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Seismic Safety Assessment of Existing Buried Pipelines

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***Abstract*—Statistical analysis was conducted on the effect of different parameters of buried pipelines that play a significant role on their seismic damage. Based on the results thus obtained, a simple criteria was proposed for the preliminary evaluation of seismic safety (or vulnerability) of existing buried pipelines. The adequacy of the criteria was examined and the water supply network of Blida city was studied.**

***Keywords*—buried pipelines, seismic event, vulnerability index, safety assessment.**

I. Introduction

Several parameters have an influence on the seismic behavior of water supply network. These parameters have been extensively investigated in HAZUS [1], RISK-UE [2] RADIUS [3], ATC 25-1 [4] and by Eidinger and Avila [5]. Several other methods do exist. Among them Sato et al. [6] and Kuwata et al. [7] who studied the effect of a fault on buried pipelines. The soil effect was studied by Koike [8] and Choo et al [9], Nojiima [10, 11] and Ueno [12] developed a vulnerability index for water pipes. Zhao et al [13] give the critical factors for a water supply network. In the present study vulnerability index (VI) for convenient evaluation of seismic vulnerability of existing pipes is presented. The proposed method is based on a statistical methodology for estimating pipes vulnerability.

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II. Statistical Model

Statistical method is comonly used for damage assessment of buried pipelines subjected to seismic motion. Typical formula for estimating number of pipe breaks and joint failure is given in (1).

$$N = L * R_{fm}(x) \tag{1}$$

Where N is the number of pipe breaks and joint failure, L is the extended length of pipeline (km), x is the ground motion parameter such as PGA, PGV, or SI (spectral intensity), and $R_{fm}(x)$ is the damage rate (breaks/km). This one is given in (2).

$$R_{fm}(x) = R_f(x) * \prod_j C_j \tag{2}$$

Where $R_f(x)$ is the standard damage rate (breaks/km) and C_j are correction factors for parameters that influence the seismic damages in buried pipes.

From bibliography and past earthquakes, the main parameters that have an influence on the safety of pipes are: pipe diameter, pipe material, fault crossings, settlement/ landslide, ground type, liquefaction and ground shaking.

III. Statistical Analysis

Fifty seven pipes damaged by the 2003 Boumerdes earthquake and forty three pipes damaged by the 1999 Ain Temouchent earthquake were selected as samples. These pipes were damaged to different degrees, from collapse to different level of breaks. Twenty two pipes collapse (fifteen for Boumerdes and seven for Ain Temouchent), while the rest were damaged but did not collapse. Degree of damage was evaluated by referring to post-earthquake reconnaissance reports. A numerical value was assigned for each sample, this value varies from 1 to 5, 1 expresses there is no damage and 5 expresses the collapse.

Let the assigned degree of damage of sample i be denoted by A_i. Seven parameters were identified as playing a main role in pipe safety. After several preliminary analyses, categories were identified for each parameter. Identification of categories was inevitably affected by the characteristics of the sample set used for analysis. As shown in Table 1, there are a total of 32 categories for the seven parameters.

TABLE I. WEIGHTING FACTORS

Parameter	Category	Weighting Factor	Range
Material	Ductile Cast Iron	0,33	15
	Cast Iron	1,07	
	PVC	1,00	
	Steel	0,42	
	Galvanised Steel	1,99	
	Asbestos Cement	3,19	
	PEHD	0,21	
Diameter	φ < 75 mm	2,23	4
	75 mm < φ <150 mm	1,0	
	150 mm < φ <250 mm	1,67	
	250 mm < φ <450 mm	1,31	
	450 mm < φ <1000 mm	0,78	
	φ > 1000 mm	0,51	
Fault Crossing	No Intersection	1,0	2.5
	One Intersection	0,8	
	Several Intersections	0,4	
Settlement/Landslide	No risk	1,0	2.7
	Average risk	0,87	
	Important risk	0,36	
Ground Type	Deposit Soil : Alluvium: very soft	6,37	6.3
	Deposit Soil : Diluvium: soft	5,92	
	Weathered Rock: Medium	4,54	
	Moderate Weathered Rock: Medium	1,0	
	Slightly / No Weathered Rock: Stiff / Hard	1,12	
Liquefaction	0≤PL<5	1,0	3.4
	5≤PL<15	3,33	
	15≤PL	3,48	
Ground Shaking	MMI<8	1,0	3.7
	8≤MMI<9	2,08	
	9≤MMI<10	2,59	
	10≤MMI<11	3,11	
	11≤MMI	3,77	

