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Failures analysis of water distribution network during 2006-2008 in Ahvaz, Iran

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Original Article

Abstract
Failures in the water distribution network are some most important factors in water losses, water shortage and dissatisfaction of users and secondary pollutions as well. This research aimed to analyze failure in water distribution networks during 2006-2008, for better water management. Daily failure reports in Ahvaz, Iran distribution network during 2006-2008, were collected from emergency department of Ahvaz water and Wastewater Company; thereafter, they were entered into an Excel database, also failures were defined by pipes type, pipe diameter, and cause of the failure, and finally the data were analyzed. Results indicated that asbestos and polyethylene pipes show maximum failures; maximum failure and fracture has occurred in pipes with 100 and 150 mm diameters. The most important factors affecting on failure were corrosion, traffic load and landslide. In addition, simultaneous influence of type and the diameter of the pipe on the failures were statistically significant. The depth of pipes establishment, corrosion and obsolescence of pipes as well as improper type of pipes were the most important causes of failures in Ahvaz Water Distribution Network. In this regard, upgrading pipe material setting standards and renewing water pipe network are the main strategies for failures minimization.

KEYWORDS: Failures Analysis, Water Distribution Network, Ahvaz

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Introduction

Optimum operation of water distribution networks is one of the priorities of sustainable development of water resources.[1] In recent years, water loss reduction has been raised as one of the most strategic and most economical ways of coping with drought in Iran.[2,3] The protection and maintenance of existing water networks is one of the projects that should be considered by water and wastewater companies.[4,5] Failure at the distribution level can be extremely critical because it is closest to the point of delivery and there are virtually no safety barriers before the consumption.[6]

Several parameters affect pipes and fittings failure. For example, numerous factors can cause the pipe failures such as, high water pressure, poor quality of pipe material, soil surrounding the pipes, age, diameter, corrosion, operational conditions, climatic conditions, traffic contribute to accidents and mechanical failure of pipes.[7-14]

In general, the mechanical failure of pipe under normal conditions (normal corrosion)

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occurs when the tensions resulting from environmental and operational conditions exceed pipe elasticity limit.[13]

Ahvaz is the center of Khuzestan province; located in the south west of Iran; with a population over 970,000 people; longitude of 49.68° North and latitude of 31.32° East; over 17,000 hectares; with an average height of 16 m from sea level.[15,16] Ahvaz has a total of three water treatment plants and a large water storage tank. Karun River is the main source of drinking water of Ahvaz,[17] with a minimum and maximum water flow of 90 m^3/s and 5,000 m^3/s in the low-water season and the flood season, respectively, and with an average flow rate of 2,500 m^3/s. The length of the water distribution network is about 2260 km.[18,19] Ahvaz water distribution network has a total of 254,888 subscribers.

Several studies have shown that most of the incidents have occurred in the iron and asbestos materials, respectively; most failures have occurred in diameters of 150 and 200 mm. The most important factors in pipes fracture incidence were corrosion, the physical pressure and the traffic; and numbers of fractures have been reduced by increasing the diameter.[20-31]

Due to lack of proper information about the failures in Ahvaz water distribution network, the importance of recognizing factors influencing it, this study was designed and performed using failures data during 2006-2008.

The main objective of this paper was to offer Ahvaz Water and Wastewater Company network modification and determination of the pipe material standards to reduce leakage and losses in Ahvaz water distribution network and have an appropriate distribution network for citizens.

Materials and Methods

Daily failure reports of Ahvaz Water Distribution Network were collected from emergency department of Water and Wastewater Company, Ahvaz, Iran, during 2006-2008. Therefore, they were entered into a Microsoft Excel database. Descriptive statistics including the maximum and minimum number of failures in distribution network were calculated and reported. All the statistical analyses were performed using Microsoft Excel program and SPSS for Windows (version 19.0, SPSS Inc., Chicago, IL, USA) with chi-square test. The P-value less than 0.05 set as a statistically significant level in all the statistical analyses. After collecting the required data i.e. pipe diameter and pipe materials, cause of the failure in the distribution network and in the divisions; and the values for every failure factors were defined. The results were compared to the standard values issued by The USEPA. Figure 1 shows the components Ahvaz Water and Wastewater Network, included (water pipes, pumps, valves, fittings, reservoir, waste pipes and manholes) and also pavements, parcels, river and rail.[21]

Results and Discussion

In this study, it was tried to analyze the failure and fracture in water distribution network of Ahvaz, Iran.

