Austin Public Health

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Austin Publishing Group

Research Article

Accidents Investigation and Cause Analysis of Urban Underground Pipelines in Beijing

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Received: September 15, 2017; **Accepted:** October 13, 2017; **Published:** October 20, 2017

Abstract

Underground pipeline accidents and the reasons why these accidents occurred are studied in this paper. First, introduce the overview of the underground pipelines in Beijing. Then, investigate pipelines of gas, heat, water, rain water, sewage, recycled water, electricity, oil, lighting, communication and information, radio and TV broadcasting using statistical data. Third, from the accident statistics, propose and rank the causes of the pipeline accident with different pipelines. At the end of this paper, we conclude that the accidents caused by construction of other projects hold the first place, accounting for 48.9% of the total amount of the accidents; followed by the underground pipeline accidents due to aging and corrosion, accounting for nearly 34.5% of the total amount of the accidents; the accidents caused by the interaction between underground pipelines account for 6% of the total amount of the accidents; besides, the pipeline accidents caused by the poor quality of some pipelines and ground subsidence also account for a certain proportion.

Keywords: Pipeline; Cause analysis; Accident investigation

Introduction

Modern society relies on a hidden network of tunnels, pipelines, and underground structures to transport people, cargo, liquids, and gasses from place to place, or to store materials, without disrupting surface activities or intruding on our views of the landscape [1]. This underground infrastructure is taken for granted until an extraordinary event occurs, such as a tunnel collapse or pipeline explosion. It aims at the rescue, repair, and restoration efforts; specialists from a variety of disciplines investigate the materials, design, and underground environment of the damaged facility [2-3] to determine the cause(s) of the failure and appropriate methods of repair.

Throughout recorded history, works have been constructed for conveying water from one place to another [5]. The Roman aqueducts are often mentioned as examples of great technical achievement [6]. Indeed, part of the early structure is still in use nowadays. Although most of the early water carrying structures were open channels, conduits and pipes of various materials were also used in Roman times. It appears, though, that the effectiveness of the early pipes was limited because their materials were weak in tensile capacity [7]. Therefore, the pipes could not carry fluid under any appreciable pressure. At the beginning of the 17th century, wood and cast iron [8] were used in water pipe applications in order to carry water under pressure from pumping, which was introduced about the same time. Since then, many materials have evolved for using in pipes. As a general rule, the goals of developing new pipe material are to increase tensile strength, reduce weight, and, of course, reduce cost [9-11]. Pipe that is buried underground must sustain other loads besides the internal fluid pressure. That is, it must support the soil overburden, ground water, loads applied at the ground surface, such as vehicular traffic, and forces induced by seismic motion. Therefore, the buried pipe is a kind of structure [12-13], but also the pipeline conveying fluid. In this case, special design procedures are needed to ensure that the two functions are met.

Theory and Method

Pipelines are used in public water systems, sewers, drainage facilities and many industrial processes. The materials of tubes used to be considered including steel, concrete and fiberglass reinforced plastics. This selection provides examples of flexible and rigid behavior. The method described here can also be applied to other materials.

Most of the design procedures provided are recommended practices based on materials or industry organizations contained in U.S. national standards. We intend to provide the basic elements of various design procedures. No claim has been made for the overall inclusiveness of the methodology discussed. Encourage comprehensive refinement of any method and the subtle interest of the reader to reference the works. For the sake of convenience, when comparing references, the symbols used in other work will be retained. Focus on large diameter lines, generally greater than 24 inches. Include work sample questions to illustrate the material provided.

The underground pipelines described here include natural gas, hot water, water, rainwater, sewage, circulating water, electricity, oil, lighting, communications and information, radio and television and other urban infrastructure underground pipelines [14-16]. By the end of 2006, the underground pipeline in Beijing has a total length of 41141.314km (901.081km) [17-20].

External loads

Overburden: The vertical load on the tube bracket extends from the ground to the top of the tube through a piece of soil and then adds (or subtracts) the shear force along the edge of the block.

Citation: Xingmeng G and Chunyan D. Accidents Investigation and Cause Analysis of Urban Underground Pipelines in Beijing. Austin Public Health. 2017; 2(1): 1010.