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) about the soil movement. The ground conditions are considered with respect to the soil type. The liquefaction is considered through the calculation of a potential of liquefaction (In this work, the method of Iwasaki was used [14, 15]). Finally the seismic intensity is considered using the MMI scale.

Define a variable x_{ijk} corresponding to category k in parameter j of sample i. This variable takes the value of 1 (one) if the properties of sample i corresponds to category k for parameter j, and 0 (zero) otherwise. This means, though they are 32 such variables for each sample, only seven of them have values of 1 and the rest are 0. Denote the weighting factor of category k in parameter j by w_{jk} and consider:

$$\alpha_i = \prod_{j=1}^{7} \prod_{k=3}^{3 \text{ or } 5 \text{ or } 6 \text{ or } 7} w_{jk}^{x_{ijk}} \qquad (3)$$

It is assumed that, if appropriate values were determined, (3) gives an estimate of the degree of seismic damage to be sustained by the pipelines defined by a set of variables x_{ijk}. Values of w_{jk} are so determined that the calculated degrees of damage α_i of the one hundred samples best agree with their assigned degrees of damage A_i. Replacing α_i by A_i and taking logarithms of both sides of (3) yield a set of linear simultaneous equations with unknowns log w_{jk}. Therefore, the solution procedure becomes similar to the least square solution of linear simultaneous equations, except for the fact that the variables x_{ijk} are subjected to the following relation:

$$\sum_{k=1}^{m} x_{ijk} = 1 \qquad (4)$$

where m is the number of categories in parameter j, namely m=3 or 5 or 6 or 7 in the present analysis.

IV. Results of the Statistical Analysis

The values of weighting factors determined by the above mentioned method are shown in Table 1. Since the number of samples was not sufficient and the quality of the sample set seems to be rather biased, the results in Table 1 shows several tendencies which are contradictory to what an ordinary earthquake engineer would expect from experience. Though the weighting factor in a case of one intersection with a fault (0,8) is greater than in a multiple intersections (0,4). Such inconsistency is also seen for the categories in parameter Settlement/Landslide. Therefore, if criteria are to be derived from these results, it is necessary to modify them by taking into account of engineering judgment based on experience.

In the last column of Table 1 are shown the ranges of weighting factors for the seven parameters. The range of a parameter is defined as the ratio of the maximum weighting factor to the minimum in the parameter under consideration. The greater the value of the range of a parameter is, the more important effect that parameter has on the degree of seismic damage to buried pipelines. It is seen that material, ground type, diameter and seismic intensity are the more important factors for the seismic safety of buried pipes.

Figure 1 shows the correlation between the assigned and the calculated degrees of seismic damage. With a few exceptions, the estimated degree of damage is within +/- 25% of the assigned value.

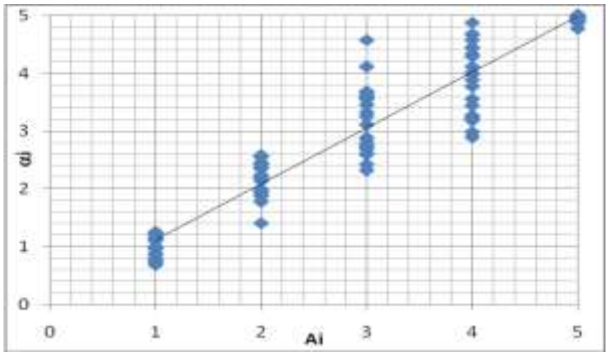

Figure 1. Correlation between estimated and assigned damages value.

