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Evaluation and Selection of Optimal Pipes for Urban Drinking Water Distribution Networks Using Hierarchical AHP (Case Study: Water Distribution Network in the City of Mahabad)

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ABSTRACT: Optimal selection of pipes in urban water distribution network is very important due to the importance of supplying drinking water and lack of resources. According to the urban water and wastewater experts and advisors the optimal pipes should have high Resistance, accommodation, long life and the lowest leakage in the water distribution network. In order to determine the coefficients of importance in this study, using 12 criteria influencing the optimal selection of pipe type the research questionnaire was developed and its validity and reliability were analyzed. The Cronbach's alpha was used to evaluate the reliability, the value of which was 0.87 which indicated the high consistency and reliability of the questionnaire. In this study paired comparison questionnaire forms were distributed among 47 urban water and wastewater experts, consultants, workers and the contractors of Mahabad City and various criteria were decided by them. After weighting and comparison of different pipes based on the effective criteria, the ductile iron pipe was chosen using hierarchical analysis of the pipes used in urban water distribution network.

Keywords: Optimal election of pipes, Ductile iron pipes, Asbestos cement pipe, PE pipes, AHP

INTRODUCTION

The development of the cities have resulted increased problems in providing social services and economic and social consequences and they have become the main concern gradually. Due to the complexity and extensiveness of decision making scope of the problems related to water distribution networks, the inadequacy of these designs is quite predictable. Hence, the improved design methods and the use of optimization techniques to reduce costs and satisfy the requirements of the hydraulic Conditions of the distribution network are inevitable. The use of new and improved methods of refining groundwater or wastewater (sewage) reuse, modification of traditional irrigation methods, correct planning at provincial and national culture, dam construction in appropriate places, education of correct consumption to the consumers and the utilization of two types of water distribution systems (potable and non-potable) in residential areas, are among scientific and proven methods consistent with our country ecosystem and set us free from using common uncontrolled methods. Providing and distribution of drinking water is one of the most fundamental infrastructure services which has a great impact in urban life quality and welfare and the lack of providing suitable and appropriate services reduces the social health and welfare besides leading to social disappointment. The drinking water system requires the use of water pipes and valves capable of transferring water from the resources to the consumers. Here considering the cost and existing conditions in the water and wastewater companies and the development reform and development projects under construction require selection the best and most appropriate pipes to be used in urban water distribution networks. Most of the pipes used in water distribution networks are asbestos cement pipes, ductile iron pipes and the PE pipes and each one has its own benefits and defects and deciding about the type of the pipe being used in the water distribution networks, is a problem with various criteria and options.

REVIW OF LITERATURE

Tabesh and Karimzade (2003) conducted a research titled “urban water distribution network optimization considering the reliability constrain and pressure-flow relationship”. This research provides a method for optimization of water networks that besides considering the common constraints in optimization of networks, it considers the reliability of the network nodes in crisis situations such as failure of the pipes, increased demand in the nodes and etc.

Khodashenas (2008) in his research on the management and control of leakage in urban water distribution networks (a strategic viewpoint) of acknowledged that the issue of leakage can be studied from another point of view which is the water being an strategic issue which means that in the discussion of preventing the water loss the problem of cost is not important and the main point is our responsibility to prevent the loss of water. Therefore, the use of various methods to control the water leakage is important.

Jahangiri and Baran, (2014) in an article entitled pressure intelligent management to reduce leakage in water distribution systems, case study: Sarfarazan-Mashhad proved that the existence of leak in the water distribution network is inevitable.

Merrill (2007) in a study titled "the introduction of the technical specifications and production processes of asbestos pipes considering the conditions and the insertion of pipes, skills in the installation and transportation of the pipes, the impact of natural disasters such as floods and earthquakes and environmental impacts are among the other most important conditions to be considered.

Paige (2001) showed that the use of ground penetrating radar (GPR) is a non-destructive method that reveals electrical discontinuity at shallow depth (less than 50 m). The radar performs this through generation, propagation, reflection and discrete pulses of electromagnetic energy with a frequency (MHz or GHz).

The main purpose of the present research is the optimal selection of pipes for drinking water distribution network in the city of Mahabad using Analytical Hierarchy process (AHP). Among other research purposes is to study the criterion and the factors affecting the choice of pipes in urban water distribution network, comparing the criteria and the factors influencing the choice of the pipes used in water distribution networks and prioritizing pipes that can be used in water distribution network in the city of Mahabad using Analytical Hierarchy process.