Shear forces are produced when the surrounding soil, prisms, or prisms correspond to each other. For example, the soil prism above the pipe in the excavated trench will tend to be relative to the surrounding soil settlement. The shear force between the backfill and undisturbed soil will resist settlement, thereby reducing the prism load borne by the pipe. For pipelines placed on the ground and covered by new fillers, the effect may be the same or the opposite, in which case the load supported by the pipe will be greater than the soil prism. Behavioral differences depend on the difference in sedimentation between the pipe itself and the filler material.

Marvin and Spangler and their colleagues at the Iowa State University [21-22, 23-28] developed methods were used to assess the overburden loads of buried conduits over a period of about 50years and were widely used in design practices. The general form of the expression developed by this group is used to calculate the load of overburden for pipeline loading is given as

$$W_c = DCwB^2 \qquad (1)$$

where:

W_c: D total load on pipe, per unit of length

C: D load coefficient, dependent on type of installation, trench or fill, on the soil type, and on relative rates of settlement of the pipe and surrounding soil

w: D unit weight of soil supported by pipe,

B: D width of trench of outer diameter of pipe.

For different installation conditions, the value of the load factor C is given in several standard references (see for example [29]). The American Water Engineering Association (AWWA) [30] in its steel pipe design manual, it is suggested that the total overlying load of the buried steel pipe be assumed to be a soil prism equal to the diameter of the pipe, and the height of the equal covering depth.

That is,

$$W_c = DwB_c h \qquad (2)$$

Where:

B_c: D external pipe diameter,

H: D depth from ground surface to top of pipe.

Surcharge at grade: In addition to the direct load exerted by the soil cover layer, the underground pipelines must withstand the load exerted on the ground. Usually, the load is due to the route of the vehicle through the pipeline. However, they may be caused by electrostatic objects placed directly above the pipe.

The experimental results of [27,31], a researcher at Iowa State University, confirm that the load strength of the tube depth can be predicted according to the elastic theory because of the surface load. As an influence function, it is possible to obtain the effect of the Boussinesq solution [32] on the arbitrary spatial distribution of the surface load on the point load in the elastic half space. Because the stress distributions provided by the Boussinesq solution decay with the distance load, the strength of the surface load decreases with the increase in depth.

Table 1: HS-20 Live Load.

Height of cover, ft	Live load, lb/ft^2
1	1800
2	800
3	600
4	400
5	250
6	200
7	175
8	100
Over 8	Neglect

Note: From American Society for Testing and Materials. 1994. A796. *Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches and Arches for Storm and Sanitary Sewers and Other Buried Applications.* With permission.

Table 2: Cooper E-80 Live Load.

Height of cover, ft	Live load, lb/ft^2
2	3800
5	2400
8	1600
10	1100
12	800
15	600
20	300
30	100

Note: From American Society for Testing and Materials. 1994. A796. *Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches and Arches for Storm and Sanitary Sewers and Other Buried Applications*. With permission.

Consequently, the consequences of traffic or other surface loads on deep buried pipelines are relatively small. On the contrary, the surface load exerted on a pipe with a shallow cover may be quite serious. For this reason, the minimum protection is usually required where any ground runs through the underground pipeline.

Prior to the development of modern computing tools, the evaluation of the Boussinesq equation determined that the total load of the buried Tube was beyond the capacity of most practitioners due to arbitrary surface loads. Therefore, based on the simple surface load distribution developed the table, and has been incorporated into most of the buried tube design documents for many years.

For example, Mathcad [33] can be used to perform the necessary analysis to assess the impact of arbitrary surface loads on buried structures, including pipelines.

Live loads: The main source of live load for buried pipelines is the wheeled passage of road trucks, railway locomotives and aircraft. Using the standard HS-20 truck load [34] Cooper E-80 Railway load transmission to the load of the buried structure has been evaluated using the Boussinesq solution and engineering judgment, for different coverage depths, which can be in different forms several publications (see, for example [35,36]). Since the aircraft wheel loads vary greatly, it is usually necessary to evaluate each case separately. FAA Advisory Circular 150/5320-5B provides information on aircraft wheel loads. The load strength of pipeline depth has been reported in many references. Table 1 and Table 2 give the simple load strength of HS-

Table 3: Basic situation of underground pipelines in Beijing.

