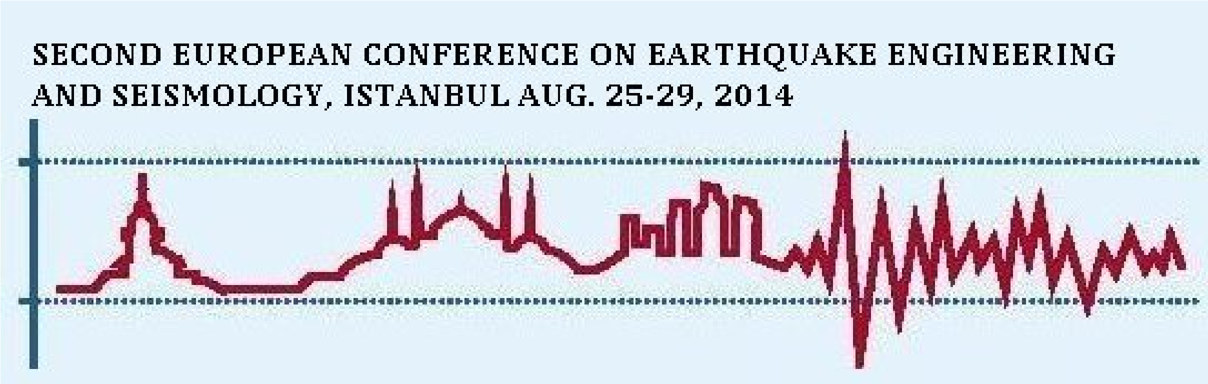


# A LIFELINE VULNERABILITY STUDY OF CONSTANTINE, ALGERIA

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## ABSTRACT

The North of Algeria is characterized by a high to moderate seismicity, therefore a seismic risk in this region is the most important threat that can cause dysfunction of lifelines (roads, telecommunications, electricity, etc.).The good functioning of these equipments, in crisis situations, is an indicator of development, which is necessary in operations management during and after the seismic event. In this work, we are interested of pipeline vulnerability to the water supply system, sanitary sewer pipelines (waste water), and telephone in Constantine city, located in North-east of Algeria, using by two different approach. The first method is that developed by Kubo-Katayama which is based on an empirical approach to estimate the damage by used of several parameters such as: materials, diameters, and soil type, While the second approach «Model proposed by Wang et al" is very simple, It can be used when there is no detailed pipeline information available and a very rough assessment of the loss is needed.

Keywords: Lifeline; Earthquake; vulnerability; Pipelines

## INTRODUCTION

Seismic vulnerability is a measurement of a structure's seismic endurance, the vulnerability–damage ratio allowing estimating the damage suffered by the structure as a result of a ground motion.

When seismic risk and potential damage are known, it is possible to calculate the seismic hazard. The seismic risk is defined as the convolution of the damage level and the losses in structural systems. There are three ways to mitigate the seismic hazard: decreasing seismic risk, decreasing vulnerability or decreasing the level of losses.

In order to estimate the vulnerability of lifelines, it is necessary to measure the size and distribution of structures. Additionally, these kinds of studies enable to determine the steps to follow in order to reduce seismic hazards.

Despite the advancement in Seismic Engineering, technology, and new materials, in recent earthquakes (Loma Prieta, 1989; Northridge, 1994; and Kobe, 1995), the interruption in roads, communications and other lifelines was the main cause of injuries, traffic problems, and breaks in

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energy systems. The Northridge earthquake has been the most important one in terms of economic losses, mainly due to the interruption in the communication and transportation systems.

In this work, the main objective is to determine the seismic hazard for lifelines in Constantine city, which is located in the Northern-East part of Algeria.

For this purpose, we used two distinct methodologies. The first method is that developed by Kubo-Katayama which is based on an empirical approach to estimate the damage by used of several parameters, While the second approach «Model proposed by Wang et al" is very simple, It can be used when there is no detailed pipeline information.

## ESTIMATION OF LIFELINES SEISMIC VULNERABILITY

The estimation of lifeline seismic vulnerability is obtained by calculating direct damage and economic losses, using the following procedures: (1) calculation of seismic risk by estimation of seismic movements, (2) inventory of damage data for each system, and (3) determination of vulnerability curves as a function of seismic intensity.