Mahabad is located in the southern part of west-Azerbaijan province in 36°45′47″N 45°43′20″E and 1320 meters above sea level. It enjoys a mild climate with cold winters and warm summers. Mahabad city is one of the Kurdish cities in the south of west-Azerbaijan which is bounded by Miandoab city in the North, Sardasht in the south, Piranshahr in the west and Bukan in the east.

A. Type of pipes used in the network

There are three types of pipes including asbestos cement, ductile iron, and polyethylene pipes in the water distribution network. The length of pipes and the accidents happened are analyzed in the following Table 1.

Table 1: Pipe type and accidents (Reference: The monthly statistics the water and wastewater office in Mahabad).

Pipe Type	Length of pipe used in the network (m)	The number of leaks and failures (percent)
asbestos cement pipe	94255	36
ductile iron pipe	6838	0
PE pipe	154586	64

ANALYTICAL HIERARCHY PROCESS

In analyzing any case we need a criterion for measuring with and index, choosing an appropriate indicator allows us to compare the alternatives appropriately. But when a few or several criteria are considered for evaluation, the evaluation becomes complex and the complexity becomes high when the multiple criteria are in the space with several material. At this situation the evaluation and comparison evades the condition that can be analyzed by mental processes and a strong practical analysis tool is required. One of the most powerful tools for such a situation is the (analytic hierarchy process). This method is used for the grading and classification and sometimes it can also be used for social and economic analysis. After these stages we form a hierarchy of the index population. In order to form the matrix, the indices must be weighted in this way the weight of each index is acquired. After multiplication of the weight of each index in the number of that index the record of each index of each location are summed up and the locations are leveled based on the obtained records. The process of the AHP model starts with specifying the elements, decision making and prioritizing them. These elements include the various methods of doing things and prioritizing the measures and features.

THE HIERARCHICAL TREE

The hierarchical tree has three main objectives, criteria and options the criteria level of which can be divided into several sub-criteria. The decision matrix is plotted in Fig. 1.

DECISION MATRIX AND PAIRED COMPARISONS

For making comparisons between different options, based on each indicator and deciding about the importance of the decision index with paired comparisons, after the hierarchy of the decision, the decision maker must create the set of matrixes that measure the numerical or qualitative priority of the indices as well as each decision option based on the indices proportionate to other options. This is done by paired comparison between the decision elements and assigning numerical score indicating the superiority of either of the two decision elements.