V. Proposed Criteria

In order to define criteria for the evaluation of the seismic safety of existing buried pipelines, account should be taken of the followings:

TABLE II. PROPOSED WEIGHTING FACTORS

Parameter	Category	Weighting Factor	Range
Material	Ductile Cast Iron	0,3	25
	Cast Iron	1,1	
	PVC	1,0	
	Steel	0,3	
	Galvanised Steel	1,8	
	Asbestos Cement	2,5	
	PEHD	0,1	
Diameter	φ < 75 mm	1,6	4
	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	2,4
	One Intersection	2,0	
	Several Intersections	2,4	
Settlement/Landslide	No risk	1,0	2,4
	Average risk	2,0	
	Important risk	2,4	
Ground Type	Deposit Soil : Alluvium: very soft	4,7	9,4
	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≤PL<5	1,0	2,4
	5≤PL<15	2,0	
	15≤PL	2,4	
Ground Shaking	MMI<8	1,0	3,5
	8≤MMI<9	2,1	
	9≤MMI<10	2,4	
	10≤MMI<11	3,0	
	11≤MMI	3,5	

TABLE III. PIPE CLASSIFICATION

IV Value	Evaluation
0 < VI < 5	Low vulnerability
5 ≤ VI < 12	Medium vulnerability
12 ≤ VI	High vulnerability

- Insufficient and rather biased data
- Values should be assigned for the weighting factors of Fault crossing parameter
- Values should be assigned for the weighting factors of Settlement/Landslide parameter
- Relative importance of parameters should be keep
- Consider weighting factors provided by anterior studies

By taking account of the above mentioned considerations and by practicing engineering judgment based on experience, criteria are tentatively proposed in Table 2. Note that, the weighting factors of Material and Diameter were taken from Nojiima studies.

The degree of seismic safety (or vulnerability) is expressed by the product of the seven weighting factors, each of which is taken from one of the seven parameters in Table 2. This is given in (5).

$$VI = \prod_{j=1}^{7} C_j \quad (5)$$

The larger the product is, the more vulnerable the pipe is to seismic effects.

Based on this statistical study, a classification for pipeline according the (Vulnerability Index) VI is proposed in Table 3.

VI. Application

A. *Study Area*

Blida is an area prone to seismicity. It is classified zone 3 according the seismic code in use (RPA, 1999, version 2003).. The most important earthquake recorded by an instrumental way is the one of 07th November 1959, with a magnitude of 5,6. The historical seismicity of the region shows that strongest earthquakes happened and caused significant damages [16]. In particular, in the 19th century, the area of Blida was shaken by two destroying earthquakes. The first one occurred on the 02nd March, 1825 of intensity X and destroyed a half of the town of Blida and two neighbouring villages. About 7000 people were found death. The second one took place on the 02nd January, 1867 of intensity XI and destroyed the village of Mouzaïa, and significant damage were noted in Blida and El Affroun [16]. 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.

B. *Water Supply Network*

The water network of Blida goes back to the French period and did not stop stretch since. So, different types of materials can be found. This network consists of various diameters of pipes going from the diameter 50 mm to the diameter 800 mm. The proportion of the various diameters and materials is given in figures 2 and 3. The total length of this network is around 95km.

For the study area, three ground classifications are used, namely, "Hard Rock,", "Medium Soil," and "Soft Soil.":

- Soft Soil, corresponds to tertiary sand and/or mud stones and conglomerates;
- Medium Soil, corresponds to diluvial soil and stiff alluvial soil.
- Hard Rock, corresponds to volcanic rocks, such as granite or basalt, and sedimentary rocks, such as pre-tertiary sand and mud stones.

The seismic risk assessment is condensed in the active fault called Bouinan/Soumâa (in bold line blue on figure 4). This fault played a great role in the historical seismicity of the town. Last studies show that it could generate an earthquake of magnitude 7,8.

