NETWORK SEISMIC RISK

by

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INTRODUCTION

Studies of recent seismic events have shown that earthquake engineering has to be strengthened in the area of public utility systems, highway systems and lifeline systems in general. Building earthquake engineering, having started after the 1933 Long Beach earthquake, has reached a certain level of sophistication. However, it is not until recently, after the San Fernando earthquake in 1971 that attention was brought to the vulnerability of lifeline systems to strong earthquakes. In computing the reliability of a lifeline system, it is impossible to treat the lifeline in its entirety. There are two reasons; first, the effect of an earthquake is not the same over the entire system, and second, the resistance of the lifeline usually varies from point to point along the network. Consequently, it is necessary to divide the system into links and nodes and then perform the reliability of the network in terms of these elements.

SCOPE OF THE WORK

This paper briefly describes the problems involved in reliability analysis of a lifeline system and outlines a methodology for its evaluation. A more detailed analysis is currently under investigation and the results of that analysis will be presented at a later date. A decision concerning an upgrading of any part of the lifeline involves multidisciplinary considerations which are very complex. For this reason, it is essential to study the following areas:

1. Seismic: Evaluation of seismic hazard in terms of occurrence of an event. Probability distribution of the parameters describing the hazards associated with an occurrence of a seismic event.
2. Lifeline Model: Modeling the lifeline in terms of links and nodes to perform the reliability of the network.
3. Impact Estimation: This involves the estimation of direct economic cost of replacement and repair, cost of outage period as determined by time required for replacement or repair, cost of rerouting the services, revenue loss due to nonsupply of services, indirect cost due to social impact on the region and other indirect losses.

The considerations mentioned above are not independent but are interrelated. Each input is needed for a rational decision based on the

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[I] Research Assistant, Department of Civil Engineering, Stanford University, California

[II] Professor of Structural Engineering; Director, The John A. Blume Earthquake Engineering Center; Department of Civil Engineering, Stanford University, California results of analytical modeling, physical evidence and judgement. In this paper lifeline modeling and damage estimation modeling are presented.

LIFELINE MODELING

It is necessary to divide the lifeline system into different elements and then perform the reliability of the network in terms of these elements. It seems that the following three components are the main elements constituting a lifeline:

Key facilities: Lifelines usually include a number of facilities which are important for the functioning of the system. Examples are, pumping stations in water supply networks and generating stations in electrical networks. These facilities are considered as nodes in the overall system. (See Figure 1).

Main network: This consists of the main arteries which interconnect the key facilities.

Fine network: Most lifelines include a fine network in addition to the main network. This part of the lifeline is usually redundant and its reliability analysis complicated. Moreover its performance during an earthquake is not vital to the overall functioning of the system.

In analyzing the lifeline system, the main network will be divided into links and nodes according to the design level of different portions of the main network and the soil structure upon which it is built. The fine network will be divided into areas, each area being homogeneous and will be considered as independent.

Simple Networks.

A system break-up is in series if the failure of one link will result into failure of the overall system. A system in parallel, by contrast, is one which does not fail if one of its elements fails. Rather the service is completely disrupted if at least one of the links in each branch of the system fails. It should be noted that this break-up must be in accordance with physical rules which govern the functioning of the system. In other words, the direction of flow distribution should be kept in mind when a lifeline is divided into simple networks.

Network Connectivity.

Several characteristics of the lifelines must be included in the modeling and analysis. These are:

1) Inputs and outputs. Some key facilities or nodes are of special importance because they represent the origin or the end of the . flow. A lifeline network may include any number of inputs and outputs. For example in an electrical network, generating stations which are key facilities are inputs. Outputs are the houses and factories that use electricity as source of energy.
2) Flow direction. This has to be included in the analysis. In some instances a link has the capacity of providing flow in both directions, as in the case of a highway network. In other cases the link provides flow only in one direction as in the case of a pipeline network.

Tie Sets.

In a complex network with many links and nodes it is difficult to establish all the possible paths connecting inputs to outputs. After a damaging earthquake the number of possible ways to go from inputs to outputs is very important. By definition a tie set is a group of links and nodes which form a connection between an input and an output in accordance with the possible flow directions. It is called minimal if no node is traversed more than once in tracing the tie set. If the system has n minimal tie sets, it will survive an earthquake if after an event m minimal tie sets are operational. The number m depends on the nature of lifeline and its function. Its value has to be decided at the beginning of every reliability analysis. In some cases m might be equal to n like in the case of a single branch lifeline. In other instances a certain fraction of n tie sets will have to be functional so that the lifeline can be operational.

It can also be said that if a system has n inputs and m outputs it will survive after an earthquake if n_1 of the inputs can supply m_1 of the outputs. The next step is to transform the lifeline system into a series system of parallel tie sets and then proceed to find the reliability of the system. The following example will further describe the methodology.

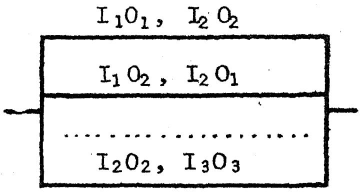
Consider an imaginary network shown by Figure 2. In this example we have 3 inputs and 3 outputs (designated by I and O). There are also two key facilities N_1 and N_2. The network is divided into 9 links and 2 nodes in addition to inputs, outputs and key facilities. It is assumed that links between different nodes provide flow in both directions. It is required, as an example, that after a major seismic event any two inputs provide flow for any two outputs. A flow connection between input I_i and output O_j will be represented by $I_i\ O_j$.

