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Seismic Vulnerability Curves of Water

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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 buried pipelines using the vulnerability index method. In this method the main parameters that have an influence on the seismic behavior of 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 different pipe material are derived. These ones allow the determination of the number of failures by kilometer of pipe versus the peak ground velocity (PGV).

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INTRODUCTION

In a city, several thousand kilometer of water supply network spreads over expanded urban area. Because of the huge stock, the majority of pipelines 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 pipes.

Several methods of damage estimation do exist. Among them, the method developed by the Applied Technology Council. The ATC-25 report gives the damage risk (number of breaks per kilometer) under the form of damage probability matrices (DPM). The ATC-25-1 report provides a practical model methodology for the detailed assessment of seismic vulnerability and impact of disruption of water transmission and distribution systems (ATC, 1991). The FEMA (Federal Emergency Management Agency) and the NIBS (National Institute of Building Sciences) developed software called HAZUS. It is used to manage seismic vulnerability of buildings and lifelines (FEMA, 1999). 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 (Oyo Corporation, 1998). The RISK-UE method was developed for European context. It aims at the realization of seismic risk scenarios (RISK-UE, 2003). Numbers of other vulnerability curves were developed by several researchers for different pipes material (Chang, C.H., 2004; Chen, W., 2004, Shih, B.J. and C.H. Chang, 2006). DPM were also given in Kuwata (2004) and Maruyama (2010). Ueno *et al*. (2004) and Nojiima (Nojiima, N., 2008) 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 pipes is presented. The proposed method is based on statistical models for estimating pipes vulnerability. Based on this method vulnerability curves for different pipes material were derived.

Vulnerability index method:

Statistical method is widely used for estimation of damage to water supply networks subjected to seismic motion. Typical method for estimating number of pipe breaks and joint failure is given by:

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

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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:

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

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 different statistical estimation models, these ones have different sets of correction factors and standard damage rate function (Nojiima, N., 2008; Ueno, J., 2004). The total number of pipe breaks and joint failures estimated using Eqn. 1 contains three major contributors: amount of facility (length of pipeline L), vulnerability (pipe diameter and material/joint type C_d and C_p), and hazard (severity of ground motion x and ground condition C_g). Paying particular attention to the vulnerability term, 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 and Zemouri (2003) noted that some correction factors may be unreliable due to statistical insufficiency. A discussion is made in Halfaya (2012).

$$VI = C_c . C_d . C_p . C_f . C_s . C_g . C_i . C_l \quad (3)$$

Where C_d is the correction factor for pipe diameter according Table 1, C_p is the correction factor for pipe material according Table 2, C_f is the correction factor for fault crossings according Table 3, C_s is the correction factor for settlement and landslide according Table 4, C_g is the correction factor for ground type according Table 5, C_i is the correction factor for the seismic intensity according Table 6 and C_l is the correction factor for liquefaction according Table 7.

Table 1: Pipe diameter factors.

Diameters	Factor
φ < 75 mm	1,60
75 mm < φ <150 mm	1,00
150 mm < φ <250 mm	0,90
250 mm < φ <450 mm	0,70
450 mm < φ <1000 mm	0,50
φ > 1000 mm	0,40

Table 2 : Pipe material factors.

Materials	Factor
Ductile cast iron	0,30
Cast iron	1,00
PVC	1,00
Steel	0,30
Galvanized steel	1,75
Asbestos cement	2,50
PEHD	0,10

Table 3: Fault crossings factors.

Intersection(s)	Factor
No intersection	1,00
One intersection	2,00
Several intersections	2,40

Table 4: Settlement/Landslide factors.

Intersection(s)	Factor
No risk	1,00
Average risk	2,00
Important risk	2,40

Table 5: Ground type factors.

Type ground (Soil)	Factor
Deposit Soil : Alluvium: very soft	4,70
Deposit Soil : Diluvium: soft	2,90
Weathered Rock: Medium	2,00
Moderate Weathered Rock: Medium	1,00
Slightly / No Weathered Rock: Stiff / Hard	0,50

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Table 6: Seismic intensity factors.

Intensity	Factor
MI<8	1,00
8≤MMI<9	2,10
9≤MMI<10	2,40
10≤MMI<11	3,00
11≤MMI	3,50

Table 7: Liquefaction factors.

Liquefaction	Factor
0≤PL<5	1,00
5≤PL<15	2,00
15≤PL	2,40

In this method, the liquefaction is considered through the calculation of a potential of liquefaction (PL) developed in Iwasaki (1982). Based on previous study by Halfaya (2012) a classification for pipeline according the VI is proposed in Table 8.