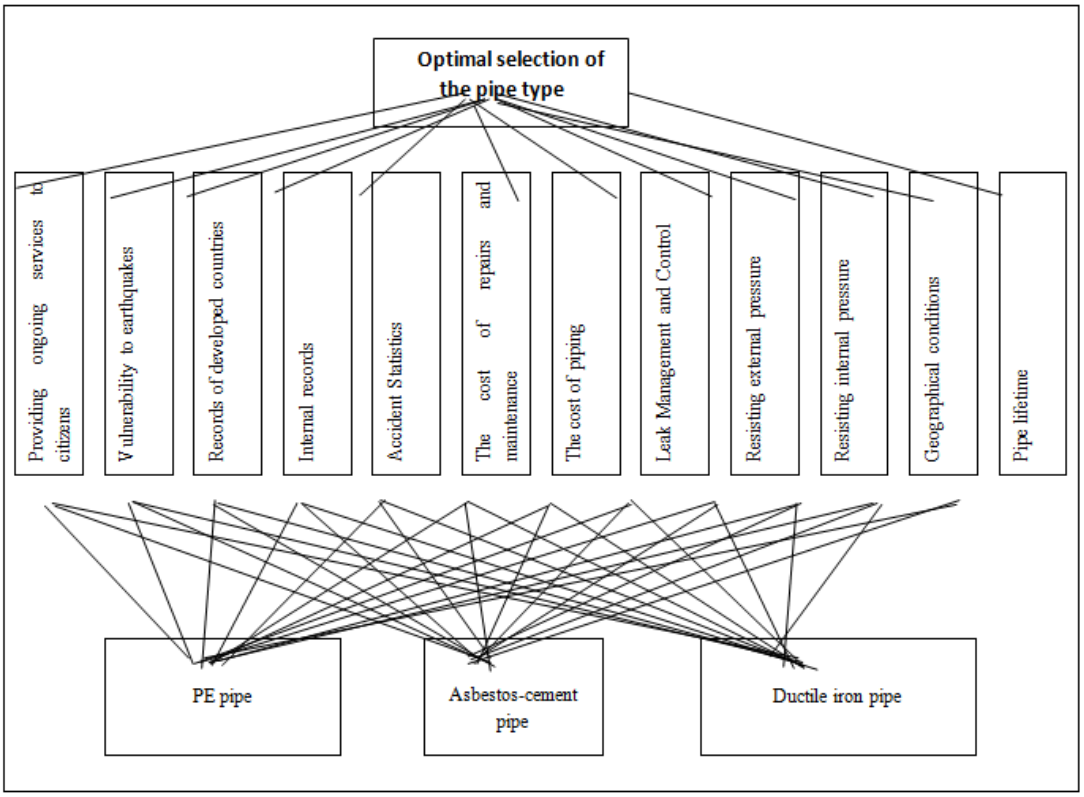

Fig. 1. Hierarchical tree.

Table 2. Matrix of paired comparisons based on x_i criterion

Asbestos-cement	Polyethylene	Ductile iron	Characteristic
a_{13}	a_{12}	1	Ductile iron
a_{23}	1	$a_{12/1}$	Polyethylene
1	$a_{23/1}$	$a_{13/1}$	Asbestos-cement

A. Calculating the relative weights

The relative weights of the "decision elements" using numerical calculations. The next step in AHP is to conduct the required calculations for determining the priority of each decision elements using the paired comparisons data matrices. Mathematical operations are summarized in the following steps. The sum of number of columns of the matrix of paired comparisons is calculated then each element of the column is divided by the sum of the numbers of the column. The obtained new matrix is called "normalized comparison matrix". The mean of the numbers of each row of the matrix is calculated. This provides the mean relative weights of decision elements with the matrix rows.

B. Compatibility Tests

Almost all calculations of AHP are carried out based on the first decision of the decision maker in the form of paired comparisons and any errors or inconsistencies in the comparison and determination of the importance between options and indicators of the final results obtained from calculations ruins the calculations.

The consistency rate that we will introduce is a tool that determines the consistency and indicates to what extent the priorities of comparisons are trusted. For example, if option A to B is more important (preferred value 5) and B is relatively more important than C (priority value 3) then we should expect that A is much more important than C (preferred value of 7 or higher) or if preferred value of A to B is 2 and preferred value of B to C is 3 then the preferred value of A to C must be 4. Perhaps the comparison of two options is easy but when the number of comparisons increases conducting comparison would not be easy and this reliability must be obtained through calculating the rate of consistency. Experience has shown that if the rate of consistency is less than 0.10 the consistency of the comparisons in acceptable, otherwise they must be adjusted. The following steps are used to calculate the consistency rate:

Step 1. Calculating total weight vector: the matrix of the paired comparisons is multiplied by the column vector "relative weight" and the obtained vector is called the total weight vector.

Step 2. Calculating the adjustment vector: the elements of the total weight vector are divided by relative preference vector. The resulting vector is the adjustment vector.

Step 3. Obtaining λmax gives the mean of the elements of the adjustment vector λmax.

Step 4. Calculating the consistency index: The consistency index is defined as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (1)$$

n is the number of options.

Step 5. Calculating the consistency rate: The consistency rate is obtained by dividing the consistency index by the random index.

The consistency rate below or equal to 0.1 indicates the consistency of the calculations (Mehregan)

$$CR = \frac{CI}{CR} \qquad (2)$$

DISCUSSION AND CONCLUSIONS

Data analysis is a multistage process in which the data that have been collected in various ways, are summarized, classified and then processed and analyzed to establish the types of relationships between the data provided to test the hypothesis.

A. Paired comparisons

In order to make paired comparisons, the expert choice 11 program is used. For this purpose, we enter the data into the program and then analyze the choices based on the selected criteria. This is done by paired comparison of the elements and by assigning a numerical score indicating the superiority or importance of either of the two elements. In order to do this usually the comparison of the options with the i^{th} index or the j^{th} indices and the type of evaluation is indicated in the following Table 3.