## ANALYTICAL APPROACH TO ESTIMATE DAMAGE

The survival of lifelines depends on their behavior during the ground motion; generally, this behavior is characterized by means of empirical data. The studies of lifeline systems response during earthquakes, as well as the calculation of their behavior, are based on their structural characteristics. Therefore, the studies of lifelines vulnerability are based on experimental data rather than on theoretical studies.

Several works (ATC-13, 1985) and (ATC-25, 1991) describe the determination of the direct damage produced by an earthquake according to the following steps:

(1) For all seismic scenarios it is necessary to calculate the intensity for each mesh cell within the region.
(2) Designation of the magnitude and determination of special zones (as faults or distinct kind of soils) for each model.
(3) Calculation of damages for each cell in the system and development of the damage curve.
(4) Determination of direct damage due to the earthquake and collateral causes.

## METHOD PROPOSED BY WANG ET AL

Wang proposed the following simplified method to estimate the seismic loss of buried pipeline system. (Wang et al., 1991)

$$
\begin{aligned}
&\text{Log } Y = 1.837(I) - 14.065 && \text{Poor soil condition} \\
&\text{Log } Y = 1.717(I) - 14.221 && \text{Average soil condition} \\
&\text{Log } Y = 1.522(I) - 14.045 && \text{Good soil condition}
\end{aligned} \quad (1)
$$

*Y:* is the number of breaks/km of lifeline.
*I:* is the MKS intensity of the ground motion at the section being evaluated.

This method is very simple, it can be used when there is no detailed lifeline information available and a very rough assessment of the loss is needed.

## METHOD PROPOSED BY KUBO-KATAYAMA

Kubo-Katayama proposed in 1975, the following empirical method to estimate the seismic loss of buried pipeline system in reference to the conditions of damage to pipelines by the earthquake in San Fernando (USA, 1971). (Katayama et al., 1975)

$$R_{fm} = R_f * C_g * C_p * C_d \qquad (2)$$

$R_{fm}$ : Report damage (is the number of breaks/km of lifeline)

$R_f$ : Report standard damage (breaks/km).

$R_f = 1{,}7 * A^{6.1} * 10^{-16}$ ---------- (maximum $R_f = 2{,}0$)

A: Pic ground acceleration (gal)

$C_g$ : Modification coefficient

$C_p$: Modification coefficient of pipe material

$C_d$: Modification coefficient of pipe diameter

Table 1. Modification Coefficient «$C_g$»

| Soil Type | $P_L$ | $C_g$ |
|---|---|---|
| Hard Soil | - | 0,50 |
| Firm Soil | $P_L=0$ | 1,00 |
| Soft Soil | $0<P_L\leq5$ | 2,00 |
| | $5<P_L\leq15$ | 2,90 |
| | $15<P_L$ | 4,70 |

Table 2. Coefficient (Cp * Cd)

| Diameter Pipe / Material Pipe | Ø ≤ 75 mm | 75mm < Ø ≤150mm | 150mm< Ø ≤250mm | 250mm< Ø ≤450mm | 450mm< Ø ≤1 000mm | 1 000mm< Ø |
|---|---|---|---|---|---|---|
| asbestos cement | 6,40 | 3,40 | 2,40 | 2,00 | 1,40 | 0,60 |
| galvanized steel | 2,70 | 1,70 | 1,10 | 1,00 | 0,90 | 0,40 |
| concrete | 2,00 | 1,50 | 0,90 | 0,50 | 0,40 | 0,20 |
| precast concrete | 0,13 | 0,10 | 0,07 | 0,05 | 0,03 | 0,02 |
| Cast steel | 1,70 | 1,30 | 1,00 | 0,60 | 0,40 | 0,20 |
| Cast ductile steel | 0,70 | 0,40 | 0,20 | 0,10 | 0,08 | 0,05 |
| Cast steel gray | 4,60 | 2,60 | 1,80 | 1,50 | 1,20 | 0,50 |
| polyethylene | 0,20 | 0,15 | 0,10 | 0,07 | 0,04 | 0,02 |
| PVC pipe | 2,10 | 1,40 | 1,00 | 0,80 | 0,60 | 0,30 |

## THE MKS INTENSITY SCALE

The MSK scale used to assess the intensity of an earthquake by observing the damage to buildings and the testimony of people. The MKS intensity *(I)* of the ground motion in Constantine City is evaluated at *I*=9.27.