No.	Category	Length (km)
1	Water	7079.54
2	Gas	7295.48
3	Heat	737.8
4	Electricity	12610.8
5	Lighting	3417
6	Communication & Information	2400
		277
		60
		59
		10
		1280
7	Rain water	1573
8	Sewage	2070
		355.44
9	Recycled water	240
10	Cable TV	776
Total	10	40240.26

20 truck load and Cooper E-80 locomotive load at different depths [37]. More comprehensive forms of truck and rail cargo have been published [38,39].

Seismic loads: In areas with high seismicity, the buried pipelines must be designed for the stress exerted by ground motions of earthquakes. The American Society of Civil Engineers (ASCE) has developed a program for the size of the axial and flexural strain caused by the seismic action of the lower line [40]. The document reflects the research results of many leading seismological engineers in China, which is widely used in various underground piping designs.

As a general rule, because of the strain caused by the earthquake movement, the stress in the tube wall is rather small and will not adversely affect the design. Since most design specifications allow for increased allowable stress or reduced load coefficients, when the seismic load is included in the load assembly, the buried tube, which is suitable for maintaining other design loads, usually has sufficient strength to withstand the stress exerted by the earthquake.

Therefore, the main consideration to be solved in underground piping design is not strength, but excessive relative motion. The unrestricted slip joint in the buried tube may be relatively moving, and the rendezvous between the two segments will exceed the joint function limit. Therefore, it is necessary to study the maximum relative motion of a sliding joint pipe during seismic motion. Types of piping usually used for sliding joints include ductile iron, reinforced and prestressed concrete, and fiberglass reinforced plastics.

Internal loads

Internal pressure and vacuum: Underground piping systems have operated under different internal pressures. Gravity sewer lines typically operate under fairly low internal pressure, while water pipelines and industrial process pipelines may be affected by hundreds of lbs of internal pressure per square inch. High-pressure

Table 4: Asset statistic table of cable transmission lines in 2006.

Voltage Level (kV)	Amount	Length (km)
220	53	142.66
110	413	512.62
35	155	123.155
Total	621	778.435

Table 5: Operating life situation of cable transmission lines (Unit: km).

Voltage Level (kV)	Before 1980	1980-1985	1986-1990	1991-1995	1996-2000	2001-2006
220	——	——	2.3	0.16	31.121	109. 079
110	1.057	4.433	17.414	24.224	159.963	305.529

piping is usually designed for continuous working pressure and short-term transient pressure. Some operational events can lead to temporary vacuums in buried pipelines. In most cases, the duration of the vacuum load is very short, and its effect can usually be examined separately from other live loads [40]. For the design, the hydraulic analysis of the system can be used to predict the amplitude and time variation of the transient of the positive and negative internal pressure.

Pipe and contents: The influence of the wall and the weight of the fluid carried by the fluid must be resisted by the structural capacity of the pipe. In most cases, these loads do not significantly affect the overall stress state. In fact, the design of steel or plastic pipes often ignores the load from these two sources, but is usually included in the design of prestressed reinforced concrete pressure pipes and can also be included in the design of concrete without pressure pipes. In the standard stress analysis reference [40], a formula for determining the bending moment and thrust of the pipe wall is provided due to the weight and fluid load. Since these loads are usually smaller than the overlying strata, they are added to the vertical soil load for simplicity and conservation.

Result

Situation of the water pipelines

At present, the Beijing Municipal Water supply network covers the area of Dingfuzhuang of Chaoyang District, west to the ancient city of Shijingshan, south of the Economic and technological development zone, north to Huilongguan cultural residential areas, Zhongguancun life Science Park and Yongfeng High-tech Industrial base, water supply area is more than 800 square kilometers, to the end of 2006, The water supply line has a total length of 7079.54km. Basic situation of the water pipelines in Beijing is shown in Table 3.