Table 8: Pipe classifications.

Range VI	Evaluation	Colour
0 < VI < 5	Low vulnerability	Green
5 ≤ VI < 12	Medium vulnerability	Orange
12 ≤ VI	High vulnerability	Red

Vulnerability Curves:

Isoyama *et al*. (2000) proposed the following equation to assess the number of damages per kilometer in water pipeline [11].

$$R_m(v) = C_p \,.\, C_d \,.\, C_g \,.\, C_l \,.\; R(v) \qquad (4)$$

With v the PGV (peak ground velocity) and R(v) expressed by Isoyama *et al*. [8] after Kobe earthquake as:

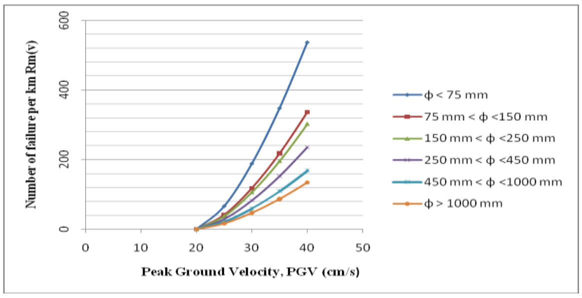
$$R(v) = 2.24\times10^{-3}(v-20)^{1.51} \qquad (5)$$

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

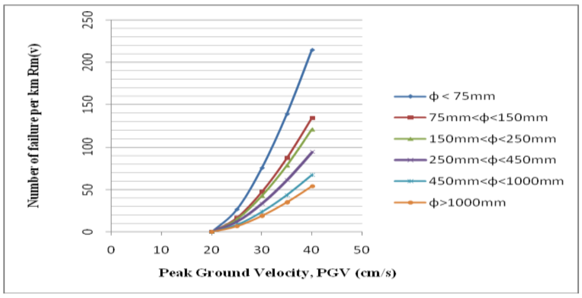
$$R_m(v) = VI' \,.\; R(v) \qquad (6)$$

With VI' = VI/ C_i in order to do not consider the seismic effect twice. The following curves are then obtained.

Figure 1 to 3 show that small diameter pipelines suffer more important damages than large diameter pipes. Pipelines with lower Cp coefficient have better seismic behavior than those with a high Cp coefficient. This is due to material ductility which allows important displacements without any breaks or failures. As it can be seen, the best material is PEHD and the worst is Abestos ciment.

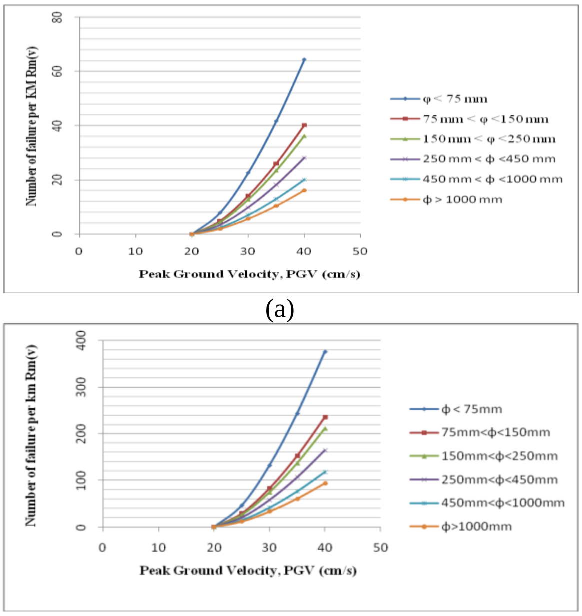


(a)



(b)

Fig. 1: Vulnerability curves: (a) Abestos cement and (b) Cast iron and PVC.



(a)

(b)

Fig. 2: Vulnerability curves: (a) Ductile cast iron and (b) Galvanized steel.

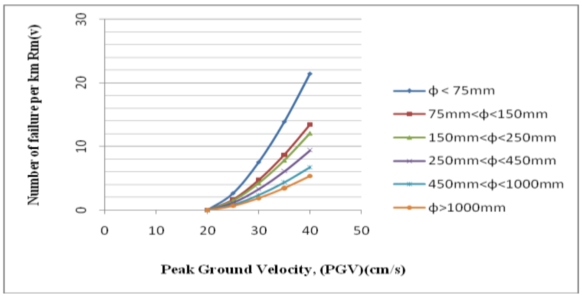


Fig. 3: Vulnerability curves for PEHD.

Conclusion:

Vulnerability assessment of buried pipelines under seismic motion was treated through the use of a vulnerability index. 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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