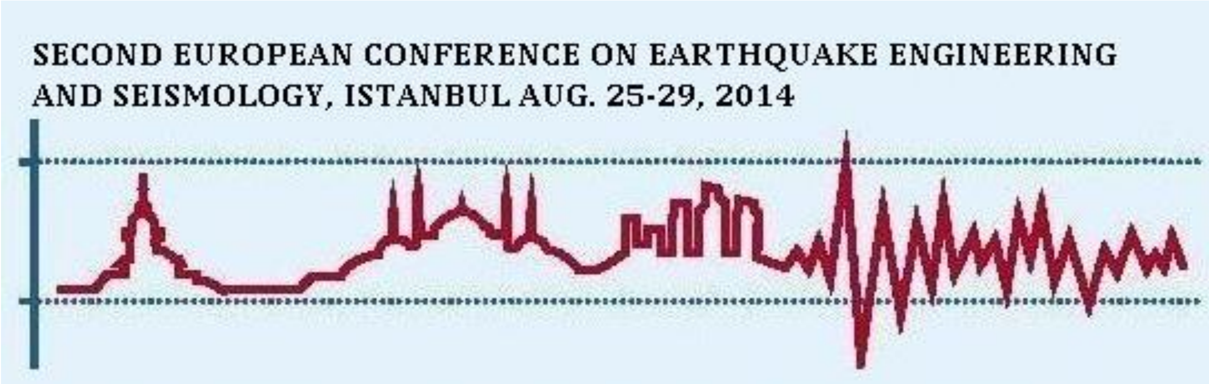

SEISMIC VULNERABILITY CURVES OF CAST IRON BURIED PIPELINES

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ABSTRACT

Water buried pipelines can be spread over a large area where different ground conditions can be encountered. Within this paper treats the seismic vulnerability of cast iron buried pipelines using the vulnerability index method. In this method the main parameters that have an influence on the seismic behavior of cast iron pipelines are identified. Then weighting coefficients are associated to those parameters.

Then a vulnerability index is calculated, this one allows the classification of each studied section pipe in one of the three defined categories (low, medium and high vulnerability). Based on this index, vulnerability curves for cast iron pipes are derived.

These ones allow the determination of the number of failures by kilometer of pipe versus the peak ground velocity (PGV).

INTRODUCTION

Damage in the water supply network does not depend only on the intensity of the disaster, but also on vulnerability of the special characteristic of each component of the entire system.

In large cities, several thousand kilometer of lifelines network facilities spread over expanded urban areas. Because of the huge stock, the majority of lifelines are highly vulnerable to strong ground motions and large ground deformations. In major events, repair works of a number of pipe breaks and joint failures are time-consuming. From the point of view of seismic risk management, it is of great importance to evaluate seismic vulnerability of existing lifeline network facilities.

Several methods of damage estimation do exist. The first one was elaborated by the ATC (Applied Technology Council) in the ATC-25 report in 1991. It gives the damage risk (number of breaks per kilometer) under the form of damage probability matrices (DPM's) in which the earthquake intensity is characterized by the Modified Mercaly Intensity (MMI). An addenda, the ATC-25-1 report, is dedicated to water supply. The FEMA (Federal Emergency Management Agency) and the NIBS (National Institute of Building Sciences) financed a project to develop a tool for estimating the damage under earthquake hazard. The methodology was implemented in the software HAZUS using a geographic information system (GIS). The European project RISK-UE had the objective to propose a methodological manual, adapted to the European context, for the realization of seismic risk scenarios.

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The most significant contribution is the structure of the suggested method. The RADIUS (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disaster) method was initiated by the UN Secretariat and aimed to provide developing countries by an efficient tool to assess the vulnerability of their cities.

Other vulnerability assessment methods were developed, all aims to reduce the seismic effect on pipelines. Ueno et al. and Nojiima, introduce a vulnerability factor (V-factor) for the evaluation of seismic vulnerability of lifeline network facilities.

In this study a vulnerability index (VI) for convenient evaluation of seismic vulnerability of concrete pipes is presented. The proposed method is based on statistical models for estimating pipes vulnerability.

