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Seismic Hazards for Lifelines

Farshad Vazinram[*] Reza Rasti[†]

[*]Department of Water Engineering, Power and Water University of Technology (PWUT), Tehran

[†]Department of Water Engineering, Power and Water University of Technology (PWUT), Tehran

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The response of lifelines against earthquakes and seismic hazard effects on them are studied in this paper. As lifelines pass through wide areas, it may be affected by many seismic hazards. These hazards are such as ground rupture, fault movement, landslides and large deformation due to liquefaction. Based on the experiences from past earthquakes, damages to the lifelines with attention to damaged parts are classified and illustrated. This classification is based on the damages of body, joints, facilities and serviceability. Since the buried lifelines are filled with some materials with almost same unit weight of soil, their seismic response characteristics are different from buildings or buried foundations. Surrounding soil affects its seismic behavior. These effective factors are ground characteristic, earthquake characteristic and structure condition.

Seismic Hazards for Lifelines

F. Vazinram[1] and R. Rasti[2]

[1] Faculty member, Department of Water Engineering, Power and Water University of Technology (PWUT), P. O. Box 16765-1719, Tehran; PH +98-21-77313062; Fax +98-21-77310425; email: vazinram@pwit.ac.ir
[2]Assistant professor, Department of Water Engineering, Power and Water University of Technology (PWUT), P. O. Box 16765-1719, Tehran; PH +98-21-77313062; Fax +98-21-77310425; email: rasti@pwit.ac.ir

Abstract

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Introduction

The 1994 Northridge, the 1995 Kobe, the 1999 Turkey (Kocaeli) and Taiwan (Ji-Ji) Earthquakes have shown that a moderate to strong earthquakes in an urban environment with population over one million people can cause multiple thousands locations in lifelines to be damaged.

A great deal of study has been done about reinforcement of welfare equipment and urban facilities against earthquakes, among which lifelines are the most significance ones. If lifeline systems were damaged by earthquake, not only there would be a waste of products, but also it could be followed by environmental damages, human casualties and economical losses.

Since lifeline networks pass through wide areas, they may be affected by many hazards including earthquakes. The seismic hazards are due to existing active faults and ground conditions. Moreover, material and geometrical characteristics of lifelines are effective parameters in their vulnerability.

As a whole, the main hazards that lifelines can be confronted are:

a) Ground shaking (dynamic effect of earthquake)
b) Ground displacements (static effect of earthquake so called “permanent or large displacements” and sometimes as “ground failures”) including: Faulting (Fault

rupture), Land slides, Liquefaction (which may results to lateral spreading or settlement of soil layers) and Non-uniform settlements so called ground subsidence

Seismic Hazards

The purpose of this paper is to introduce the various seismic hazards for lifelines. In fact, various damages in lifeline occur due to these hazards. The ground and fault characteristics influence the type of the damage. The followings are mainly the static aspects of earthquakes.

Ground Rupture and Faults Movement

Since lifelines are usually installed in a wide area, there are more hazards comparing to buildings. For example, a long pipeline in area with high degree of seismic hazard inevitable may pass through active faults and susceptible regions for liquefaction, landslides or other hazard.

Deformation due to displacement of ground can cause faulting phenomenon. Movement can be done suddenly or imperceptibility in a long time. The faulting phenomenon that causes the ground surface rupture is very important. Because, it has severe effect on pipeline crossing faults or the structures that their foundations are on faults. Ground ruptures may occur across the fault. Length and quantity of the rupture depend on the magnitude and focal depth of earthquakes. Sometimes, there are many single faults together in parallel that can be assumed as a faulting zone. Ground movement in faulting zone may occur in each number of single faults. Also, the movement of single faults and total faulting zone must be considered.

The fault movement depends on the fault type, magnitude of earthquake, focal depth and topography of site.

Landslide

Landslide is a natural phenomenon through which the soil mass resting on top of a slippery layer, such as clay, starts to slowly move due to the impact of groundwater. By the time that the landslide movement has ceased a specific topography associated with a landslide has been formed.

Compared to land collapse, landslide movement has the following characteristics:

-Gentler slope gradient

-Slow movement of soil mass while retaining original shape

-Repetitive occurrence on same slope

Landslides are hill movement of ground, which occur due to earthquakes. There are many models of landslides. Falls, topples, slides, lateral spreads and flows, which are illustrated in Figure 1 (Schuster and Fleming, 1982).