Number of failures based on the pipes materials

Figure 2 shows the frequency of failures in Ahvaz water distribution network in the different materials during 2006 to 2008.

According to figure 2, the highest number of incidents in Ahvaz water distribution network during the 2006-2008 has occurred in the type of asbestos (86.35%) and polyethylene (8.9%); and the lowest number of accidents has occurred in the ferrous type (0.0232%). The data analyzed using chi-square test also showed a statistical significant effect of type on fracture rates ($P = 0.0001$).

According to a study performed by Kettler and Goulter, failure rates for cast-iron pipe were found to decrease with increase in diameter. They found that failure rate of asbestos-cement and cast-iron pipes increased with time, but for different reasons. Analysis of the modes of failure showed that joint failure was predominant for cast-iron pipe systems with bolted and universal joints whereas the predominant mode of failure for asbestos-cement pipe systems was circumferential cracking.[32]

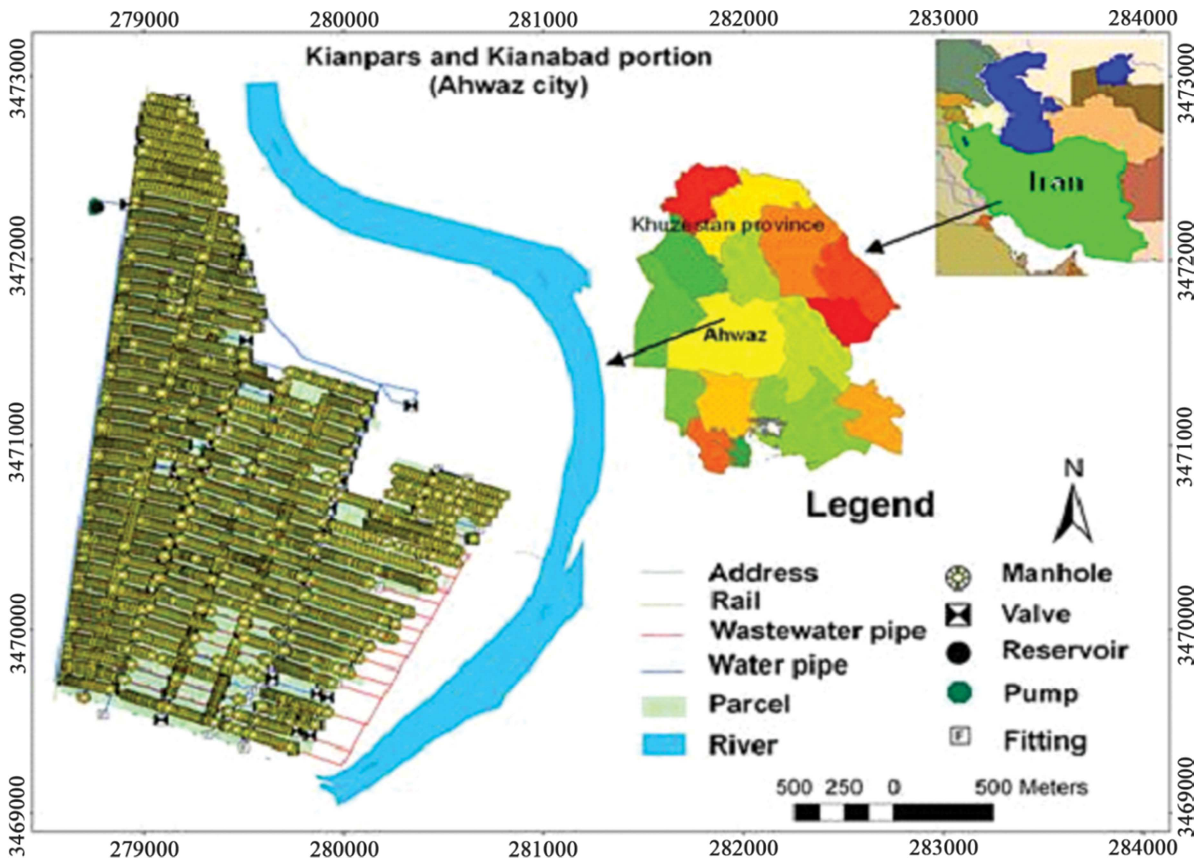

Figure 1. Study site location in the Ahvaz Water Distribution Network, in the south west of Iran21

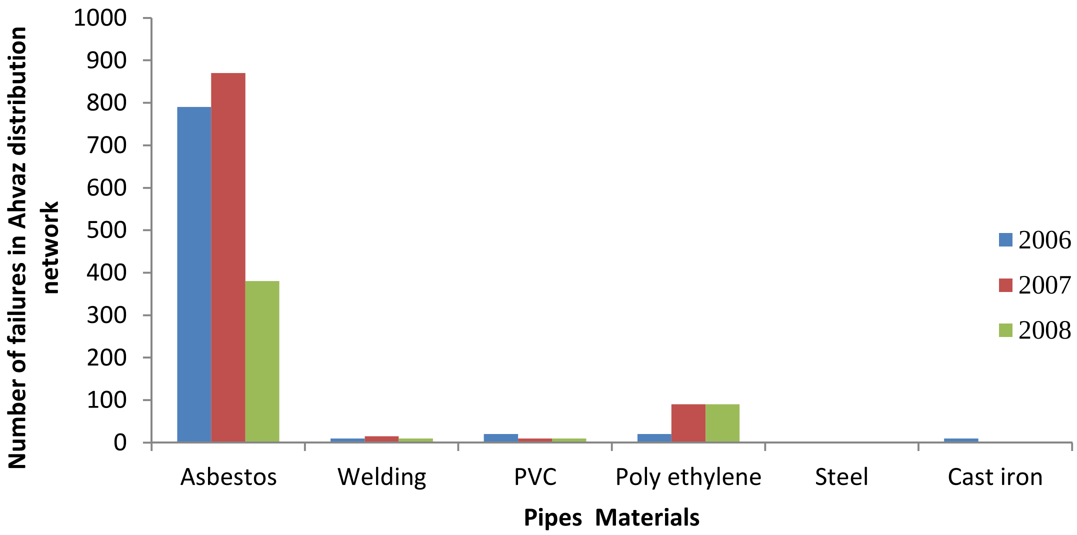

Figure 2. Number of failures in Ahvaz, Iran distribution network based on type of the pipe during 2006-2008
PVC: Polyvinyl chloride

Studies in Gorgan, Iran showed that over 50% of the failures have happened on polyvinyl chloride (PVC) pipes.[20]

Studies conducted in 21 cities in Canada, showed that more than 50% of the failures have happened in the ferrous pipes and the lowest amount of accidents and fractures in the PVC pipes (10%).[21]

According to a study conducted by Schuster (2008) in Toronto, the greatest failures and incidents happened in ferrous pipes.[23]

Number of failures based on the pipes diameter

Figure 3 shows the frequency of failures in different diameters in Ahvaz Water Distribution Network from 2006 to 2008. As the figures show, the greatest number of failures have occurred in diameter of 100 (39.78%) and 150 mm (18.39%) and lowest in diameters of 400 and 1500 (0.0424%)

The data were analyzed using chi-square test also shows a statistical significant effect of diameter on fracture rates (P = 0.0001).

The combined effects of type and diameter in the number of fractures in various years were evaluated using chi-square test. The diameter of the pipes was categorized in three 80-200 mm, 200-500mm and 500 mm > groups, and pipe type was divided into six groups: asbestos, welded, PVC, polyethylene, iron and cast iron; and the impact of both type and diameter was evaluated; and results showed that the type of fracture has a significant effect on the fracture rate.