## NUMERICAL RESULTS

## METHOD PROPOSED BY WANG

The following results were obtained applying Wang's model (Wang et al., 1991) to Constantine lifelines for correspond soil type.

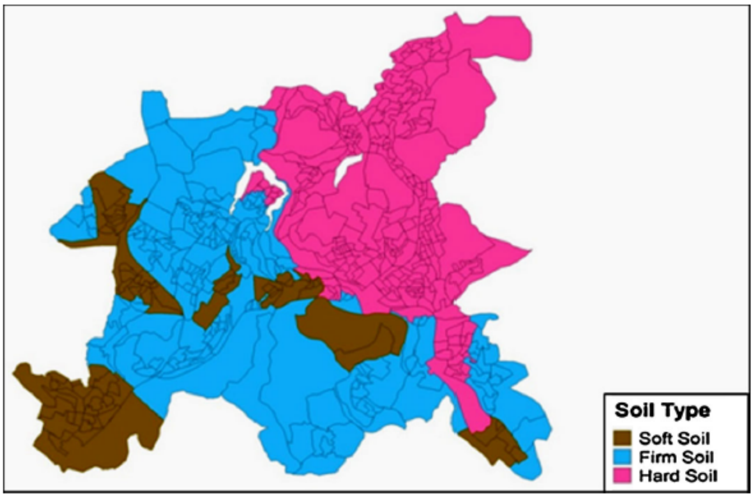


Figure 1. Soil Classification in Constantine urban area (Boukri et al., 2014)

Table 1. Results for water pipelines

| Intensity | breaks/km | Length (km) | Wang et al (Total) |
|---|---|---|---|
| 1 | 0.00 | 631 | 0.00 |
| 2 | 0.00 | | 0.00 |
| 3 | 0.00 | | 0.00 |
| 4 | 0.00 | | 0.00 |
| 5 | 0.00 | | 0.00 |
| 6 | 0.00 | | 0.00 |
| 7 | 0.11 | | 69 |
| 8 | 0.62 | | 391 |
| 9.27 | 5.45 | | 3440 |
| 10 | 19.08 | | 12044 |
| 11 | 106.27 | | 67083 |
| 12 | 591.70 | | 373510 |

Table 2. Results for sewage pipelines

| Intensity | breaks/km | Length (km) | Wang et al (Total) |
|---|---|---|---|
| 1 | 0.00 | 34 | 0.00 |
| 2 | 0.00 | | 0.00 |
| 3 | 0.00 | | 0.00 |
| 4 | 0.00 | | 0.00 |
| 5 | 0.00 | | 0.00 |
| 6 | 0.00 | | 0.00 |
| 7 | 0.11 | | 3.75 |
| 8 | 0.62 | | 21.14 |
| 9.27 | 5.45 | | 185.89 |
| 10 | 19.08 | | 650.81 |
| 11 | 106.27 | | 3624.86 |
| 12 | 591.70 | | 20182 |

Table 3. Results for telephone pipelines

| Intensity | breaks/km | Length (km) | Wang et al (Total break) |
|---|---|---|---|
| 1 | 0.00 | 110 | 0 |
| 2 | 0.00 | | 0 |
| 3 | 0.00 | | 0 |
| 4 | 0.00 | | 0 |
| 5 | 0.00 | | 0 |
| 6 | 0.00 | | 0 |
| 7 | 0.11 | | 12 |
| 8 | 0.62 | | 68 |
| 9.27 | 5.45 | | 601 |
| 10 | 19.08 | | 2102 |
| 11 | 106.27 | | 11710 |
| 12 | 591.70 | | 65200 |

## METHOD PROPOSED BY KUBO-KATAYAMA

The following tables show the result of the damages in the lifelines (water, sewage, and telephone) depending on the material and the diameter of each pipe. (Katayama et al., 1975)