FACTORS CAUSING DAMAGE TO BURIED PIPES

The main elements that have an influence on the seismic vulnerability of buried pipelines are presented here after.

1/ Ground Shaking

Ground shaking refers to transient soil deformations caused by seismic wave propagation. It affects a wide area and can produce well-dispersed damage. The level of ground shaking at a pipeline location can be measured in terms of PGV, PGD, PGA or MMI.

2/ Landslides

Landslides are permanent deformations of soil mass, producing localized severe damages to pipe.

3/ Liquefaction

Liquefaction is a phenomenon affecting generally saturated granular soils (silts and sands) in loose condition under dynamic loading such as the case during an earthquake.

4/ Settlement

Pipe breaks occur due to relative vertical (differential) settlements in areas of young alluvial soils prone to localized liquefaction. Breaks can also occur where pipes enter tanks or buildings.

5/ Fault Crossings

Localized permanent ground deformations occur in surface fault areas will be heavy when crossing surface faults.

6/Material pipe

Material pipe are referenced as one of the main factors that have a significant role on the seismic behavior. In this study the considered material is Cast Iron.

7/ Pipes diameters

Past earthquakes show the influence of the diameter on the number of breaks and failures in pipelines. Small diameters experienced more damages that great ones.

8/ Soil conditions

Classification or zoning of ground conditions is important in the earthquake damage estimation process because ground conditions directly affect seismic amplification of ground shaking.

STATISTICAL MODEL FOR ESTIMATION OF PIPELINE DAMAGE

Statistical method is widely used for estimation of damage to lifeline networks subjected to strong ground shaking and ground deformations. Typical method for estimating number of pipe breaks and joint failure is to multiply extended length of pipeline by damage rate representing the average number of pipe breaks and joint failure per unit length.

$$N = L \, . \, R_{fm}\,(x) \qquad (1)$$

Where N: number of pipe breaks and joint failure, L: extended length of pipeline (km), x: ground motion parameter such as PGA, PGV, or SI (spectral intensity), and R_{fm} (x) : damage rate (breaks/km). Damage rate R_{fm} (x) is given by the following equation:

$$R_{fm}\,(x) = C_d \,.C_p \,.C_g \,. \, R_f\,(x) \qquad (2)$$

Where $R_f\,(x)$: is the standard damage rate (breaks/km) as a function of ground motion parameter x , C_d is the correction factor for pipe diameter, C_p : is the correction factor for pipe material/joint type, C_g : is the correction factor for ground and liquefaction. Standard damage $R_f\,(x)$ (breaks/km) is defined for a combination of a particular type of pipe material, joint, and pipe diameter on the basis of damage statistics from past earthquakes. Although the framework of Eqns. (1) and (2) are common to various models of statistical estimation methods, different models have different sets of correction factors and standard damage rate function.

EVALUATION METHOD OF VULNERABILITY INDEX OF PIPELINES

A simple method termed “Vulnerability Index (VI) method” to quantify relative vulnerability of buried pipeline is proposed. As equation (3) shows, the VI is evaluated by considering number of parameters influencing the behavior of the pipe with weighting factor derived from past Algerian earthquakes (Ain Temouchent 1999 and Zemouri 2003), note that some correction factors may be unreliable due to statistical insufficiency.

$$VI = C_m \,.C_d \,.C_p \,.C_f \,.C_s \,.C_g \,.C_i \,.C_l \qquad (3)$$

C_m =1,1 this value is commonly used for cast iron buried pipelines

C_d is the correction factor for pipe diameter.
C_f is the correction factor for fault crossings.
C_s is the correction factor for settlement and landslide.
C_g is the correction factor for ground type.
C_i is the correction factor for the seismic intensity.
C_l is the correction factor for liquefaction.

These correction factors are given in Table 1.

