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Fragility Analysis of a Water Supply System

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Summary

The seismic performance of a water supply system depends on the individual performance of its components and on system configuration. Components of a water supply system include pipes, tanks, tunnels, reservoirs, and other components. Complete fragility analysis is performed on pipes, including analysis of pipes under seismic wave hazard and fault displacement hazard, two commonly occurring types of hazard following a seismic event. The influence of seismic wave hazard is assumed to be more prominent for pipes located far away from seismic source, while fault displacement hazard is assumed to affect only pipes located on seismic sources, i.e., faults. Fragility information for other components is taken from the literature. Ongoing work focuses on performing Monte Carlo simulation and hydraulic analysis to generate fragility information on a damaged water supply system.

Introduction

The seismic performance of a water supply system depends on the individual seismic performance of its components (e.g., pipes, tanks, reservoirs, and other components). A methodology is developed for assessing the seismic performance of water supply systems by using fragility surface; providing the failure probability of the system as a function of seismic moment magnitude m and site-to-source distance r. Seismic performance of pipelines is analyzed under the influence of seismic wave and fault displacement to develop the fragility surfaces for pipes. Fragility data for other components of the water supply system are taken from the literature.

Combining flow analysis and Monte Carlo simulation, a damaged water supply system can be analyzed in order to produce a fragility surface for the system. Life cycle seismic hazard analysis and cost benefit analysis can be incorporated to optimize a retrofitting scheme appropriate for the damaged system.

Motivation for Using Fragility Surface

The seismic performance of components of a water supply sytem usually involves only one seismic parameter, such as peak ground acceleration (PGA). This type of characterization can be misleading; for example, the same PGA can lead to varying degrees of damage states. Fragility surface, which provides the failure probability of a system as a function of two or more seismic parameters, can yield a better representation of the seismic performance of a water supply system.

Methodology

Seismic wave and fault displacement are two types of seismic hazards considered herein to assess the seismic performance of a water supply system. Two types of ground motion excitation are generated: (1) far-fault ground motion for site-to-source distance more than 15 km (Papageorgiou and Aki, 1983a and b), and (2) near-fault ground motion for site-to-source distance less than or equal to 15 km (Mavroeidis and Papageorgiou, 2003).

Generation of fragility information for a pipe involves the calculation of the probability that some specified limit states are violated (O'Rourke, Grigoriu, and Khater, 1985). The typical limiting parameter for a pipe is the pipe limit strain ε_{limit}. The limit strain is used to calculate the limiting force F_{limit} for seismic wave analysis, and the limiting fault displacement D_{limit} for fault displacement analysis. Fragility analysis is performed by using Monte Carlo simulation to generate ground motion time history, and to calculate maximum force F_{max} for seismic wave analysis and maximum fault displacement D_{max} for fault displacement analysis. Failure is defined when response of the pipe is greater than the limit state. Figure 1 is a flowchart of pipe fragility analysis.

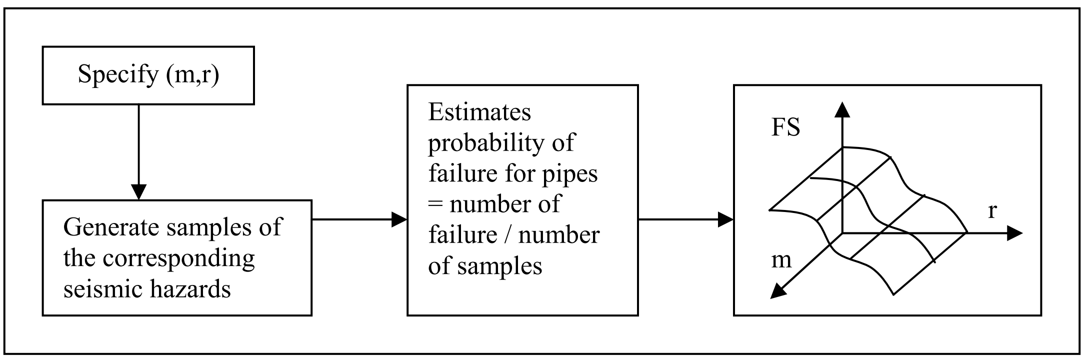

Figure 1. Flowchart of fragility analysis of pipes

An example of a fragility surface generated for a pipe under seismic wave analysis is shown in Figure 2. The limiting strain ε_{limit} of the pipe is assumed to be 0.025%. The pipe is made of steel with a modulus of elasticity E = 29000 ksi, 12 inch diameter and a thickness of ½ inch. The center of the pipe is located 4 ft below the soil surface. The soil is categorized as stiff soil with a unit weight of 120 pcf, a coefficient of lateral earth pressure at rest of K_0 = 1, an angle of friction of 30 degrees, an apparent wave propagation of 2500 ft/s, and an angle between wave propagation and pipe of 0 degrees.