Table 3: Paired comparison matrix based on criterion x_i

Asbestos-cement	Polyethylene	Ductile iron	Characteristic
a_{13}	a_{12}	1	Ductile iron
a_{23}	1	$a_{12/1}$	Polyethylene
1	$a_{23/1}$	$a_{13/1}$	Asbestos-cement

In the Fig. 2 the optimal selected pipe and the final weight of each pipe is displayed. Since the consistency rate is less than 0.1 we can conclude that the judgments are correct and the choice of ductile iron pipe is a priority. The following chart reflects the judgment of experts, corporate executives and the technicians of urban drinking water of Mahabad city along these pipes. Since during the last few years there have been no report of leakage or accident in these pipes, it can be concluded that the lifetime of these pipes is better than the others.

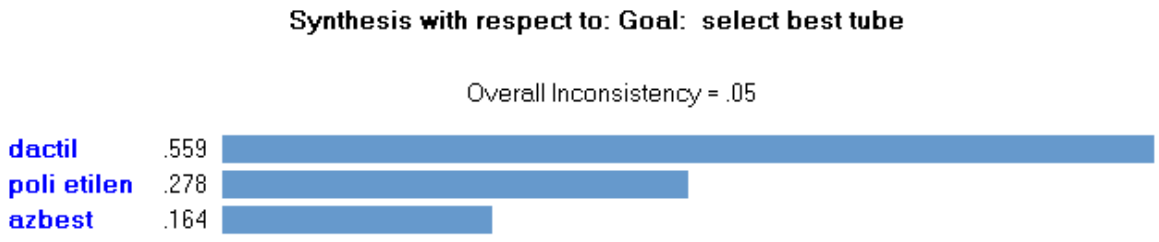

Fig. 2. The final weight of the pipes.

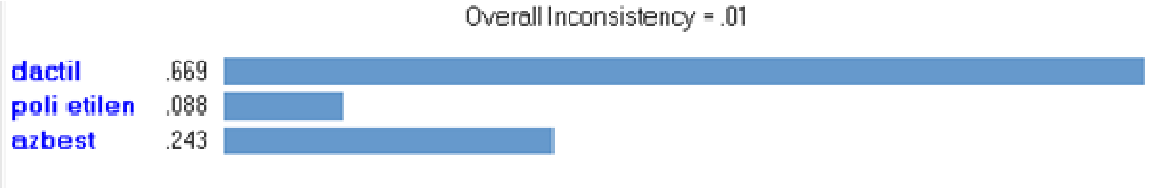

Fig. 3. Importance coefficients based on the lifetime criterion.

The Sulphate soils or soils with a high chloride are harmful for cement. In addition, these coatings reduce the flexibility of the pipe so the pipe can not be bended under external loads and it also reduces the allowed level of expansion under internal pressure of the pipe is reduced and leads to the appearance of cracks in the coating. Although the strip coatings are more flexible than the cement but they are stronger than cement in conditions such as Sulphate soils, so when they might be damaged during the transformation or installation it needs expensive cathodic protection with high maintenance costs. So the respondents are expected to choose the ductile iron pipe which is consistent with the conditions of Mahabad. Because as discussed before the ductile iron pipe with the added factors is consistent with pipe water, soil type and land. The ductile iron pipe has been successful in its test the result of which is indicated in domestic and foreign experiences.

The most significant difference in the ductile iron pipe in comparison with other types is the modeling the design of internal pressure design. The ductile iron has a standard coating while the other pipes lack such coating. The ductile iron uses the confidence coefficient in designing internal pressure.

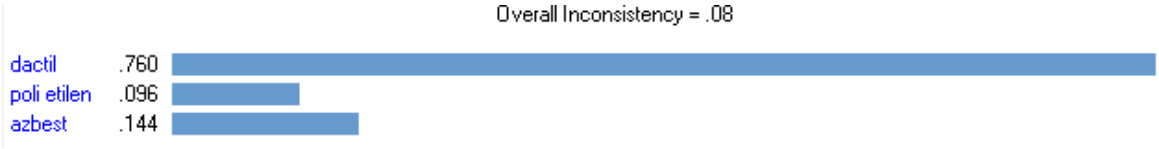

Fig. 4. Importance coefficients based on geographical condition criterion.

Table 4: Internal pressure tolerated by different pipes.

