Iran, Esfahan
SIMULATION OF SOCIO-ECONOMIC IMPACTS DUE TO SEISMIC DAMAGE OF TEHRAN WATER NETWORK

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INTRODUCTION

Water distribution network, water pipeline, tanks and other accessories may be damaged by a severe earthquake.

Restoration of a water system as well as supplying in a short time after an earthquake is very urgent.

The purpose of this study is to estimate physical damage, to determine place and period of water cut-off and to simulate socio-economic impacts due to damage in water pipe network.
There are 35000 killed and more than 380000 injured in average every year due to earthquakes.

The economic losses exceed several billions dollars per year.

The 1995 Kobe Earthquake caused more than 105 billions US dollars, which was 8 percents of Gross National Product (GNP) of Japan.
# Economic losses in some recent earthquakes

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Date</th>
<th>Magnitude</th>
<th>Loss (million US $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loma Prieta (USA)</td>
<td>89.10.18</td>
<td>7.1</td>
<td>5,600</td>
</tr>
<tr>
<td>Northridge (USA)</td>
<td>94.01.17</td>
<td>6.8</td>
<td>15,000</td>
</tr>
<tr>
<td>Kobe (Japan)</td>
<td>95.01.17</td>
<td>7.2</td>
<td>100,000</td>
</tr>
<tr>
<td>Izmit (Turkey)</td>
<td>99.08.17</td>
<td>7.8</td>
<td>20,000</td>
</tr>
<tr>
<td>Chi Chi (Taiwan)</td>
<td>99.09.20</td>
<td>7.6</td>
<td>12,000</td>
</tr>
<tr>
<td>Gujarat (India)</td>
<td>01.01.26</td>
<td>7.9</td>
<td>4,500</td>
</tr>
<tr>
<td>Bam (Iran)</td>
<td>03.12.26</td>
<td>6.5</td>
<td>2,000</td>
</tr>
</tbody>
</table>
The economic loss estimation may be categorized in two types:

Direct loss
Indirect loss

Direct economic losses occur just during the earthquakes or immediately after them.

Indirect losses are resulted from direct losses.
DIRECT ECONOMIC LOSSES

- Capital Loss: It includes partial or complete damage to residential and official buildings, factories, hospitals and so on.
- Deposit loss: loss to the stored materials in the store, which are deposited for different utilities
- Loss due to search and rescue operation (S&R)
- Repair and restoration
Direct economic loss distribution in earthquakes

- Capital: 75%
- Deposit: 5%
- S&R: 20%
INDIRECT ECONOMIC LOSSES

- A reduction in employment income
- A reduction on manufacturing products resulted from demand reduction
- A reduction in taxation
- A reduction in export
- An increase in import
- An increase in rate of inflation
- An increase in government budget
- An increase of earthquake loss due to fire spreading
DIRECT AND INDIRECT LOSSES:

Direct economic loss: The money, which goes.

Indirect economic loss: The money, which does not come.
DIRECT ECONOMICAL LOSS OF WATER SUPPLY SYSTEM

Capital Losses: losses of direct physical damage of wells, rivers, water treatment plants, pumping plants, reservoirs, transmission pipes, distribution pipes junctions, hydrants, valves.

Water selling loss: this includes the loss due to the emergency water supply.

Repair loss: this loss including manpower salary and expenses for machinery and equipment.
INDIRECT ECONOMICAL LOSS OF WATER SUPPLY SYSTEM

- Damage caused by the fire extension due to water cut off.
- A reduction in water rate prices.
- A reduction in economic activities related to those factories which water is the main material for them such as food and coke factories.
- Increasing of diseases and hospital services related to water cut off.
ESTIMATION OF GROUND MOTION

For calculating the loss estimation a design earthquake must be considered.

The probabilistic approach

Peak ground acceleration is calculated based on the available earthquake for a certain return period.

Deterministic approach

It is based on the choose the scenario fault which may cause damage.
ACCELERATION AT BASE ROCK

Make scenario faults based on the data of the past earthquakes.

The area meshed by  250x250 m, 500x500 m or 1x1 km.

Geographic Information System (GIS) is used and time-histories of base rock motion are generated for different meshes.
SITE EFFECTS

From base rock to surface ground the characteristic of seismic wave is changed based on rigidity, damping, thickness and property of soil layer and water table.

Effect on earthquake ground motions (velocity, acceleration, displacement and time duration).

Ground failure such as liquefaction, landslides etc.
The procedure for estimation of physical damage in buried pipelines is represented by damage ratio.