Fragility data for two other components of water supply system, tunnels and tanks, are provided by the American Lifelines Alliance (ALA 2001). Table 1 gives the complete tank database per ALA 2001. Table 2 gives the complete bored tunnels database per ALA 2001. Damage state one (DS1) indicates no damage, DS2 slight damage, DS3 moderate damage, DS4 extensive damage, and DS5 indicates total failure or collapse of the component.

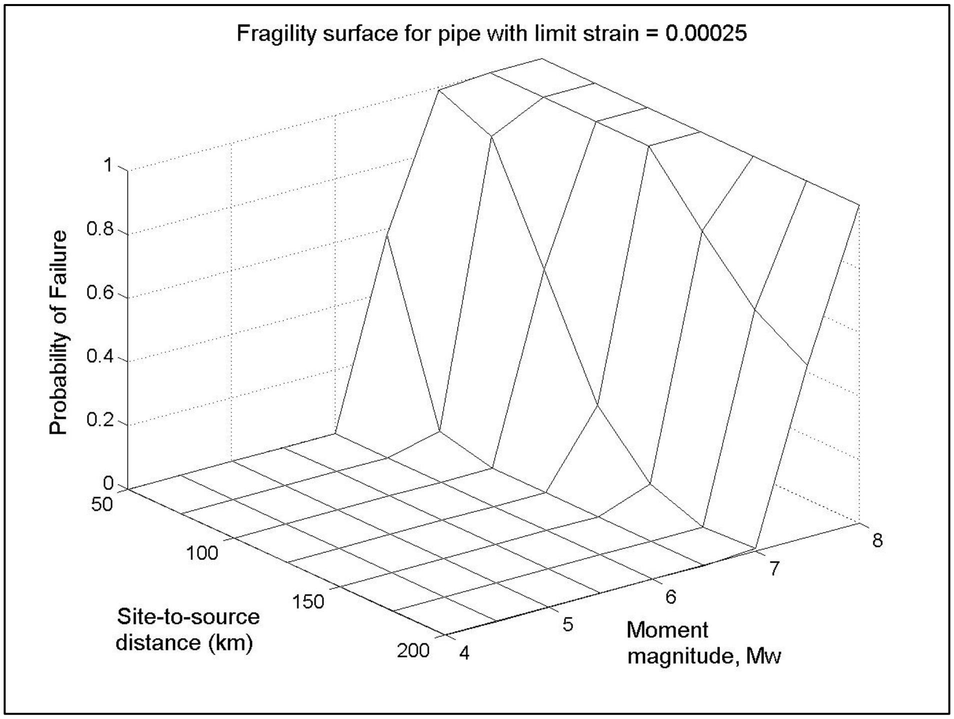

Figure 2. An example of fragility surface for pipe under seismic wave analysis

Table 1. Complete tank database

PGA (g)	All Tanks	DS = 1	DS = 2	DS = 3	DS = 4	DS = 5
0.10	4	4	0	0	0	0
0.16	263	196	42	13	8	4
0.26	62	31	17	10	4	0
0.36	53	22	19	8	3	1
0.47	47	32	11	3	1	0
0.56	53	26	15	7	3	2
0.67	25	9	5	5	3	3
0.87	14	10	0	1	3	0
1.18	10	1	3	0	0	6
Total	531	331	112	47	25	16

Table 2. Complete bored tunnels database					
PGA (g)	**All Tunnels**	**DS = 1**	**DS = 2**	**DS = 3**	**DS = 4**
0.07	30	30	0	0	0
0.14	19	18	1	0	0
0.25	22	19	2	0	1
0.37	15	14	0	0	1
0.45	44	36	6	2	0
0.57	66	44	12	9	1
0.67	19	3	7	8	1
0.73	2	0	0	2	0
Total	217	164	28	21	4

