Annex 3
Method for Estimating Damage in Pipes as a Consequence of Intense Earthquakes

Introduction

Following is a methodology for estimating the expected number of breaks in pipelines affected by seismic activity. It is based on a study made of the earthquake in Limon, Costa Rica, 1991.[23]

Evaluation of Seismic Hazard

Step 1. Assign a hazard factor by soil profile type (FSPT) as shown in Table A3.1

Table A3.1

Soil profile	Description	FSPT
Rocky	Rocky strata or very consolidated soils with propagating waves in excess of 750 m/s.	1.0
Hard	Well-consolidated or soft soils with depths of less than 5 meters.	1.5
Soft	Soft soil strata with depths in excess of 10 meters.	2.0

Step 2. Assign a hazard factor for potential soil liquefaction (FPSL) as shown in Table A3.2.

Table A3.2

Hazard	Description	FPSL
Low	Well-consolidated soils and with high drainage capacity, adjacent strata without appreciable sand content.	1.0
Moderate	Soils with moderate drainage capacity, adjacent strata with moderate sand content.	1.5
High	Poorly drained soils, high water table, adjacent strata with high sand content; river deltas and alluvial deposits.	2.0

[23] PAHO/WHO, Estudio de caso: *Terremoto del 22 de abril de 1991*, Limón, Costa Rica; 1996.

Step 3. Assign hazard factor for permanent displacement of the soil (FPDS) as shown in Table A3.3

Table A3.3

Hazard	Description	FPDS
Low	Well-consolidated soils, low slopes, well-compacted fill. Not located near river beds or geologic faults.	1.0
Moderate	Consolidated soils, slopes less than 25%; compacted fill; close to river beds or geologic faults	1.5
High	Poorly consolidated soil, slopes greater than 25%, located in or near river beds or geologic faults	2.0

According to this process, the seismic hazard factor of the area is characterized by the product:

FSPT x FPSL x FPDS

Values of less than 2 are considered of low seismic hazard; between 2 and 4 moderate seismic hazard; equal to or greater than 4, high seismic hazard.

Estimating Vulnerability

The vulnerability of different pipe systems to seismic activity is expressed by the number of expected failures per kilometer. As an example, the number of breaks caused by an earthquake in cast iron pipes for different degrees of Mercalli intensity are given in Table A3.4. Values are assigned to damage from: i) propagation of seismic waves only and ii) propagation of waves and permanent deformation in the soil. These are called basic damage indices and depend on the seismic hazard factor (SHF) calculated in the previous section.

Table A3.4

Mercalli intensity	Basic damage indexes (faults per km)	
	SHF(*) <2	SHF(*) $\geq$ 2
VI	0.0015	0.01
VII	0.015	0.09
VIII	0.15	0.55
IX	0.35	4.00
X	0.75	30.0

(*) Seismic Hazard Factor

For the calculation of the seismic vulnerability take the following steps.

Step 4: Select the basic damage index as shown in Table A3.4.

Step 5: If the pipe is not of cast iron, it is advisable to use the correction factor given in Table A3.5

Table A3.5

Material	Correction factors
Steel	0.25
Cast iron	1.00
PVC	1.50
Asbestos cement	2.60
Reinforced concrete	2.60

These factors can be affected by the general condition of the pipe and/or years of use, and should be judged by the professional responsible for making the evaluation. For pipes that are old or in poor condition values in Table A3.4 can increase by as much as 50%; if its status is considered average this percentage should not exceed 25%; for pipes in good condition is it not necessary to modify the values in Table A3.4.

Step 6: Available data indicate that pipes with smaller diameters tend to be more vulnerable. An increase in the correction factor of up to 50% can be applied for pipes measuring 75 mm or less in diameter; the correction factor for pipes between 75 mm and 200 mm can increase up to 25%. For pipes with diameters of more than 200 mm the given values should not be increased.

Calculation of Expected Breaks

To illustrate the calculation of number of breaks in pipes per kilometer, the following example is useful. The pipeline is located in an area where earthquakes measuring IX in Mercalli intensity are expected. The pipeline is reinforced concrete, which is relatively new and in good condition; it is 500 mm in diameter and 15.5 km in length. Three sections are subject to the following three levels of seismic hazards (as presented in Table A3.4):

Section 1: 1.8 km long in areas of low seismic hazard (SHF<2);

Section 2: 12.7 km long in areas of moderate seismic hazard (SHF>2);

Section 3: 1.0 km long in areas of high seismic hazard (SHF>2).

The total expected breaks equal:

$$1.8 \times 0.35 \times 2.6 + 12.7 \times 4.0 \times 2.6 + 1.0 \times 4.0 \times 2.60 = 144 \text{ breaks/km.}$$

If the piping were of flexible steel, the number of faults calculated per kilometer would be ten times less, i.e., 144 x (0.25/2.60) = 14.