## RESULTS

Table 4. Results for water pipelines (Cast ductile steel) ,CGS(2012)

| Cast ductile steel | | | | | |
|---|---|---|---|---|---|
| Diameter (mm) | 40 | 60 | 80 | 100 | 125 |
| Length ( km) | / | 0,06 | 15,32 | 96,73 | 2,12 |
| Total break | / | 0,084 | 12,26 | 77,39 | 1,70 |
| Break/Km | / | 1,4 | 0,8 | 0,8 | 0,8 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | 175 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 600 | 700 | 800 | 1000 |
| 68,355 | 2,2 | 32,15 | 18,25 | 26,38 | 9,62 | 12,21 | 0,986 | 1,601 | 0,93 | 3,835 | 4,587 | 0,25 |
| 54,68 | 0,88 | 12,86 | 7,30 | 5,27 | 1,92 | 2,44 | 0,19 | 0,25 | 0,14 | 0,61 | 0,73 | 0,04 |
| 0,8 | 0,4 | 0,4 | 0,4 | 0,2 | 0,2 | 0,2 | 0,2 | 0,16 | 0,16 | 0,16 | 0,16 | 0,16 |

Table 5. Results for water pipelines (Cast steel gray) ,CGS(2012)

| Cast steel gray | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diameter (mm) | 40 | 60 | 80 | 100 | 125 | 150 | 175 | 200 | 250 | 300 | 350 | 400 | 800 |
| Length ( km) | 0,45 | 1,55 | 13,63 | 12,83 | 1,64 | 6 | 1,71 | 6,3 | 5,273 | 1,8 | 0,92 | 0,73 | 0,33 |
| Total break | 4,14 | 14,26 | 70,92 | 66,71 | 8,52 | 31,2 | 6,15 | 22,68 | 18,98 | 5,4 | 2,76 | 2,21 | 0,79 |
| Break/Km | 9,2 | 9,2 | 5,2 | 5,2 | 5,2 | 5,2 | 3,6 | 3,6 | 3,6 | 3 | 3 | 3 | 2,4 |

Table 6. Results for water pipelines (Cast steel) ,CGS(2012)

| Cast steel | | | | |
|---|---|---|---|---|
| Diameter (mm) | 80 | 100 | 150 | 200 |
| Length ( km) | 0,15 | 8,08 | 1,60 | 0,19 |
| Total break | 0,39 | 21,00 | 4,17 | 0,39 |
| Break/Km | 2,6 | 2,6 | 2,6 | 2 |

Table 7. Results for water pipelines (Galvanized steel) ,CGS(2012)

| Galvanized steel | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Diameter (mm) | 26 | 33 | 40 | 50 | 60 | 75 | 80 | 90 | 100 |
| Length ( km) | 20,38 | 28,103 | 63,628 | 28,804 | 1,629 | 2,89 | 1,43 | 3,52 | 0,21 |
| Total break | 110,05 | 151,75 | 343,59 | 155,54 | 8,79 | 15,62 | 4,86 | 11,97 | 0,74 |
| Break/Km | 5,4 | 5,4 | 5,4 | 5,4 | 5,4 | 5,4 | 3,4 | 3,4 | 3,4 |

Table 7. Results for water pipelines (Polyethylene) ,CGS(2012)

| Polyethylene | | | | | |
|---|---|---|---|---|---|
| Diameter (mm) | 25 | 32 | 40 | 50 | 63 |
| Length ( km) | 1,32 | 3,56 | 4,95 | 10,31 | 6,42 |
| Total break | 0,52 | 1,42 | 1,98 | 4,12 | 2,56 |
| Break/Km | 0,4 | 0,4 | 0,4 | 0,4 | 0,4 |

| | | | | | |
|---|---|---|---|---|---|
| 75 | 90 | 110 | 125 | 160 | 200 |
| 2,90 | 7,33 | 4,52 | 0,80 | 1,05 | 1,01 |
| 1,16 | 2,19 | 1,35 | 0,24 | 0,21 | 0,20 |
| 0,4 | 0,3 | 0,3 | 0,3 | 0,2 | 0,2 |

Table 8. Results for water pipelines (PVC) ,CGS(2012)

| PVC | | | | | |
|---|---|---|---|---|---|
| Diameter (mm) | 40 | 50 | 63 | 75 | 90 |
| Length ( km) | 1,70 | 2,66 | 4,12 | 0,22 | 12,78 |
| Total break | 7,15 | 11,17 | 17,33 | 0,94 | 35,78 |
| Break/Km | 4,2 | 4,2 | 4,2 | 4,2 | 2,8 |

| | | | | |
|---|---|---|---|---|
| 110 | 125 | 160 | 200 | 250 |
| 17,23 | 0,52 | 7,06 | 6,27 | 0,41 |
| 48,24 | 1,45 | 14,13 | 12,54 | 0,82 |
| 2,8 | 2,8 | 2 | 2 | 2 |

