

RESEARCH SPOTLIGHT

STRUCTURAL AND NETWORK FUNCTIONALITY LOSS ASSESSMENT OF THE SAN FRANCISCO BAY AREA TRANSPORTATION SYSTEM

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Introduction

Transportation systems are well known for their exposure and vulnerability to seismic effects. Damage and failure of these systems can seriously hamper emergency response following a disaster and can result in significant economic losses from the physical damage and from reduced functionality of the system. An initial study (Kiremidjian et al., 2005) supported by the Pacific Earthquake Engineering Research Center (PEER) focused on estimating the physical and functionality losses from scenario earthquakes impacting the San Francisco Bay Area transportation system.

A study is currently under way that considers all earthquakes in the region that contribute to the total risk of the system, includes the uncertainty in bridge damage factors and replacement costs, assesses the functional losses from unavailability of the system (Stergiou and Kiremidjian (2006), incorporates ground motion and bridge damage correlations, and provides an efficient algorithms for total risk computation (Lee and Kiremidjian, 2006). In this spotlight, we present the results from the total risk analysis that includes direct structural and reduced system functionality losses from all significant earthquakes in the San Francisco Bay Area.

Methodology

The seismic risk of a transportation system is defined as the annual probability of exceeding the loss from all possible events to which the system is exposed. The main contributors to the loss are damage to network components and traffic time delays. For the direct loss analysis a modified form of the framework PEER equation is formulated:

$$P[L > I] = \int \int \int dF_{L/RC,DF,A} dF_{RC} dF_{DF,DS} dF_{DS|\lambda A} \lambda A \quad (1)$$

where L is the total direct loss, F(*) is the cumulative distribution function of *, RC is the replacement cost, DF is the damage factor, DS is the damage state, A is the local ground effect (ground shaking, liquefaction or landslides) and λA is the hazard rate at the site.

Since Eq.1 cannot be evaluated in closed form, a simulation approach is considered. In addition, an approximate integration approach is developed by Stergiou and Kiremidjian (2006). More efficient methods applicable to large systems are currently being investigated by Lee and Kiremidjian (2006).

Equation 1 requires that all possible earthquakes in the study region be defined by their magnitude, rupture location, and probability and frequency of occurrence. Assuming independence between events, the direct losses are computed for each scenario and the annual rate of loss exceedence is:

$$P[L \geq I_k] = 1 - \prod_{i=1}^n (1 - p[E_i]) \quad (2)$$

where L is the loss random variable, λ_i is the loss for event E_i , $P[E_i]$ is the annual rate of occurrence of event E_i , and n is the total number

of events resulting in losses.

In this study bridges are considered as the critical links in the system and damage to these components will result in reduction in traffic flow and/or possible loss of connectivity between travel zones. Thus, network performance is defined as the total travel delay for passenger and freight traffic which is correlated to dollar loss. The functionality and direct loss curves are added to obtain the total annual loss exceedence curve.

Application to the San Francisco Bay Area Transportation Network

The risk assessment methodology is illustrated through an application to the transportation system within five counties of the San Francisco Bay area. The system considered in the analysis has 1125 bridges and 1120 Transportation Analysis Zones (TAZ). Physical and engineering attributes for the bridges were obtained from the CALTRANS bridge database. The TAZ zones account for both intra and inter regional traffic. The earthquake events and the probability of occurrence for each event were evaluated using the information in the Working Group Study (USGS, 2003). Figure 1 summarizes the losses from physical damage to bridges and the corresponding network functionality loss for each scenario event on the San Andreas Fault causing nonzero loss. The contribution of ground shaking, landslides and liquefaction to the overall loss is included in this analysis (see Stergiou and Kiremidjian, 2006 for detail). It was determined that liquefaction is the main contributor to the direct physical loss.

The network functionality losses were evaluated as a function of the time to restore full functionality. The overall operational loss is then evaluated by summing the losses over the time period when the system is 100% functional.

In comparison to Figure 1, it can be observed that the functionality losses are consistently higher than the direct losses for all scenario events. In majority of cases the functionality loss is more than 50% higher than the loss from physical damage. The aggregate risk from direct physical and functional losses is shown in Figure 2.