Table 1: Weighting factors

Parameter	Category	Weighting Factor
Diameter	φ < 75 mm	1,6
	75 mm < φ <150 mm	1,0
	150 mm < φ <250 mm	0,9
	250 mm < φ <450 mm	0,7
	450 mm < φ <1000 mm	0,5
	φ > 1000 mm	0,4
Fault Crossing	No Intersection	1,0
	One Intersection	2,0
	Several Intersections	2,4
Settlement/Landslide	No risk	1,0
	Average risk	2,0
	Important risk	2,4
Ground Type	Deposit Soil : Alluvium: very soft	4,7
	Deposit Soil : Diluvium: soft	2,9
	Weathered Rock: Medium	2,0
	Moderate Weathered Rock: Medium	1,0
	Slightly / No Weathered Rock: Stiff / Hard	0,5
Liquefaction	$0 \leq PL < 5$	1,0
	$5 \leq PL < 15$	2,0
	$15 \leq PL$	2,4
Ground Shaking	MMI<8	1,0
	8≤MMI<9	2,1
	9≤MMI<10	2,4
	10≤MMI<11	3,0
	11≤MMI	3,5

In this method, the pipe diameters are those commonly used in Algeria. The fault crossings pipe is considered with no crossings, one crossing and more than one crossing. Settlement and/or landslide are considered also through a geological conclusion (if there is no risk, an average risk or an important risk) on the soil movement. The ground conditions are considered with respect to the soil type. The seismic intensity is considered using the MMI scale. Finally the liquefaction is considered through the calculation of a potential of liquefaction (PL) (In this work, the method of Iwasaki was used). Based on previous study, Halfaya and al, and on past Algerian earthquakes (Ain Temouchent 1999 and Zemouri 2003) a classification for pipeline according the VI is proposed in Table 2.

Table 2: Pipe Classification

Range VI	Evaluation	Colour
$0 < VI < 5$	Low vulnerability	**Green**
$5 \leq VI < 12$	Medium vulnerability	**Orange**
$12 \leq VI$	High vulnerability	**Red**

In this classification when the vulnerability index ranges between zero and five the vulnerability of the pipe is low and the green color is associated. When it is more than twelve it means a critical situation and the pipe is vulnerable so the red color is associated. Then for intermediate situation (VI ranges between five and twelve) the orange color is associated. These values are for Algerian case; despite the fact they need more statistical data to be checked, they will be used here.

VULNERABILITY CURVES

Isoyama et al. proposed the following equation to assess the number of damages per kilometer in water pipeline.

$$Rm(v) = Cp \,.\, Cd \,.\, Cg \,.\, Cl \,.\, R(v) \tag{4}$$

With v the PGV (peak ground velocity) and R(v) expressed by Isoyama et al. after Kobe earthquake as:

$$R(v) = 2.24x10-3(v-20)1.51 \quad (5)$$

In this work an expression to assess vulnerability curves for Algerian case is proposed in equation 6.

$$Rm(v) = VI' \; . \; R(v) \quad (6)$$

With VI' = VI/ Ci in order to do not consider the seismic effect twice.

APPLICATION

1/Study area

Blida is an agglomeration located South west of the capital Algiers (Algeria). The town has got considerable amount of population in constant increases and an important economic activity. The population will reach 272 088 inhabitants by 2025. Blida is an area prone to seismicity. It is classified zone 3 according the seismic code in use (RPA, 1999, version 2003). The historical seismicity of the region shows that strongest earthquakes happened and caused significant damages, Halfaya and al. Considering this seismicity and the requirements of water for the population which currently established around 30,000 m^3/day, it is of great importance to ensure its availability, especially following a strong earthquake. This availability can be carried out only if the water network remains functional.

2/Water supply network

The water network of Blida goes back to the French period and did not stop stretch since.
This network consists of various diameters of pipes going from the diameter 80 mm to the diameter 800 mm. The length of the various diameters according to material is given in figure1. The total length of this network is around 95km.

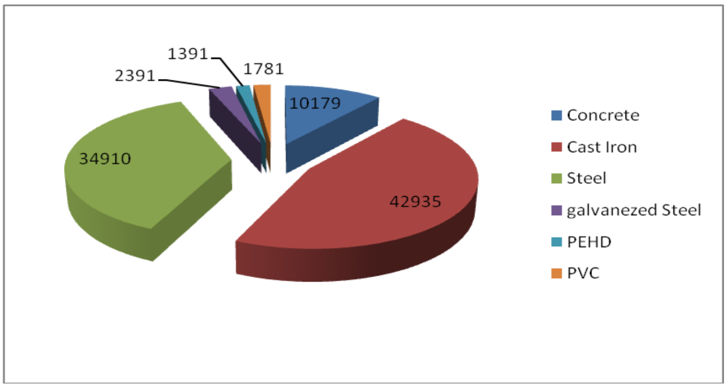

Figure 1. Total length of the network according to material

The total length of cast iron pipes is given in table 3.