Based on studies conducted, most of the failures have happened in diameters less than 200 mm.[24]

According to a study conducted by Schuster and McBean in Toronto, the most accidents and incidents had happened in diameters of 150 (50%) and 300 mm (30%).[23]

According to a study conducted by O'Day et al., the greatest failures and accidents had happened in diameters 150-200 mm.[25]

The results show that in the diameters less than 200 mm during 2006, 92% , 4.4%, 3%, 0.2%, and 0.4%, of the failures had occurred in the asbestos, PVC, polyethylene, ferrous, and cast iron types, respectively. In diameters of 200-500, 100% of the accidents happened in the asbestos type, and in diameters more than 500, 96.7%, and 3.3% of the failures had happened in the fusion, and in the ferrous types, respectively.

In this year, the simultaneous impact of type and diameter on fracture was statically significant, so that increase in diameter causes to decrease in frequency of fractures (the Pearson chi-square = 0.0001).

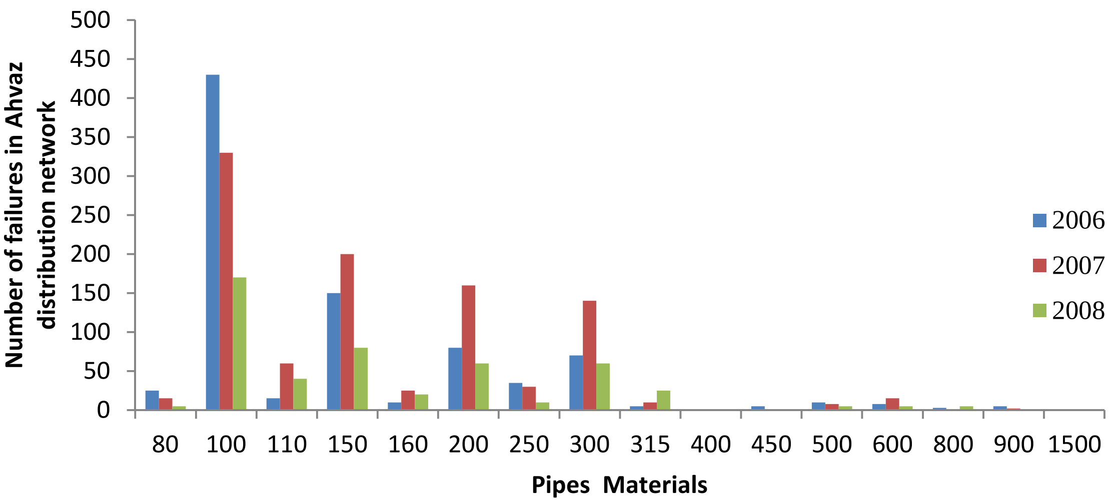

Figure 3. Number of failures in Ahvaz, Iran distribution network based on the pipes diameter during 2006-2008

In diameters less than 200 mm during 2007, 84.7%, 2.2%, and 13.1% of failures happened in the asbestos, PVC, and polyethylene types, respectively. In diameters 200-500mm, 95.9%, and 4.1% of failures happened in the asbestos and polyethylene types, respectively. In diameters more than 500 mm, 100% of the accidents happened in the fusion type. In this year, the simultaneous impact of type and diameter on fracture was statically significant, so that increase in diameter causes to decrease in frequency of fractures (the Pearson chi-square = 0.0001).

In diameter less than 200 mm during 2008, 77.3%, 2.8%, and 19.9% of failures happened in the asbestos, PVC, and polyethylene types, respectively. In diameters 200-500 mm, 84.8% and 15.2% of failures and accidents happened in the asbestos and polyethylene types, respectively. In diameters more than 500 mm, 100% of the accidents happened in the fusion type. In this year, the simultaneous impact of type and diameter on fracture was statically significant, so that, increase in diameter cause to decrease in frequency of fractures (the Pearson chi-square = 0.0001).