Situation of the drainage pipelines

The construction of Beijing urban drainage system has a long history, as early as the Yuan Dynasty to build a large capital of the time began to build drainage ditches, to Beijing liberation, the city has a total confluence of sewers more than 300 kilometers, some are still in use. The existing drainage system includes: sewage pipe network system, rainwater pipe network system, confluence pipe network system, drainage pump station and sewage treatment plant and other infrastructure facilities. By the end of 2006, the city has a total of more than 4,000 kilometers of sewers, including more than 1500 kilometers of rainwater pipelines, sewage pipelines with more

Table 6: Gas pipeline distribution of the Beijing Gas Group.

No.	Unit	Length of pipeline/ km	Remarks
1	Station 1	1312	High-pressure B: 76k; sub-high-pressure A:110km; mid-pressure A: 422km; low-pressure : 704km
2	Station 2	2410	High-pressure B:74km; sub-high-pressure A:104km; mid-pressure A:766km; low-pressure: 1466km
3	Station 3	1848	High-pressureA:10km; high-pressureB:55km;sub-high-pressure A:109km; mid-pressure A:551km; low-pressure:1123km
4	Station 4	793	High-pressure B: 51km; sub-high-pressureA:101k; mid-pressure A:328km; low-pressure:313km
5	Station 5	723	Mid-pressure A: 210km; low-pressure:513km.
6	Caiyu station	27	High-pressure A:19km; high-pressure B: 8km
7	Sixth ring high-pressure pipeline	110	High-pressure A (design pressure: 4.0MPa, operating pressure: 3.5-3.9 MPa, diameter:1000 mm)

Table 7: Accident statistics of water pipeline in Beijing.

	2001		2002		2003		2004		2005		2006	
Cause	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage
Material quality	56	5.39%	87	7.80%	69	6.71%	53	6.31%	252	24.23%	72	5.23%
Engineering leakage	267	25.70%	81	7.26%	72	7.00%	66	7.86%	66	6.35%	51	3.70%
Substandard foundation	90	8.66%	128	11.48%	102	9.91%	85	10.12%	55	5.29%	148	10.70%
Corrosion	392	37.73%	565	50.67%	480	46.65%	406	48.33%	552	53.08%	773	55.99%
Rolling of trucks	65	6.26%	87	7.80%	97	9.43%	51	6.07%	35	3.37%	72	5.23%
Breakage of accessories	169	16.27%	167	14.98%	209	20.31%	179	21.31%	80	7.69%	264	19.15%
Total	1039		1115		1029		840		1040		1381	

than 2000 kilometers, rain and sewage confluence ditch more than 800 kilometers (including the legacy of the Ming and Qing dynasties over 160 kilometers).

Situation of the electricity pipelines

By the end of 2006, the number of cable transmission lines of 35kV and above under the jurisdiction of the Beijing Power Company was 621, and its total length was 778.435km, including cable tunnels with a length of 405km. Among this, 53 cables of 220kV with a length of 142.66km; 413 cables of 110kV with a length of 512.62km; 155 cables of 35kV with a length of 123.155km, see Table 4.

The amount of 10kV cables is 36451, totally 13,248.5km, and the number of 0.38/0.22kV low-voltage cable is 39,744, totally 5737.9km.

By the end of 2006, more than 10years of cable transmission lines run by Beijing Electric Power Corporation are totally 49.59km (35kV and over), accounting for 6.37% of the total, its operating life situation is shown in Table 5.

In 2006, the Beijing Power Company set that the perfectness ratio of the cable transmission lines was determined to be 100% in its production assessment report.

In addition, there are street lighting cables with a length of more than 3,000km in Beijing.

Situation of the gas pipelines

By the end of 2006, the Beijing Gas Group's natural gas pipeline is 7300km long, including sub-high-pressure pipeline over 800km. The natural gas pipeline network of the city covers regions from Tongzhou in the east to Fangshan, Mentougou in the west, from Daxing, Liangxiang, Yungang in the south to Shunyi, Changping in the north. In Beijing there have been three gate stations above high-pressure B including Caiyu station, Ciqu station and Yamenkou station, two gate stations of sub-high-pressure A including the southern suburb station and the eastern suburb station; the high-pressure lines along the city's third ring road, fourth ring road and fifth ring road has been built as circular pipe networks, currently, the first phase of the sixth ring high-pressure pipeline project has been completed and put into operation, three high-pressure A regulator stations (Yizhuang station, Tongzhou station and Lee Bridge station) have been officially put into operation; most parts of the urban's mid-pressure pipelines are interconnected.