Pipe Type	Working pressure (atm)	Factory test pressure (atm)
Polyethylene	8	20
Asbestos-cement	10	25
Ductile iron	12	30

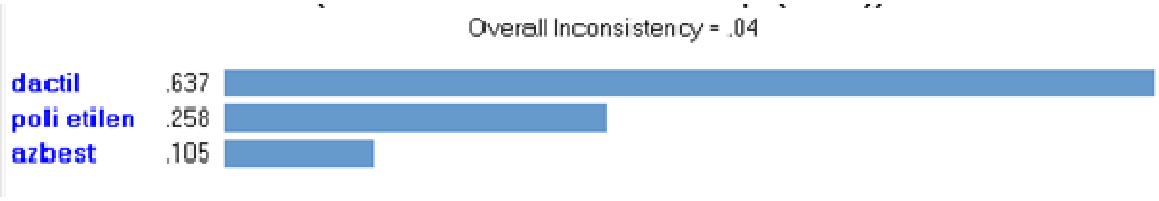

Fig. 5. Importance coefficients in terms of the internal pressure criterion.

The results of paired comparisons show that the selection of ductile iron pipes is consistent with reality. The ductile iron pipes are made in the pipe and machine building factory with ISO centrifugal method. These pipes are offered in the market in three classes according to international standard. The class LA is made to tolerate low pressure the maximum 8 atmosphere. These pipes are tested under 20atm in the factory.

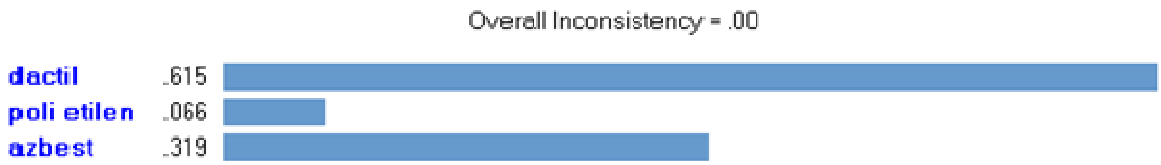

Fig. 6. Importance coefficients based on the criterion of resistance to external pressure.

The A class are made to bear medium pressures i.e. 10 atm and they are tested under 25atm in the factory. And finally the B class are made to bear high pressures i.e. 12 atm and they are tested under 20atm in the factory. When a metal or non-metal pipe is carrying water is damaged and has a leakage, the water comes out with high pressure. Ignoring the quality and the factors affecting the leakage sound, the created sound comes out of the surface ground with some changes and the leak detection system determined the location by obtaining these weak signals through its sensor and strengthening and filtering them.

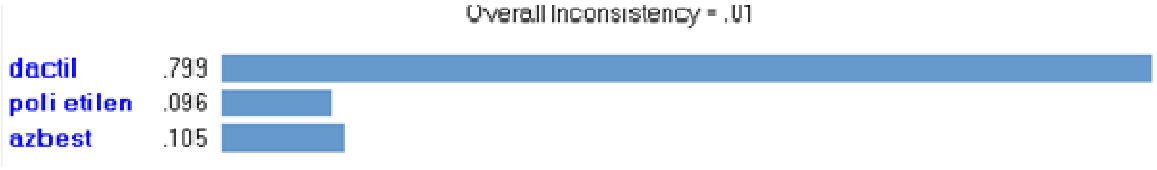

Fig. 7. Importance coefficients based on the criterion of resistance to external pressure.

Ductile iron pipelines do not need maintenance. But this is not true about the PE pipes. But in general these pipes (PE) are lower in terms of initial cost and can be bought much cheaper than other pipes. It is evident when comparing the cost of the pipes, these pipes are selected. The following diagram represents the judgment of the response confirming this issue.

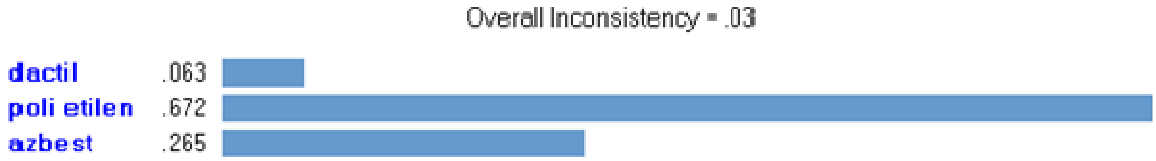

Fig. 8. Importance coefficients based on the criterion of resistance to the cost of the piping.