In this method vulnerability curve for different pipes should be developed and used.
Estimation pipe damage
DETERMINING THE DESIGN EARTHQUAKE

Tehran is the capital of Iran and located at the southern slope of the “Alborz Mountain”.

Tehran City is existing within $51^\circ 10'$ to $51^\circ 15'$ longitudes $35^\circ 34'$ to $35^\circ 49'$ latitudes.

The altitude is 1040 m in south areas and 1800 m in the north. There are several active faults located at the north, west and south of Tehran.

Historical studies show that Tehran has been devastated by destructive earthquakes several times.

Most of these quakes were less than magnitude 7.0 and the average return period about 150 years.
Tehran Region and active faults
SCENARIO FAULTS

Based on historical activity, length of fault and distance from Tehran, two faults are selected as the scenario faults.

(1) North Tehran Thrust: This fault is running along the mountains slope in Tehran City and is the most prominent tectonic structure. The running direction of this fault is towards the north-east with variations between 30 to 60 degrees. The length and displacement of fault are 75Km and 130 Cm.

(2) North Ray Fault: This fault is located at the south of Tehran and the length of the fault is 16.5 Km.
BASE ROCK ACCELERATION

Tehran area is meshed by 1X1 km and time-histories of base rock motion are generated for different meshes.
Time history and Fourier spectrum of acceleration near the fault (at base rock)

Time history of acceleration by North Tehran Thrust

Fourier spectrum of acceleration by North Tehran Thrust
There are two methods to estimate the vulnerability curve:

**Empirical method**

This method is based on an empirical formula obtained from statistical analyses of pipes damage in past earthquakes. A lot of data from the past earthquakes are required. For obtaining formulae, damage should be classified according to pipe material, diameter and soil condition under ground acceleration or velocity.

**Analytical method**

This method is based on the comparison of the numerically calculated stress, strain and deformation with the allowable levels.

We obtained empirical formulae from statistical analyses of many damages during the Kobe Earthquake and was calibrated based on Tehran soil condition.
\[ R_d = 0.000068 \cdot C_d \cdot C_m \cdot C_l \cdot e^{0.0124A} \]

Rd : Damage ratio for pipes (point per Km)
A  : Maximum ground acceleration (gal)
Cd : Coefficient for pipe diameter
Cm: Coefficient for pipe material
Cl : Coefficient for liquefaction
DIRECT LOSS

Surface accelerations based on scenario fault is calculated. Damage ratio and vulnerability curves for pipes are obtained.

- **Capital loss due to pipes damages**
  Cost of pipe in different types, diameters and materials are determined. Considering the number of damage per mesh Capital loss due to facilities is also obtained.

- **Water selling loss**
  Based on damage and failure ratio the areas and population without water is determined.

- **Repair expense**
  Repair expenses include salary of workers, engineers and expense of consumption machinery.
The loss is estimated about 840 million US $
INDIRECT LOSS

- **Indirect loss for Water Company**
  Just income, which does not come from water selling in zones where there have no water.

- **Indirect loss for decrease economic activity**
  A simple approach is Gross Regional Product (GRP). This method estimates the aggregation by economic sector of days of business interruption due to loss of water supply.

- **Indirect loss due to fire extension**
  Damage caused by the fire extension due to water cut off is negligible in Tehran City because most of buildings and components are concrete also water for fire transport by trucks.
The indirect economic loss is estimated about 320 million US$, one-third of direct loss.
Relationship between acceleration and direct loss in Tehran Water Supply

\[ DL = 49.873e^{0.0044 a} \]

Comparison of direct economic losses in water systems of three mega cities

<table>
<thead>
<tr>
<th>No</th>
<th>Case</th>
<th>Direct loss (10^6 $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Los Angeles</td>
<td>1100</td>
</tr>
<tr>
<td>2</td>
<td>Kobe</td>
<td>5600</td>
</tr>
<tr>
<td>3</td>
<td>Tehran</td>
<td>900 (estimated)</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The estimated loss by the proposed method is in an acceptable amount comparing to Kobe City (Japan) and Los Angeles (USA).

Less damage due to stronger soil and earthquake intensity, low cost for manpower, maintenance and repair in Iran makes the estimated loss to be less.

The direct loss in Tehran Water Network is very low for the accelerations less than 300 gal, while it is almost constant with very gentle slope for the accelerations more than 850 gal.

The major economy losses are emergency water supply and repair expense.

Recovery time is estimated to be longer in Tehran due to limited machinery.
Thanks for listening