Conclusions

A method for evaluating the risk from direct physical damage and functional loss of a transportation system in a seismic region is summarized that considers various sources of uncertainty. Application of the method shows that the functional loss is of the same order of magnitude as the direct physical loss and somewhat higher than the physical loss. Liquefaction appears to be a major contributor to physical loss pointing to the needed for more detailed studies. The risk curve

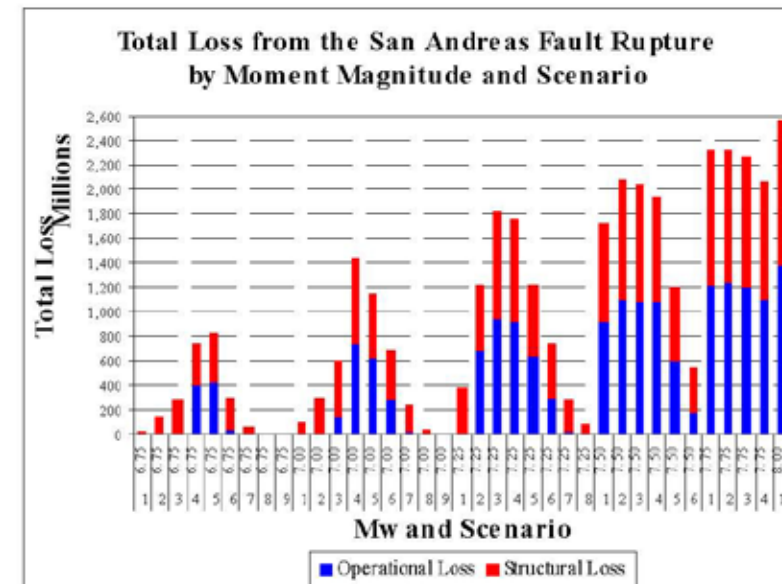


Figure 1. Direct and functionality loss for the San Francisco Bay Area transportation network

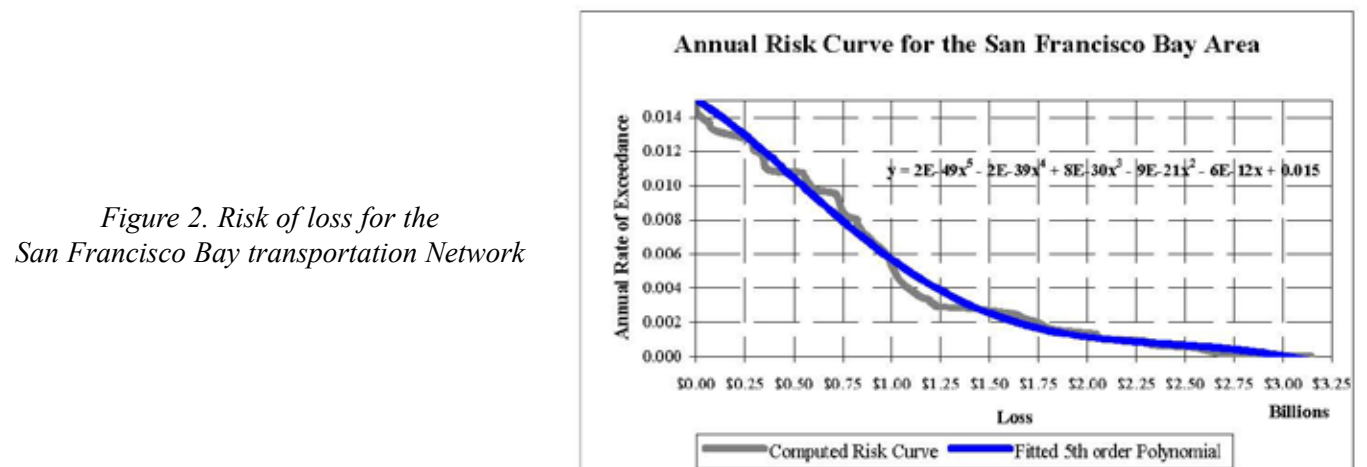


Figure 2. Risk of loss for the San Francisco Bay transportation Network

provides critical information for emergency response, optimal network rehabilitation and design.

Acknowledgement

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