The basic situation of the gas pipelines in Beijing is as follows:

1. The situation of gas pipelines managed by the Beijing Gas Group Transmission and Distribution Company is shown in Table 6;

2. The Beijing Liquefied Petroleum Gas Company currently has a liquefied petroleum gas pipeline with a length of 180km, and the liquefied petroleum gas required by the company is mainly transported through the pipeline from the gas source plant to the reserve branch, and then is distributed to the southern suburb filling plant and northern suburb filling plant.

3. The Beijing Shunyi District Gas Company:

The Beijing Shunyi District Gas Company is located in Pinggezhuang, Shunyi District, Beijing, the company's natural gas pipeline includes: high-pressure pipeline with a length of 15km, outside mid- and low-pressure pipeline with a length of 500km.

4. The Capital Airports Holding Company Beijing Power Energy Branch:

The Capital Airports Holding Company Beijing Power Energy Branch is located at 2#, Building 3, Dongliyi, Jichang South Road, Chaoyang District. The company's natural gas pipeline is 93km long.

5. Other units holding gas pipeline ownerships are shown as follows:

- The Beijing Beiran Ganghua Gas Co., Ltd (Beijing Yizhuang Economic and Technological Development Zone);
- The Beijing Huayou United Gas Development Co., Ltd. (Beijing Yizhuang Economic and Technological Development Zone);
- The Beijing Changdongshun Gas Co., Ltd. (Beiqijia Town, Changping District, Beijing);
- Part of the self-control households.

Situation of the heat pipelines

By the end of April 2007, the Beijing Thermal Group Co., Ltd. Transmission and Distribution Branch's outside network pipeline has a length of about 743.42km. The central heating pipes are distributed mainly in the eight districts of the city, the heating pipeline starts from Gaobeidian in the east, ends at Shijingshan heating plant in the west, and starts from Fangzhuang (outside the South Third Ring Road) in the south, ends at the western gate of Beijing University in the north. By the end of December 2006, central heating area reached 106 million square meters. In addition, there are some self-control households' lines as well, the situation is quite complicated.

Situation of the communications and cable TV lines

The ownership units of electroweak underground pipelines mainly include Beijing Netcom, Beixin Basic, Gehua Cable, Beijing Telecom, Beijing Mobile and Beijing Unicom and Beijing Tietong.

The Beijing Netcom Pipeline Bureau maintains a communication channel with a length of 2484.104km (along trunk roads in Beijing urban), spreading all over the districts and the counties of Beijing.

By the end of December 2006, the pipeline officially maintained by Beixin Basic had a length of 1280km, of which the pipeline about 400 kilometer long was built in the past 5years, and the pipeline over 800 kilometer long was built in the past 5-10 years, the total number of manholes reached 9793. The main distribution is shown in Table 6.

Gehua Cable's pipeline is 380km long, including a 250-kilometer length built in the past 5years and a 130- kilometer length built in the past 5-10 years.

In addition, by the end of 2006, Beijing Telecom had a 277-kilometer pipeline, Beijing Mobile's pipeline was 60km long, Beijing Unicom's pipeline was 59km long, and Beijing Tietong has a pipeline with a length of 10km.

Situation of the oil and gas transportation pipelines

By the end of 2006, the oil and gas transportation pipelines within Beijing City include:

- China Natural Gas Corporation Limited: 2 pipelines with a total length of 75km went through Fangshan, Daxing, Fengtai, Shijingshan, and Tongzhou;
- Oriental Petrochemical: 6 pipelines with a total length of 85.6km respectively transported medias ethylene, oxygen, propylene and gas through Fangshan, Daxing, Fengtai, Xuanwu, Chongwen, Chaoyang and Tongzhou;
- CAO: a 185-kilometer pipeline transported aviation kerosene through Shunyi, Tongzhou;
- Sinopec: a pipeline with a length of 58km transported gasoline through Fangshan, Daxing, Fengtai and Chaoyang;
- Yanshan Petrochemical: 2 pipelines with a total length of 132.4km respectively transported oil and natural gas through Fangshan, Fengtai, Shijingshan and Haidian;
- Huadian (Beijing) Thermal Power: 4 pipelines with a total length of 90km transported heavy oil through Fangshan, Daxing, Fengtai and Xuanwu;
- Huabei Oilfield No.4 Production Factory: a pipeline with a length of 68.5km transported natural gas through Daxing and Tongzhou.