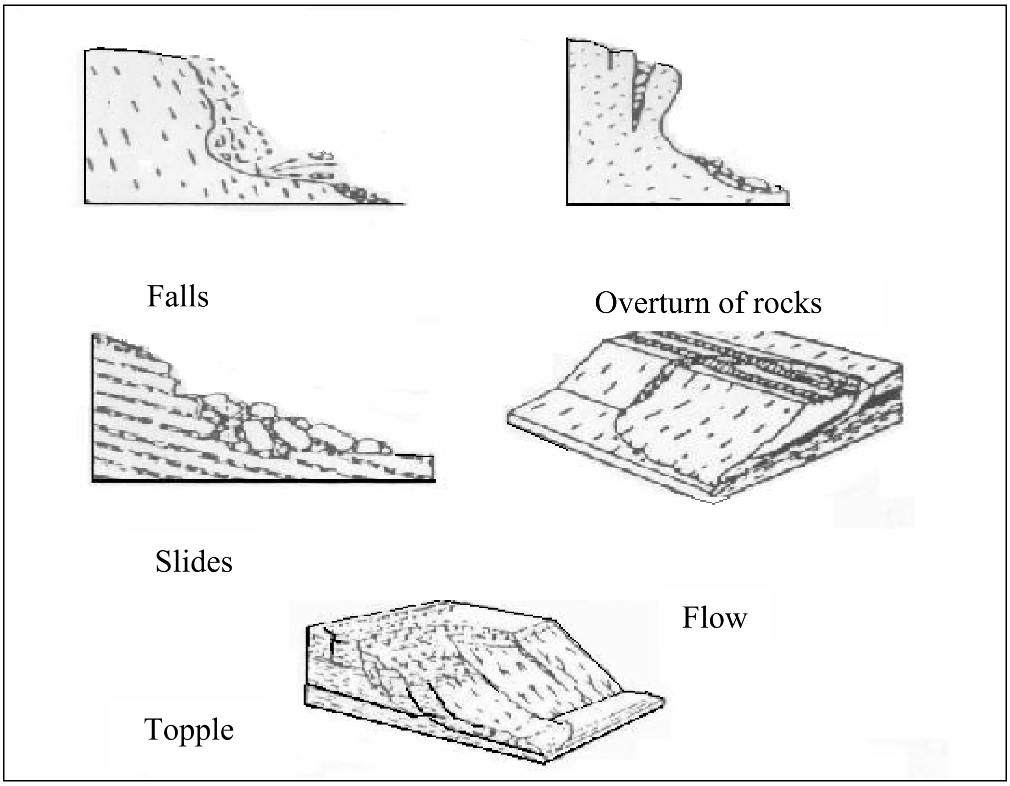


Figure 1. Models of landslides (Schuster and Fleming, 1982)

Liquefaction

Liquefaction is a phenomenon in which saturated, unconsolidated and cohesion less soils lose their shear strength due to shaking and are temporarily transformed into a liquefied state. A loose saturated sand deposit tends to compact and decrease in volume when subjected to vibration. If there is no drainage the pore water pressure increases. If the pore water pressure in the sand deposit is allowed to build up by continuous vibration, a condition will be reached at some time where the overburden pressure will be equal to the pore water pressure. Based on the effective stress principle:

$$\sigma ' = \sigma - U$$

Where $\sigma '$ is the effective stress, σ is the total overburden pressure, and U is the pore water pressure. If σ is equal to U, $\sigma '$ is zero. Under this condition, the sand does not possess any shear strength, and develops into a liquefied state. Liquefaction of saturated sands during earthquakes has been the cause of much damage to buildings, lifelines and other structures.

Four basic types of ground failure are associated with liquefaction as followings:

1) Lateral spreading

Limited displacement of surface soil layers move down mild slopes or toward free faces, such as riverbanks. This movement occurs in the low slope (0.5~1 degree) and several hundreds meters in length. Based on the past earthquakes, the specific conditions are able to liquefy with lateral spreading such as beach area, old rivers beds, man made embankment, glacially deposit sediments, weak and cohesion less soils.

2) Flow failures

Flow failure is a case of liquefaction that, soil materials flow rapidly down slope in a liquefied state and often happens in saturated sand with 5 degree slope and the more. Many flow failures occurred under sea such as failure in Valdes Sea in Alaska Earthquake in 1964 where, 70 millions cubic meters of sediments were moved (Kachadoorian and Plafker, 1966).

3) Loss of bearing strength

Bearing capacity failure of foundations because of weakening of underlying or adjacent soil material may results in structures sinking.

4) Flotation

Buried objects lighter than the displaced liquefied soil such as tanks, access holes (man-hole) and gravity pipelines float to the surface.