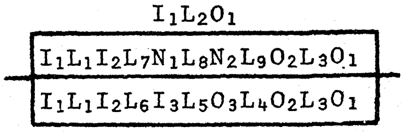
The distribution of tie sets are as follows:

- -4 between I_1 and O_3, I_3 and O_1.
- -3 between all others.

Hence there are a total of 29 tie sets. In order to compute any reliability for the total network an analytical model is first developed.

The equivalent system of series and parallel model is shown below. This system has 18 branches (This number is equal to $2C_3^2C_3^2$ which is the total possible combination of inputs and outputs). Each component of the model is itself a combination of other elements in series and parallel. For example between I_1 and O_1 there are three minimal tie sets. Therefore its equivalent model is as shown here:





Once this modeling is complete the probability of damage of each component should be found. Then they all should be combined according to probability theory rules to find the reliability of the total network.

LOSS FORMULATION

As was mentioned earlier, the loss can be correlated with the outage time. The longer any component is disrupted the larger the loss is. (This includes economic loss, replacement cost, social impact, etc.).

In order to estimate the above loss, the earthquake parameter such as the peak ground acceleration (PGA) should be related to the outage time (and hence loss). It is obvious that finding such a relationship is very difficult if not impossible. There are many unknown parameters. For example, the level of material damage induced upon certain parts of a lifeline can be repaired in different time lengths depending upon the accessibility of the damaged portion, manpower and material availability. Consequently this relationship is very nondeterministic and a probability distribution should be introduced for this purpose. See Figure 3. However, since we almost do not possess any real data on damage to lifelines and the corresponding repair time, this distribution will have to be hypothesized, based on judgment and theoretical research. Thus, the conditional probability of outage time (or loss) for a given level of PGA can be combined with the probabilistic information on the PGA. This information is obtained by developing isoacceleration maps for the region under investigation (see reference 1). The resultant joint distribution on loss and the PGA can be used in the series and parallel system model developed in the previous section.

CONCLUSION

Modeling of a network can become very complex for even a small lifeline. A computer program should be developed to do some of the computation associated with system modeling and probability analysis.

Damage and loss formulation is still at a preliminary stage and further research is needed in this area. A model is currently under development which can be used if some future data will be available on lifeline damages.

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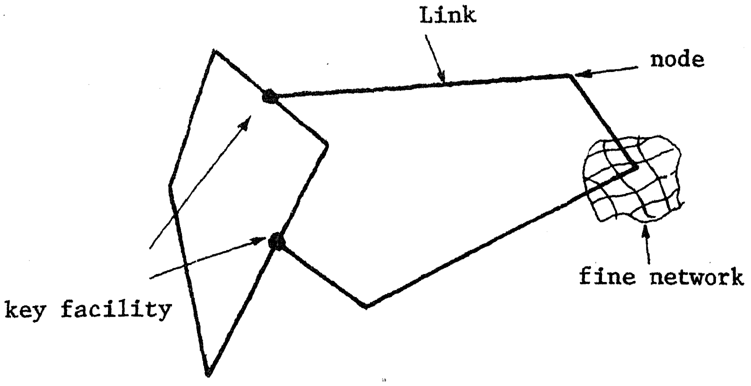

Figure 1

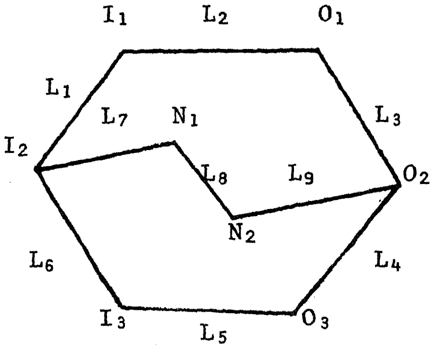

Figure 2

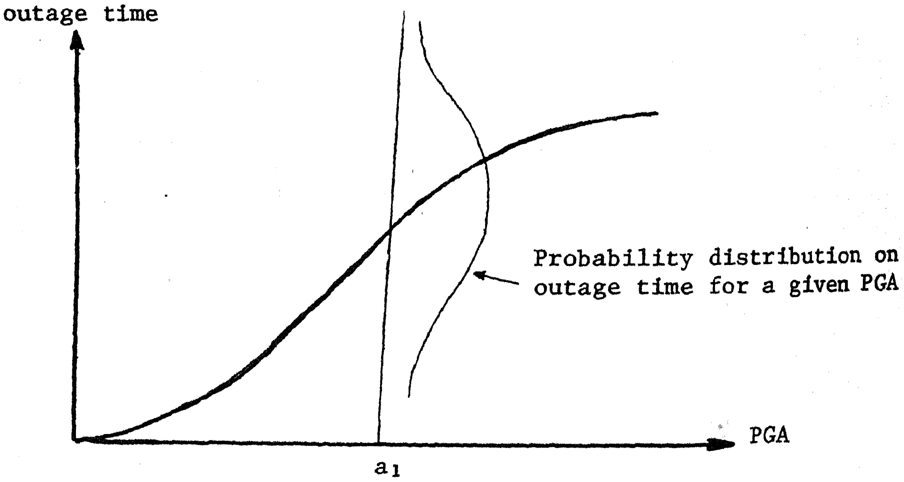

Figure 3

DISCUSSION

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A point of clarification : if the network is extended spatially over significant distances conventional seismic hazard analysis (e.g., maps of isoseismals with given return periods) is not sufficient.

Author's Closure

Not received.