Discussion

Cause analysis of water pipeline accidents

In the research, 23 accident cases of water pipeline in Beijing were obtained by searching media information, and 5 cases were provided by water companies.

Through analysis, we found that the accidents were mainly caused by construction damage, aging, corrosion, vehicles damage, foundation subsidence, building occupying, man-made malicious sabotage (stealing pipe accessories) and others. These accidents include regional water outage, traffic blocking and road subsidence caused by pipeline leakage. 2001 -2006 accidents statistics given by water companies is shown in Table 7.

Cause analysis of the drainage pipeline accidents

In the survey, 10 accident cases of drainage pipelines in Beijing have been collected from the Beijing Municipal Engineering Administration Department. Through analysis, the main causes of these accidents are found: foundation subsidence, construction damage, aging and corrosion of facilities, building occupying, overload, poor way of downstream, the low standards of early design and others. The effects of these accidents mainly include ground subsidence, traffic blocking, housing collapse, and other damages caused by pipeline leakage.

In addition, the highly flammable and explosive gases existing in sewage are highly explosive in case of open flame [41].

Cause analysis of the power pipeline accidents

In this research, 10 accident cases of power pipeline (cable) have been collected from power companies. The major causes of these accidents found through analysis include poor quality of construction and equipment, cable aging, external damage, the impact of other pipeline accidents. These accidents mainly include breakdown, collapse, explosion of power tunnels (triggered by explosive gas entering electricity tunnels), regional power outage (caused by cable damage), etc.

According to the statistics by power companies, from 1998 to 2006 there were 40 main network cable failures, including 19 cable failures caused by product quality problems, 6 cable failures due

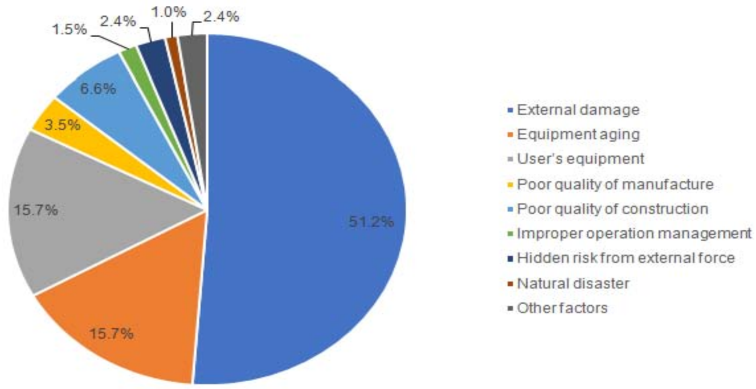

Figure 1: 2006 analysis of 10kV cable failure causes.

Table 8: 2000 - 2005 statistics of gas pipeline accidents in Beijing.

Item	2000	2001	2002	2003	2004	2005	Total
Construction damage	48	51	67	60	60	60	346
Aging or corrosion	40	29	32	39	62	84	286
Welding spot cracking	5	2	8	12	7	20	54
Leakage from reinforced plastic connector	1	0	0	0	0	0	1
Broken plastic pipe	2	0	0	0	0	0	2
Broken spacer in insulated joint	1	0	0	0	0	0	1
Poor quality of construction	0	1	8	0	1	0	10
Foundation corrosion	4	1	1	3	4	0	13
Cable breakdown	0	0	0	1	0	0	1
Man-made damage	0	0	0	2	4	0	6
Others	0	0	0	0	2	1	3
Total	101	84	116	117	140	165	723

to poor construction quality,8 failures due to external causes and 7 failures due to other reasons. In 2006, there occurred 287 trips on 10kV distribution cable; the main reason is still mainly due to external damage, while the line trips caused by aging equipment and user equipment also occupy a considerable proportion. The specific reasons are shown in Figure 1.