Influencing Factor on Lifelines Behavior during Earthquake

Since the buried lifelines are installed in the ground surface, seismic behaviors of them are affected by surrounding soil. These influencing factors are as followings: site ground characteristics, earthquake characteristics and structure conditions.

Site Ground Characteristic

Generally, damages due to earthquake in steady and uniform ground are less than other types. Topography, ground water table, thickness and strength of soil layers are effective on ground response. The following factors decrease steady of the ground.

- Landslide potential
- Liquefaction and floating ability
- Slope
- Man made embankment land
- Soft layer
- Variation of soil condition between location of lifelines and facilities

It is necessary to provide regional map of ground motion, liquefaction potential, landslide, and facilities far from these areas or make necessary countermeasures. In addition, type of soil effects on natural ground periods and magnitude of horizontal acceleration.

Earthquake Characteristics

Intensity of quake, time histories of accelerations of horizontal and vertical waves, duration, peak ground acceleration (PGA), peak ground velocity (PGV) and amplitude are earthquake characteristics which affect on seismic lifelines behavior. These are classified based on ground condition as flows:

1. Earthquake hazard

There are two generally accepted methods that can be used for evaluating the seismic performance of an existing facility: Deterministic or probabilistic earthquakes.

A deterministic earthquake is defined as the occurrence of a particular magnitude earthquake at a particular location. The selection of scenario earthquakes will usually include large magnitude or maximum credible earthquake as well as smaller magnitude but more probable earthquakes. Scenario earthquakes are often considered in risk evaluations when the utility owner wishes to determine system-wide performance during a particular earthquake.

A probabilistic earthquake is defined as the ground motion hazard at a particular location within a given time frame. A common way of expressing a probabilistic earthquake is, using a hazard curve.

2. Level of earthquake

There are two hazard levels of earthquakes in seismic design of structures. Level 1(L_1) is the probabilistic earthquake, which may occur one or two times during the lifetime. Level 2(L_2) contain a larger magnitude with less probable earthquake. Level 2 earthquakes, is the one, which is obtained from a specified local fault movement.

As a conclusion of all the sections up to here, it is well understood that the ground displacements (large and permanent ones) are more severe comparing to ground shaking on the behavior of lifelines.

Structure Characteristic

Many factors, which affect on lifeline behavior during earthquake, are related to material, size and joint type. Structural characteristic affects on buried pipes are less than surface (on or above ground) pipes.

Relation between Damage and Ground Behavior

Generally, less damage due to earthquakes is found on firm and uniform ground. Buried lifeline is affected by deformation of the surrounding soil. Nevertheless, a considerable number of water networks and facilities are built on weak or uneven ground. The status of the ground depends on factors such as topography, the layer order, layer thickness, strength of each layer and the ground water level. The followings are not good ground conditions:

- Sliding
- Slopes
- Different soil layer interfaces
- Weak ground
- Reclaimed ground
- Ground subject to liquefaction or lateral spreading during an earthquake

Damage and Ground Behavior during Past Earthquakes

The word “Utilities” which is some times used in stead of lifelines shows the lifeline categories more clear than other definitions. These are the ones that the people are paying periodically (usually monthly) bill for them. These are Water, Gas, Electricity, Telecommunication and Waste-Water systems. The networks of these systems are mainly buried under roads, specially the water pipelines. Therefore, they are so sensitive to ground failure more than shaking.

Behavior of Buried Lifeline in Liquefied Ground

It has en investigated and cleared that in saturated sandy soils, there are water in a pore configuration among the sands and when there is some shaking to the soil then the pore water escape from the pore form and the water pressure which is know as pore pressure increases, making the fine sands floating inside the water. This phenomenon which is called liquefaction occurs during earthquakes in sandy soil with low water table.

This may happen in a wide area or in a local form in at surface layer or beneath it.

When the liquefied soil changes to liquid state, then it will flow if there is some inclination (slope) and settle too. If this happens at some deep layer then there may be lateral spreading at the surface layers and some huge cracks will appear at the surface which may cause large strains on the buried pipelines.

The main features of liquefaction concerning the buried pipelines are lateral spreading (displacements in the soil flow direction, which is almost horizontal) and settlement (vertical displacement). There are some new proposed formulae for calculating lateral displacements while the maximum settlement is considered almost 5% of the thickness of the liquefied soil layer.

For seismic damage evaluation using the empirical vulnerability curves for water pipes, the effect of liquefaction is considered as a coefficient which increase the standard damage ratio (mesh oriented analysis) while in route or line analysis of pipes, the obtained displacement due to quake-induced liquefaction should be applied on the pipe for analysis.