The results of the statistical analysis using chi-square test indicated that the impact of simultaneous number of failures in the type and diameter had been significant in the water distribution network during 2006-2008, also shows that with increasing the diameter, number of fractures reduces. Different studies have shown such result.[22-25]

Factors and number of failures in distribution network and connection network

Table 1 and 2 respectively show incidence factors in the distribution network and divisions network during 2006-2008.

The ratio of failure to total length of Ahvaz distribution network during 2006, 2007 and 2008 are 0.37, 0.509 and 1.089 cases per kilometer, respectively and from 2006 to 2008, this value was 0.211 cases per kilometer.

In the United States, (USEPA Standards; US Environmental Protection Agency) there are an estimated 237600 pipe breaks in 1,408,000 km, length of the water supply network, per year (The ratio of failure was 0.168).[33,34] Table 1 shows that average number of failures in Ahvaz distribution network was 845 in 2,349 km, length of the water supply network, during 2006-2008 (The ratio of failure was 0.359), which was higher than USEPA standards.

Table 1. Factors and number of failures in Ahvaz, Iran distribution network during 2006-2008 (Ahvaz Water and Wastewater Company)

Failure factors	Mean 2006		Mean 2007		Mean 2008		Mean 2006-2008	
	Number of failures	Percent	Number of failures	Percent	Number of failures	Percent	Number of failures	Percent
Corrosion	310	36.0465	594	50.1689	278	56.6192	1182	46.6272
Improper context	78	9.0698	94	7.9392	11	2.2403	183	7.2190
Improper quality of pipes and fittings	69	8.0233	23	1.9426	17	3.4623	109	4.2998
Scissors on (in a landslide)	140	16.2791	65	5.4899	53	10.7943	258	10.1775
Department of Gas	35	4.0698	13	1.0980	10	2.0367	58	2.2880
Department of Telecommunications	10	1.1628	10	0.8446	2	0.4073	22	0.8678
Department of electrical	4	0.4651	14	1.1824	2	0.4073	20	0.7890
Municipal	46	5.3488	74	6.2500	34	6.9246	154	6.0750
Sewage unit	77	8.9535	62	5.2365	29	5.9063	168	6.6272
Customer affairs	2	0.2326	21	1.7736	1	0.2037	24	0.9467
Car transportation	69	8.0233	179	15.1182	42	8.5540	290	11.4398
Oil company	3	0.3488	7	0.5912	0	0.0000	10	0.3945
Unauthorized connections	17	1.9767	11	0.9291	0	0.0000	28	1.1045
Water contractor	0	0.0000	10	0.8446	9	1.8330	19	0.7495
Subway contractor	0	0.0000	7	0.5912	3	0.6110	10	0.3945
Total	860	100	1184	100	491	100	2535	100

Table 2. Factors and number of failures in Ahvaz, Iran connection network during 2006-2008 (Ahvaz Water and Wastewater Company)

Failure factors	Mean 2006		Mean 2007		Mean 2008		Mean 2006-2008	
	Number of failures	Percent	Number of failures	Percent	Number of failures	Percent	Number of failures	Percent
Corrosion	6630	40.2599	10388	43.2761	4171	46.1751	21189	42.8017
Air entering the network	586	3.5584	250	1.0415	0	0.0000	836	1.6887
Context inappropriate	649	4.0017	407	1.6956	11	0.1218	1067	2.1553
Traffic load	450	2.7933	261	1.0873	3	0.0332	714	1.4423
Unsuitable quality of pipes and fittings	400	2.4897	360	1.4998	124	1.3727	884	1.7857
Department of Gas	226	1.3724	549	2.2871	176	1.9484	951	1.9210
Department of Telecommunications	206	1.2995	471	1.9622	109	1.2067	786	1.5877
Department of electrical	31	0.1882	187	0.7790	23	0.2546	241	0.4868
Municipal	272	1.6517	633	2.6371	267	2.9558	1172	2.3674
Sewage unit	312	1.8946	528	2.1996	193	2.1366	1033	2.0867
Eclipse (low pressure and water cut)	1298	8.4892	2178	9.0735	636	7.0409	4112	8.3062
Customer affairs (water cut accidents and fractures)	107	0.6497	255	1.0623	35	0.3875	397	0.8019
Destructive	110	0.6680	375	1.5622	108	1.1956	593	1.1979
Car transportation	795	4.8275	1459	6.0782	823	9.1110	3077	6.2155
Repair groups the network	71	0.4311	212	0.8832	43	0.4760	326	0.6585
End of the useful life of the pipe	2262	14.0393	3003	12.5104	1434	15.8751	6699	13.5319
Events by the water contractor	21	0.1275	198	0.8249	11	0.1218	230	0.4646
Adhesive outwear	772	4.6879	514	2.1413	127	1.4060	1413	2.8543
By common	275	1.6699	559	2.3288	168	1.8598	1002	2.0240
Unknown	807	4.9004	1217	5.0700	571	6.3213	2595	5.2419
Total	16468	100	24004	100	9033	100	49505	100