The regular pipes in which the graphite composition is needle type are fragile. To overcome this disadvantage and increase their pressure tolerance, the graphite compositions are formed into spheres. These pipes which are known as ductile iron pipes have maintained the components of iron pipes as well as elasticity properties and their ability to withstand the pressure increases. So they are called break-proof ductile iron pipes in Iran. Therefore the ductile iron pipes are faced with less damage.

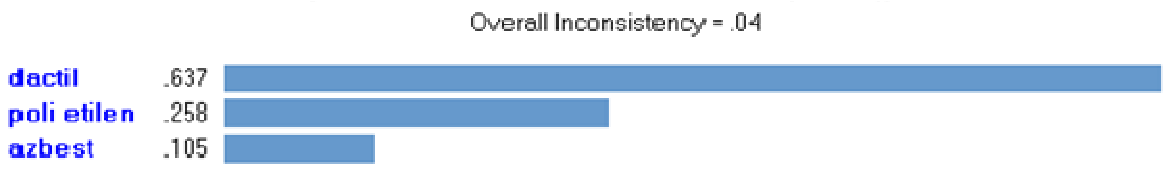

Fig. 9. Importance coefficients based on the incidents recorded criterion related to the pipes.

The most accidents associated with the water distribution network in the country are linked to polyethylene pipes. The following table shows the number of incidents in a day. According to the following table it can be expected that the experts have better judgment than ductile iron pipes. In 1950 a detailed study was conducted on the causes of spills and leaks in the water distribution network in Tokyo and the results indicated that the ductile iron pipes are the most resistant pipes against breaks and leakage and they are the most appropriate pipes for water distribution network and the stainless steel pipes are the best pipes for installing water splits and resistant against earthquake.

Table 5: The number of the incidents recorded in the water distribution network.

Pipe Type	No	Percent (%)
Asbestos	64	4
PE	1037	64
Ductile iron	9	1
PVC	474	29
Steel	25	2

Therefore, it was planned to replace the whole water distribution network pipes with ductile iron pipes till 2000 and the split pipes were replaced by stainless steel pipes. Since 1980 the program of replacing the split pipes with stainless steel pipes started and during 20 years the whole pipelines were replaced by ductile iron pipes. The postwar rate of leakage –after 1960 the ductile iron pipes being used- the stainless steel pipes being used- the rate of break-proof ductile iron-stainless steel pipe rate. The Fig. 10 shows the use of ductile iron pipe and the amount of leakage of the water network which is consistent with the results of the research.

The main orientation of the leakage control program is the correction of water distribution networks using high quality pipes, good connections and resistance against earthquake. As long as there is not the necessary insurance about the pipes and connections of the network for optimal operation the operation of leakage detection program is not enough. Based on the results of the research conducted by the research team of West Azerbaijan Province Water and Wastewater Company from Japan we conclude that the ductile iron pipe is more appropriate.