These different aspects are represented on a GIS format (Geographical Information System) on Figure 4.

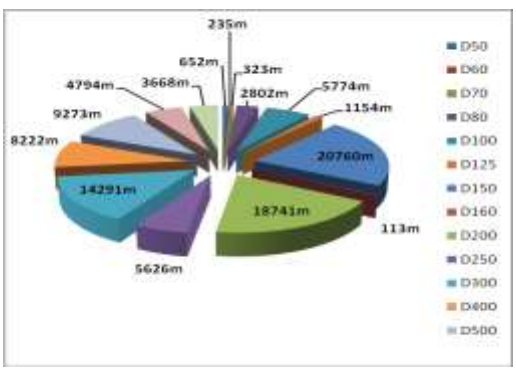

Figure 2. Proportion of the various diameters

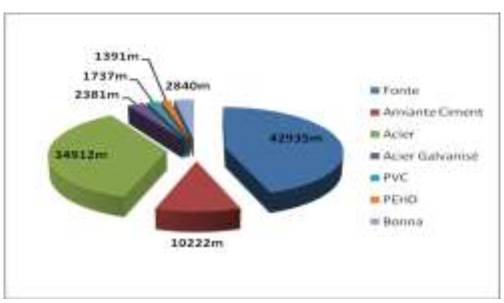

Figure 3. Proportion of the different materials

Figure 4. Water network and ground conditions

C. *Results*

A Geographical Information System (GIS) may be a convenient way to illustrate the results of the VI estimation and classification of the network. Figure 5 shows the classification of the pipes belonging to the water network of Blida.The results (figure 6) show that 24% of the total length of the network are vulnerable to seismic action so they must be replaced first. Then the orange one must be replaced, beginning by the small diameters (more vulnerable that the great ones). This category represents 38% of the network.

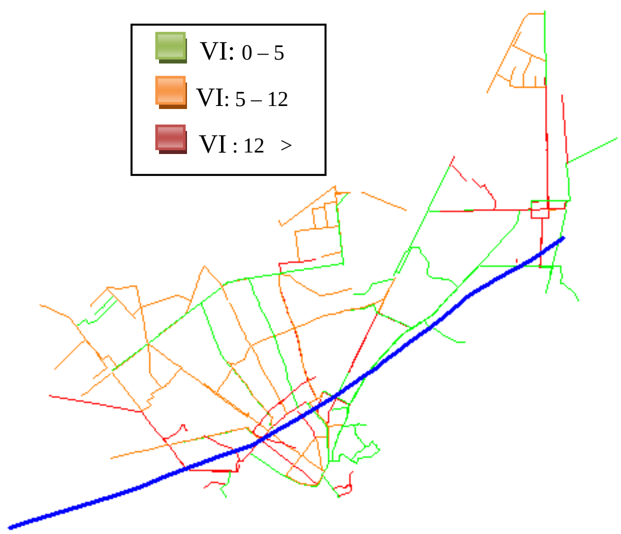

Figure 5. Pipe classifcation on GIS (Scale 1/380)

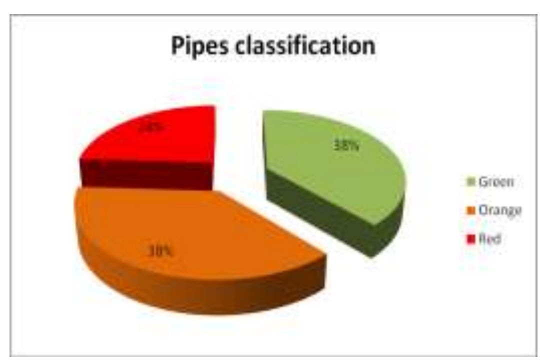

Figure 6. Pipe classifcation

VII. Conclusion

Although the framework of this study is common to various models of statistical estimation method, the vulnerability index developed method is an easy way to show the most vulnerable pipe of a supply water network. Despite the fact that the ranges of the classification need to be improved, the proposed classification give satisfactory results according what was observed in situ..

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