As shown in table 1, the most important factors in the occurrence of failures in the distribution network in 2006-2008 were corrosion (46.62%), car transportation (11. 43%) and landslide (10.17%), respectively; and weakest factors were occurrence of accidents in the metro contractors and Oil Company (0.3945).

According to a study conducted by Kleiner and Rajani in Australia, the most important factors in occurrence of failures in pipes were corrosion and high age of pipes.[26] Leaks often occur through a buildup of corrosion that causes structural failures in aging pipes, particularly at joints.[35]

As shown in table 2, the most important factors in occurrence of the failures on the divisions during 2006-2008 were corrosion (42.8%), eclipse (8.3%) and car transportation (6.2%), and weakest factor was contractor (0.4646).

The ratio of the failures in the distribution network to the total length of pipes of the water distribution network in Ahvaz in 2006, 2007 and 2008 was 0.37, 0.509, 1.089 cases per kilometer, respectively and in 2006-2008, this value was 0.211 cases per kilometer. According to a study conducted by Agbenowosi, the rate of accidents and fractures in the water distribution network in Europe was 311 cases per kilometer.[27]

According to a study conducted by Agbenowosi, the rate of accidents and fractures in the United States water distribution network was the 0.137 cases per kilometer.[27]

In the United States, The ratio of the failures of division to the total length of the pipes in water distribution network was 5.92 cases per kilometer.[34] The ratio of the failures of division to the total length of the pipes in Ahvaz city water distribution network in 2006, 2007 and 2008 was respectively 7.08, 10.32, 3.88 cases per kilometer, and in 2006-2007, this value was 21.28 cases per kilometer which is higher than USEPA standards.

Based on studies conducted by Beigi in 1999, the number of failures in divisions in the water distribution network in 1998 was 9.48 kilometers of the distribution network.[24]

In the United States, an estimated 7,000 km of pipe requires replacement each year at a cost of around USD 2.7 billion while water losses (estimated to be 10%) cost around USD 4.3 billion per year.[33]

Given the most of the failures were due to corrosion and obsolescence of pipes in the distribution network, the necessary measures should be taken for replacing them. Since the failure rates on the pipe of the asbestos has the upper value, so replacing this type of pipes with some other high quality pipes, particularly polyethylene pipes for divisions is necessary. Considering the rate of 95.1% of the failures in the divisions, paying attention to the standardization of the divisions is necessary. Another cause for failures is low depth of pipes in the network due to the pressure created by vehicles traffic. With the increasing growth of urbanization, redesign and modification of the network and creation of more pressure zones with a right amount of pressure is necessary, which would reduce leaks, pipe breaks and water losses.

Conclusion

According to results, most of failures in Ahvaz water distribution network are resulted from corrosion and amortized pipes. Therefore, it is necessary to replace damaged pipes with new ones. With regard to results, failures in Ahvaz water distribution network are frequent, and consequently lead to cost wasting in water supply operation. In order to reduce failures in water distribution network, structural amendment in network is critical. According to the increasing population and development of urbanization it considers redesigning and modification of water distribution network is essential. Furthermore, creating additional pressure zones with appropriate pressure is necessary. This can be reduced leaks and failures in the piping distribution network.

Conflict of Interests

Authors have no conflict of interests.

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