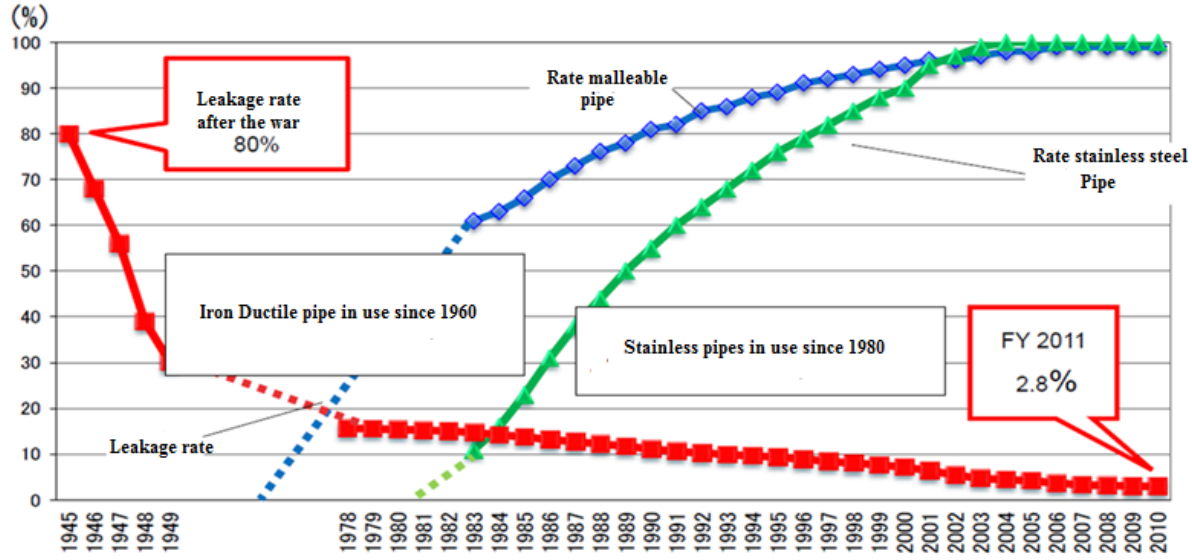

Fig. 10. Comparing the use of ductile iron pipes based on breakage and leakage rate.

Fig. 11. Importance coefficients based on the records of developed countries.

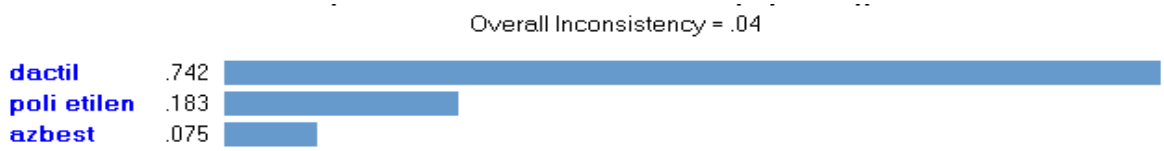

Fig. 12. Importance coefficients based on the criterion of resistance to earthquakes.

It should be mentioned that the replacement of the ductile iron pipes approach in the water distribution network and using the stainless steel pipes in the splits as well as strengthening the ductile iron pipes are among the measures taken in this regard. Providing continuous services and providing residents' drink water requires accurate and reliable network. Using the successful experiences of Japan in reducing water loss is among the most important things to do by the water and wastewater company. Water is an important issue and not a joke and the water and wastewater companies must take the necessary step to prevent water loss and people do not accept the inappropriate and insufficient services. The judgment of the experts is mostly based on the incidents happened in water network and the water company of Mahabad.

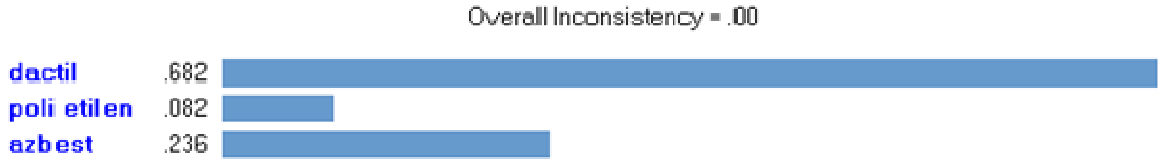

Fig.13. Importance coefficients based on continuous services criterion.

RESULTS

The results of studies indicated that ductile iron pipes are the most resistant pipes against breakage, leakage and earthquake. Therefore, it was planned to replace the whole water distribution network pipes with ductile iron pipes till 2000 and the leakage of Tokyo water is reduced to less than 3%. Japan is planning to reduce the water loss below 1% level. It was indicated in this study that the entire distribution network uses ductile iron water pipes.

According to the announcement of the water and wastewater company of west Azerbaijan the oldest pipes used in water distribution network of Urmia city are ductile iron pipes with 600 mm diameter. These pipes were installed in conjunction with construction of the refinery plant in Urmia and there has been no report of breakage or leakage so far. The results of this study are quite similar.

Also the results are consistent with Merrill (2007). In this study titled "the introduction of the technical specifications and production processes of asbestos pipes considering the conditions and the insertion of pipes, skills in the installation and transportation of the pipes, the impact of natural disasters such as floods and earthquakes and environmental impacts are among the other most important conditions to be considered.

SUGGESTIONS FOR FUTURE RESEARCH

(i) Conducting the present study with other multi-criteria decision making techniques

(ii) Conducting the present study with other decision making and innovative techniques

(iii) Research in order to select the optimal type of pipe used in water splits

(iv) Conducting the present study in other cities and provinces

(v) Evaluation of projects related to piping in other parts of the country

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