Cause analysis of the street lamps pipeline accidents

Through interviewing officers of the Beijing Municipality Street Lamps Management Center, cable theft is found a major problem of underground pipelines. In 2005, the street lamps management center lost underground cables with a total length of 11km, causing direct economic losses of 330 thousand Yuan. From January to August 2006, the total length of stolen copper cables and aluminum cables owned by the Beijing street lamps management center was up to 3290 meters, these thefts not only caused great losses, but also resulted in the possibility of pedestrian electric shock due to touching the manhole covers contacting with cables cut off by thieves [42].

Cause Analysis of the gas pipeline accidents

In the research, 10 accident cases of the gas pipelines in Beijing are collected from media information. Through analysis of these cases, we find that the main causes of the pipeline accidents include: construction damage, vehicle damage, aging, corrosion, welding spot cracking, effects of other pipelines and so on. These causes had resulted in gas leakage, gas interruption, fire and explosion [43-44], physical explosion and asphyxiation.

The accident statistics (including attachments) of gas pipeline in Beijing from 2000 to 2005 provided by Beijing Gas Group is shown in Table 8.

According to the statistics data in Table 8 & 9, construction damage, corrosion and aging are the two main causes of gas pipeline accidents. Through the analysis we found:

- In the statistics, the districts in which accidents of mid-pressure and high-pressure gas pipeline occurred most frequently are Haidian and Chaoyang. The accident-prone pipelines include: the mid-pressure pipeline in the northern suburb, the mid-pressure pipeline in the front of Beiji Temple Cabaret Bardon Karaoke Hall, Yuhui Road mid-pressure pipeline, the mid-pipeline pressure near Jiuxianqiao and the Beiji Temple mid-pressure pipeline.
- In addition, there have occurred many accidents of gas pipeline leakage at Sanlihe, Gongzhufen, Guchengbei Road, as well as in region near Jinglun Hotel, Jinsong and other regions.

Cause analysis of the thermal pipeline accidents

Through related media information, 16 accident cases of thermal

Table 9: 2001-2005 statistics of gas pipeline accidents in Beijing.

District	Low-pressure									Mid-pressure									High-pressure								
	Construction	Agingand Corrosion	Welding	Project	Ground subsidence	Man-made	Vehicle	Pipeline	Others	Construction	Agingand Corrosion	Welding	Project	Ground subsidence	Man-made	Vehicle	Pipeline	Others	Construction	Agingand Corrosion	Welding	Project	Ground subsidence	Man-made	Vehicle	Pipeline	Others
Dongcheng	2	6					2			1	1																
Xicheng	10	8	1							2	1		1														
Chongwen	3	1			1						2																
Xuanwu	1	3									1	1															
Chaoyang	30	23	3			2	3		6	4	36	3						1		6	1		1				
Haidian	38	16	4		2	2	4			8	17	2		1	1	2		1		6							
Fengtai	11	2	1		2		5		1	2												1					
Shijingshan	5	9					1	1	1	3	1										2						
Shunyi											3																
Cangping	5			1						2																	
Tongzhou	3											1								1							
Yanqing																											
Miyun																											
Daxing	4	1							1	1									1								
Mentougou																											
Fangshan	1	1																		1							
Pinggu																											
Huairou																											

Table 10: Risk sources of underground pipeline accidents may occur during the Beijing Olympics.

Category	Risk source	Cause	Remark
Third party damage	Construction damage	Irregular construction; Insufficient supervision of relevant departments; Improper identifications; Insufficient informational management; Insufficient publicity and education.	This kind of accidents collected accounts for 49% of all accidents collected in this research.
	Vehicle damage	Great traffic pressure; Inadequate protective measures	This kind of accidents collected accounts for 0.6%of all accidents collected in this research.
	Occupying of building	Insufficient informational management Improper planning; Inadequate protective measures Insufficient publicity and education	This kind of accidents collected accounts for 0.1% of all accidents collected in this research.
Aging and corrosion	Defect of aging and corrosion	Corrosive environment; Inadequate anti-corrosion measures Exceeding service life; Lack of detection and evaluation; Insufficient care and maintenance; Inadequate management.	This kind of accidents collected accounts for 34.5% of all accidents collected in this research.
Improper operation of equipment	Improper operation	Lack of error-proofing measure; Imperfect operating specification; Relaxed implementation of operating specification; Insufficient training and management of personnel; Lack of safety management.	No real data collected, but this kind of accidents needs adequate attention.