Table 3: Lengths of cast iron pipes according to diameter.

Diameter (mm)	Cast iron (m)
50	230
60	191
70	323
80	385
100	4272
125	213
150	15462
200	14217
250	842
300	6489
500	311
Total (m)	**42935**

For the study area, three ground classifications are used, namely, "Hard Rock,", "Medium Soil," and "Soft Soil". Note that all the water network of the town is situated on soft soil, see figure 2. A study , (Bahi) shows that this region has a low potential of liquefaction.
The seismic risk assessment is condensed in the active fault called Bouinan/Soumâa (in bold line blue on figure 2). This fault played a great role in the historical seismicity of the town. The last studies show that it could generate a seism of magnitude 7,08.

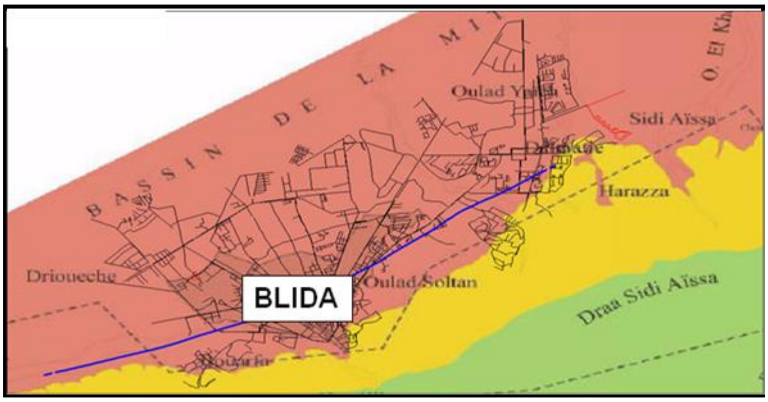

Figure 2. Ground conditions and Bouinan /Soumaa fault

VULNERABILITY INDEX FOR WATER DELIVERY SYSTEM IN BLIDA

A program was developed to give the classification of the different section pipe of Blida network. The result of the present study can be given on a GIS format (figure 3).