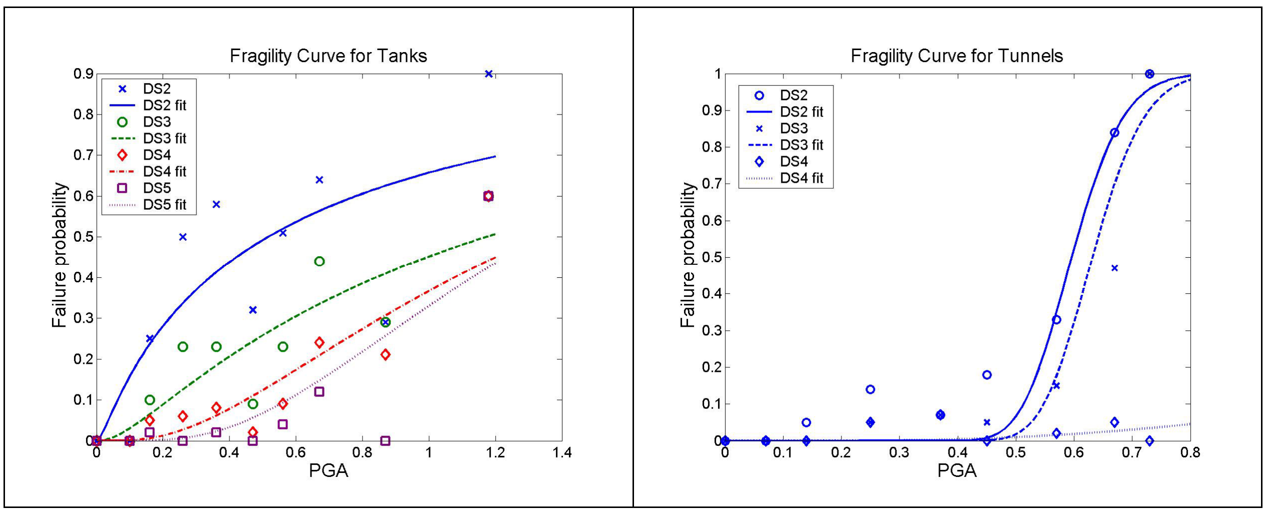

Figure 3. Fragility curves for tanks and bored tunnels

Based on the data given in Table 1 and Table 2, fragility curves for tanks and tunnels can be generated for the different damage states. Fragility curves provide the failure probability of a system (in this case tunnels and tanks) as a function of PGA. The fragility curves seen in Figure 3 are generated by curve fitting through the data by lognormal functions.

Future Works

The fragility of a water supply system will be generated based on the fragility information of its components. The methodology for the process is as follows:

1. Generate *n* damage states of a water supply system under a specified seismic magnitude *m* and site-to-source distance *r* and its corresponding components fragility information.

2. Perform hydraulic analysis on the damaged water supply system.

3. Check the satisfaction of system performance under some specified requirements.

4. Produce fragility surface for the overall system.

Figure 4 provides the flowchart of fragility analysis for water supply system.

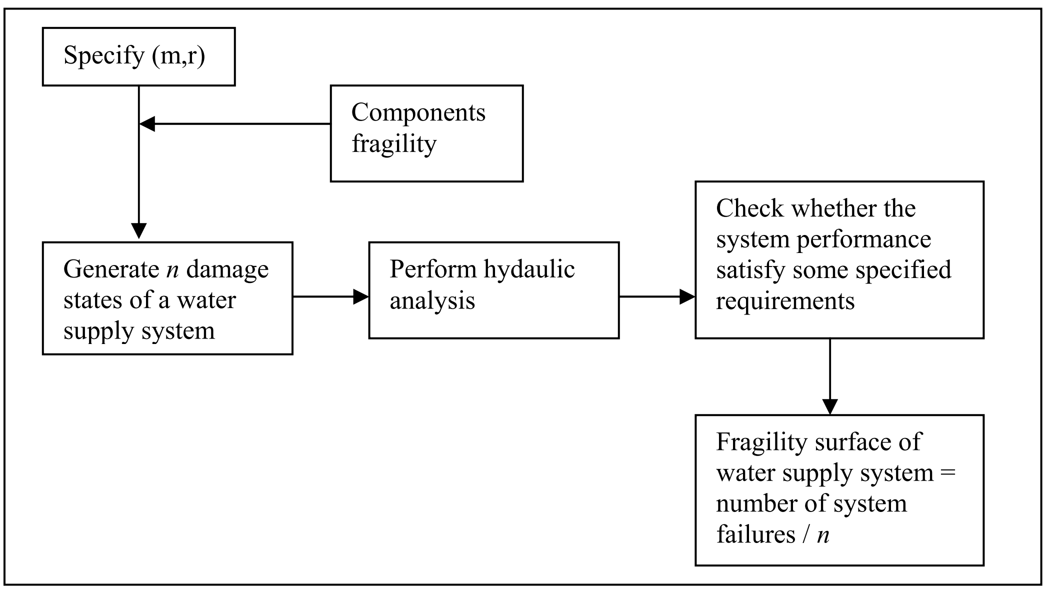

Figure 4. Flowchart of fragility analysis of water supply systems

Concluding Remarks

Fragility analysis has been performed on pipes under the influence of seismic wave hazard and fault displacement hazard. Fragility data for other components (e.g., tanks and tunnels) are taken from the literature. Ongoing work is on generation of fragility surface of a damaged water supply system using Monte Carlo simulation and hydraulic analysis.

Life cycle seismic hazard analysis and cost benefit analysis will be performed on the damaged system in order to optimize the retrofitting scheme for the water supply system.

Acknowledgements

This research was carried out under the supervision of Professor M.D. Grigoriu, and primarily supported by the Earthquake Engineering Research Centers Program of the National Science Foundation, under award number EEC-9701471 to the Multidisciplinary Center for Earthquake Engineering Research.

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