipeline; October 1, 1973, U.S. Department of Transportation.

3. ASME Guide for Gas Transmission and Distribution Piping Systems - 1976.

4. Muleski, G.E., Ariman, T., and Aumen, C.P., "A Shell Model of a Buried Pipe in a Seismic Environment, 1979, Journal of Pressure Vessel Technology, ASME Vol. 101, pp. 44-50.