pipelines in Beijing were collected. Through analysis of these accident cases, the main causes of these accidents are found: external damage, broken pipeline accessories, aging, corrosion, poor quality of pipeline materials, misuse and so on. The main effects of thermal pipeline accidents include: pipelines leakage, road collapse, physical explosion, heating interruption of service districts, traffic blocking

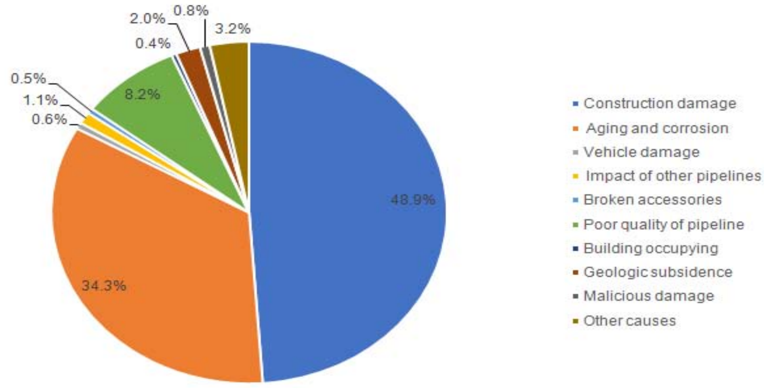

Figure 2: Proportion statistics of underground pipeline accidents in Beijing.

and so on [45-46].

Cause analysis of the communication and cable TV pipeline accidents

In this research, 68 accident cases of communications and cable TV pipeline were collected (provided by Beijing Netcom, Beijing Information Infrastructure Construction Co. Ltd. and Beijing Gehua CATV Network Co., Ltd.). Through analysis of these cases, the main causes of these accidents are found: construction damage, the impact of other pipelines, ground subsidence, and so on. Main impact of the accident is signal interruption [47-48].

Through statistical analysis of 855 underground pipeline accidents collected in the investigation, the possible underground pipeline accidents and risk sources in Beijing during the Olympic Games in Beijing are shown in Table 10.

Conclusion

Overall, among the accident cases of underground pipeline collected in this research, accidents caused by construction of other projects hold the first place, accounting for 48.9 percent of the total amount of the accidents; followed by the underground pipeline accidents due to aging and corrosion, accounting for nearly 34.5% of the total amount of the accidents; the accidents caused by the interaction between underground pipelines account for 6% of the total amount of the accidents; besides, the pipeline accidents caused by the poor quality of some pipelines and ground subsidence also account for a certain proportion. Proportion statistics of the overall cause of the accidents is shown in Figure 2.

With the development of urbanization, construction scale has been expanding, and the use of functions is increasingly complex. As part of urban public facilities, urban underground pipelines are developed from a single, simple form to a multi-category, multi-ownership and complex pipeline network. The contradiction between the rapid development of urban construction and the means of backward management is also increasingly sharp; any kind of pipeline failure will bring significant losses. In order to build a harmonious, livable modern city, it is necessary to maximize the construction and protection of urban underground pipelines, prevent or reduce the occurrences of underground pipeline accidents. In this study, the underground pipeline safety management laws and regulations and the standard systems were established and improved to strengthen law enforcement efforts. Furthermore, the main responsibility of safety management was implemented according to the requirements of urban planning and management and the conditions of the city. Finally, technological innovation was applied to promote technological progress in the industry and improve professional technical level and urban underground pipeline safety and security service capability.

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Austin Public Health - Volume 2 Issue 1 - 2017
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Citation: Xingmeng G and Chunyan D. Accidents Investigation and Cause Analysis of Urban Underground Pipelines in Beijing. Austin Public Health. 2017; 2(1): 1010.