Table 9. Results for water pipelines (Asbestos cement) ,CGS(2012)

| Asbestos cement | | | | | | |
|---|---|---|---|---|---|---|
| Diameter (mm) | 80 | 100 | 125 | 150 | 200 | 250 |
| Length ( km) | 3,06 | 4,61 | 0,3 | 10,41 | 1,19 | 4,17 |
| Total break | 20,83 | 31,40 | 2,04 | 70,80 | 5,75 | 20,05 |
| Break/Km | 6,8 | 6,8 | 6,8 | 6,8 | 4,8 | 4,8 |

Table 10. Results for water pipelines (Precast concrete) ,CGS(2012)

| Precast concrete | | |
|---|---|---|
| Diameter (mm) | 40 | 50 |
| Length ( km) | 0,5 | 0,33 |
| Total break | 0,13 | 0,08 |
| Break/Km | 0,26 | 0,26 |

Table 11. Results for sewage pipelines (Cement) ,CGS(2012)

| Cement | Collector A | Collector B | Collector C | Collector D – North- | Collector D | Collector E –East- | Collector E – South- | Collector F | Collector G |
|---|---|---|---|---|---|---|---|---|---|
| Diameter (mm) | 300 | 1000 | 800 | 1000 | 1600 | 600-1000 | 1200-1600 | 400-1000-1600 | 2000 |
| Length ( km) | 1.67 | 4.17 | 1.50 | 2.66 | 1.85 | 8.00 | 5.7 | 4.96 | 3.6 |
| Total break | 1.67 | 3.33 | 1.20 | 2.12 | 0.74 | 6.40 | 2.28 | 3.96 | 1.44 |
| Break/Km | 1 | 0.8 | 0.8 | 0.8 | 0.4 | 0.8 | 0.4 | 0.8 | 0.4 |

Table 12. Results for telephone pipelines, CGS(2012)

| Telephone | Area 1 | Area 2 | Area 3 |
|---|---|---|---|
| Length ( km) | 36.69 | 31.68 | 41.82 |
| Total breaks length (m) | 11.00 | 9.50 | 12.54 |

## SUMARY OF RESULTS

Table 13. Results for water pipelines

| Intensity | Average breaks/km | Length (km) | Kubo-Katayama (Total break) |
|---|---|---|---|
| 9.27 | 2.68 | 631 | 1691 |

Table 14. Results for sewage pipelines

| Intensity | Average breaks/km | Length (km) | Kubo-Katayama (Total break) |
|---|---|---|---|
| 9.27 | 0.68 | 34 | 23 |

Table 15. Results for telephone pipelines

| Intensity | Average breaks/km | Length (km) | Kubo-Katayama (Total break) |
|---|---|---|---|
| 9.27 | 0.3 | 110 | 33 |

## COMPARISON OF RESULTS

The comparison of the results obtained, in this work, is summarized in Table.16. It can be noticed, that the lifelines damage results given by using Wang et al method are in overestimation, compared to those obtained by the method of Kubo-Katayama.

Table 16. Results for pipelines

| Pipelines | Intensity | Length (km) | Kubo-Katayama (Total break) | Wang et al (Total break) |
|---|---|---|---|---|
| Water | 9.27 | 631 | 1691 | 3440 |
| Sewage | | 34 | 23 | 185 |
| Telephone | | 110 | 33 | 601 |

## CONCLUSION

The vulnerability of lifelines is a problem for which research has been conducted to try to quantify and predict the disorders that may occur in case of earthquake. The reliability of the estimate of damage to lifelines depends on the method to be used.

In this work, we made a comparison between two methods. The first method is that developed by Kubo-Katayama which is based on an empirical approach to estimate the damage by used of several parameters such as: materials, diameters, and soil type, While the second approach «Model proposed by Wang et al" is very simple, It can be used when there is no detailed pipeline information available and a very rough assessment of the loss is needed.

The results obtained show that their accuracy depends essentially of the various characteristics surrounding and intrinsic of these networks (soil, diameter and material used). Thus, the results obtained by the method of Kubo-Katayama, which uses the characteristics of networks, gives more accurate results, which reflects the reality compared to the Wang et al. method.

Although, the use of the method of Wang is indispensable, in case of emergency and the absence of precise information networks for rapid decision support.

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