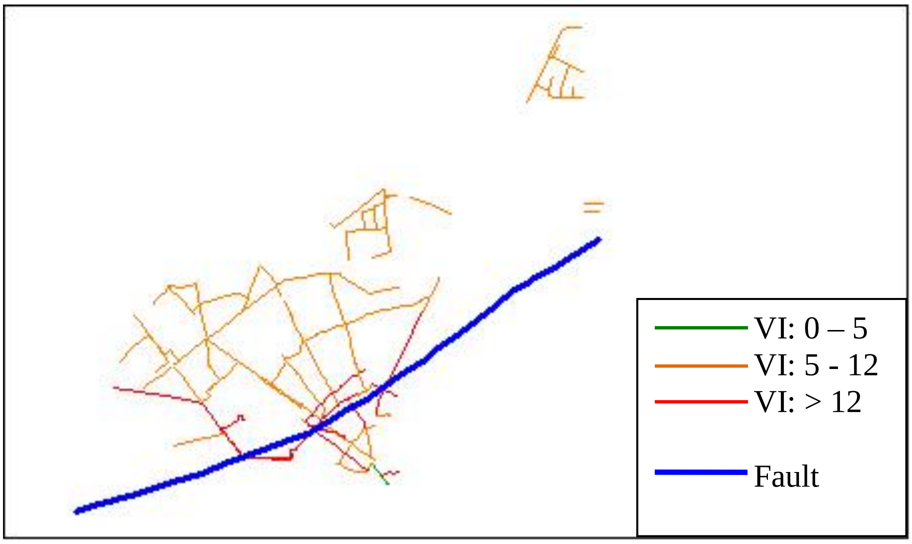

Figure 3. Cast Iron pipes classification

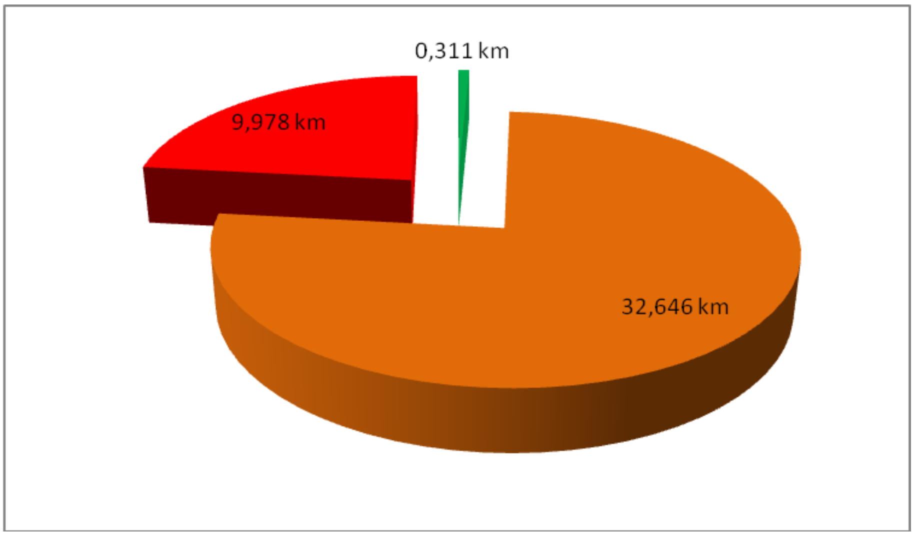

Figure 4. Pipe classification according length

As it can be seen around 10 kilometers of pipes need an urgent replacement and most of the network (around 33 km) is vulnerable and must be replaced as soon as possible. This vulnerability is due to the lack of maintenance and the age of the section pipes.

From equation 6, vulnerability curves for cast iron pipes can be derived. They are given in figure 5.

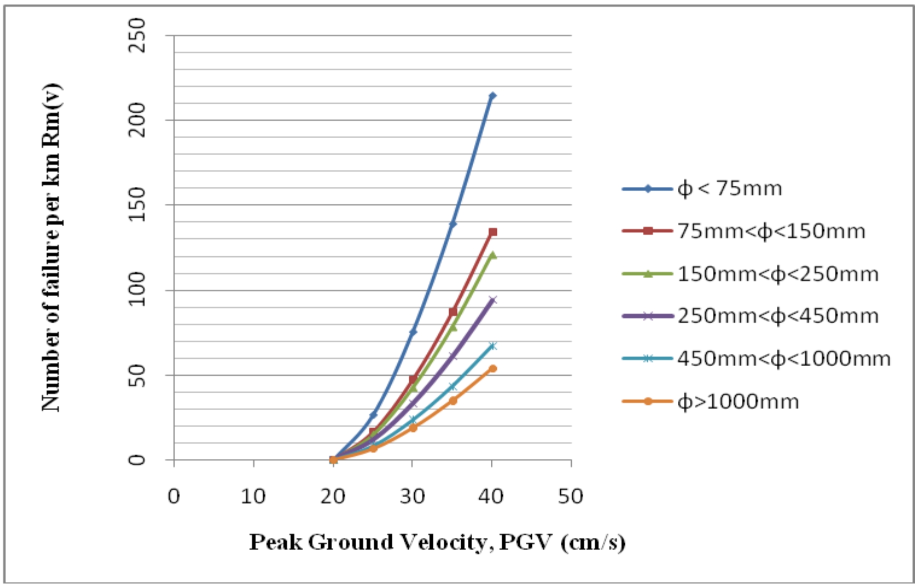

Figure 5. Cast iron vulnerability curves.

As it can be seen from this figure, small diameters are more vulnerable than great ones, so these ones must be replaced first.

CONCLUSIONS

Vulnerability assessment for the cast iron pipe under seismic motion was treated through the use of a vulnerability index method. This one allows the diagnosis of the different section pipe according a proposed classification. Based on this index, vulnerability curves were derived. These ones allow performing seismic scenarios in order to establish priority setting.

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