Relation between Damage and Fault Movement

Since the lifelines are very long structures, there are many cases that they should be buried crossing active fault, (which are appeared at ground surface). As shown in Fig.4, here are two kinds of displacement for a fault. One is horizontal displacement, which is known as strike-slip fault. The sides of the fault may be displaced in right or left directions against each other. In the case of vertical displacement, if one side is going lower or upper against the other side, it is named normal or reverse fault, respectively. In fact, both horizontal and vertical displacements usually occur in an active fault.

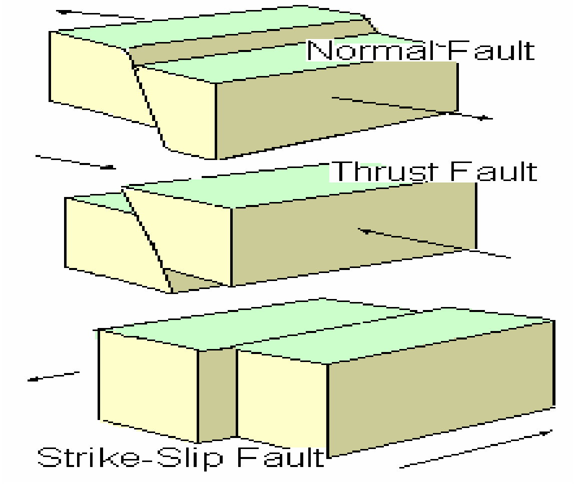
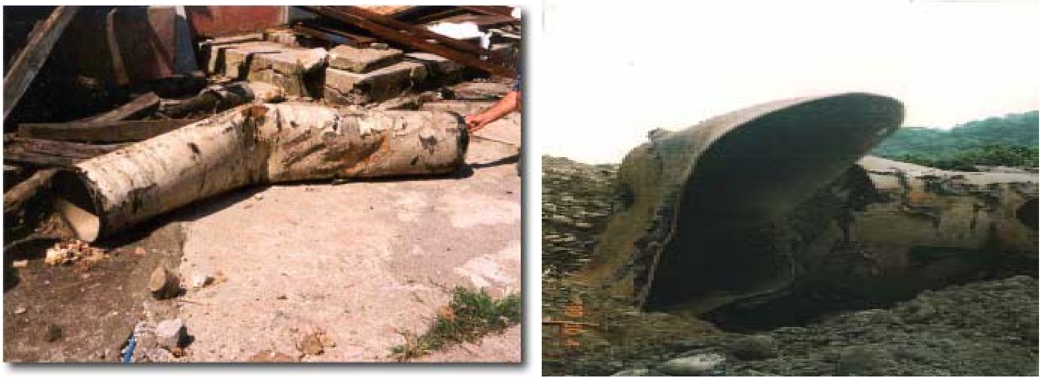


Figure 2. Different types of faults movement

The buried pipelines suffered sever damage due to surface faulting. Specially, during recent earthquakes in Turkey and Taiwan, there were more clear experiences of pipe damage crossing active faults Figures 3 and 4 (Takada, 2000).



a) The 1999 Kocaeli Earthquake in Turkey b) The 1999 Chi-Chi Earthquake

Figure 3. Failure of steel pipes crossing the active faults

Figure 4. Large deformation of steel pipe section crossing the active fault (The 1999 Chi-Chi Earthquake in Taiwan

Conclusions

In this paper many seismic hazards, which may be effective on lifeline, are introduced. These hazards are due to existing active faults, ground shaking and ground failure. Various earthquake-induced damages occurred in lifeline systems are illustrated and classified. The effects of ground failures such as non-uniform settlement and liquefaction on lifelines are also explained. The main purpose of this paper is introduce the countermeasure methods for reducing the effect of ground deformation, liquefaction and fault movements on the lifelines which are as follows:

a) Ground improvement
  - Improvement of density and increase in strength by compacting
  - Improvement grain size by consolidation, substitution and injection
  - Reducing the saturation degree, fill and water level
  - Preventing the axial subsidence and controlling the shear deformation by buried wall and sheet pilling
  - Reducing lift pressure by gravel drainage

b) Strengthening the lifeline structure
  - Increasing the weight
  - Increasing the flexibility as flexible expansion loops
  - Increasing the vertical support
  - Making the structure uniform
  - Increasing the pulling out resistance
  - Using concrete foundation in the limited weak soil
  - Using pile foundation in the deep weak soil
  - Avoiding from fault crossing
  - Anchorage with concrete blocks in the fault-crossing zone for prevention of additional stress due to side bending.

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