Proposed Best Practice

Seismic Retrofit Decision-making for a Large System
Bay Area Rapid Transit (BART) system
Date Implemented: December 2000 to June 2002

Description
The Bay Area Rapid Transit (BART) system used a risk analysis approach to develop a prudent, cost-effective retrofit program that ensures system safety and balances costs with restoration of operability after a major earthquake.

Problem
Although BART was constructed to high seismic standards for the 1960s and 1970s, advances in the understanding of Bay Area earthquake hazards and their potential effects on structures suggested that retrofitting of the system needed to be considered. The BART Board of Directors requested a report on the system’s vulnerability and retrofit alternatives. In a large system such as BART, a wide range of retrofit options can be considered, with the associated wide ranges of costs, levels of post-earthquake damage, and impacts on system performance. Not all facilities need to be retrofitted to the same level to achieve acceptable system performance. A prudent program is one that results in a substantial level of earthquake risk reduction at a reasonable cost. Achieving this balance between cost and risk reduction is difficult, and was the goal of BART’s risk analysis approach.

Solution
Based on recommendations from the California Seismic Safety Commission and BART’s own Peer Review Panel, BART applied a risk assessment strategy to determine a prudent level of retrofit, consisting of:

1. Defining levels of performance for various facilities, with the primary objectives being life safety and BART’s ability to provide service after an earthquake. This included an initial determination of which facilities should remain operational, and how long other facilities could remain out of service after the earthquake without unacceptable consequences. BART also prepared a Seismic Risk Management Plan to describe the process that it intended to use to determine the overall level of retrofit.

2. An analysis to evaluate the vulnerability of the existing BART system to earthquakes, based on potential earthquake magnitudes and locations (scenarios) and evaluating the likely behavior of BART facilities under scenario earthquake forces. BART used a GIS-based computer analysis to estimate the likely damage to the system from various scenario earthquakes, the costs associated with repair, the impact to BART commuters, and the impact to non-BART commuters.

3. Developing and evaluating five alternative retrofit packages, with associated costs and benefits. Because more of the BART system would be returned to operation sooner as more retrofit was done, community and business “benefits” would be increased.

4. Using results of the analysis described above, BART determined that the most cost-effective package would be retrofitting the “core” system to operational standards, while retrofitting the remainder of the system for safety only. Although not a direct result of the risk analysis process, BART also concluded that some of its original performance goals were not cost-
effective. In particular, BART’s original goal of returning system-critical facilities to operation within 72 hours after a major earthquake was modified to a period of one to two weeks.

A copy of the BART Seismic Risk Management Plan (SRMP), the final Vulnerability Report and the Seismic Risk Analysis are available from BART upon request.

Resources

Deciding on the seismic retrofit of a large complex system requires the substantial resources, including:

- **Owner’s Policy**: The owner must initiate the process by describing its objectives for the seismic retrofit program. These are usually expressed in terms of a desired post-earthquake performance level. However, the owner must realize that it may not be able to achieve all of its goals if funding is insufficient, and should be prepared to prioritize its objectives.

- **People**: The seismic retrofit evaluation process is quite labor intensive, and requires personnel knowledgeable in the specialized areas of seismic retrofit design (as distinguished from seismic design of new facilities), seismology, soil behavior, and seismic risk analysis. Considerable effort must be expended in reviewing existing drawings, structure characteristics, existing soil conditions, and other site-specific information in order to understand how earthquake forces will interact with existing structures, and what effect retrofits will have on this interaction.

- **Computers/Information Technology**: BART utilized up-to-date computer software for structural analysis, and used a GIS-based risk analysis program. For a small or less critical system, the use of standardized FEMA or other procedures may reduce the need for computer software.

- **Time**: The analysis of structures and the setup of the risk analysis software require an extensive period of time. In BART’s case, the study took approximately one and one-half years to complete.

- **Peer Review**: A high-quality peer review of the risk analysis process and results are strongly recommended. BART created a Peer Review Panel consisting of world-renowned engineers and seismologists to review the overall process and ensure that it resulted in a prudent, cost-effective seismic retrofit program. For a smaller property, the use of a smaller panel or even an individual engineer knowledgeable in seismic retrofit issues may be sufficient.

Adaptability/Sustainability

The basic risk analysis procedure is adaptable to other public agency properties, with appropriate scaling of the time, effort, and analysis. For example, the amount of structural analysis and risk analysis modeling used can be scaled to fit the particular needs of the owner. Standard FEMA or other screening techniques could be used for smaller properties or where the structures involved are similar to FEMA standard types. The California Seismic Safety Commission has published a number of documents that describe the general risk analysis process, and these can be used to help develop an owner-specific program. The documents can be obtained from the Commission’s website at [www.seismic.ca.gov](http://www.seismic.ca.gov).