Performance-based seismic design: the future practice

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Objekttyp: **Article**

Zeitschrift: **IABSE reports = Rapports AIPC = IVBH Berichte**

Band (Jahr): **83 (1999)**

PDF erstellt am: **22.07.2024**

Persistenter Link: https://doi.org/10.5169/seals-62890

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Performance-Based Seismic Design – The Future Practice

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Abstract

Performance-based design has been a normal part of building design for many years, and owners frequently make performance-based decisions. Shall we select an expensive roofing system such as slate or copper which will perform well for many decades, or shall we select an inexpensive single ply membrane roof that will require repairs or replacement in 10 to 20 years? Building designers and owners commonly discuss such issues, and owners make selections based on their budget and the years of performance they desire before replacement.

Structural engineering routinely faces similar issues, although they may not be as clear. Since we know most of our structural loads and forces with reasonable certainty, most of our performance decisions center around material performance. We routinely design more durable concrete when it is exposed to weather and chemical attack, and take steps such as coated reinforcement or thicker concrete cover over reinforcement to reduce the possibility of corrosion or deterioration of concrete. The owner is seldom brought into a discussion of these structural issues and is often just informed of future maintenance needs.

But seismic-resistant design is different. Seismic forces in regions of high seismicity are the largest lateral loads we have to consider in design, and are comparable only to large explosive or bomb blasts very close to a building. Seismic-resistant design for most buildings is based on greatly reduced force levels, recognizing the ductility of structural systems to maintain their load-carrying capacity under severe inelastic deformations. This recognition of ductile performance, which is specified as prescriptive material detailing and proportioning provisions in modern building codes, allows us to design structures economically for high seismic ground motions. But the ductile or inelastic performance brings with it extreme damage to the structure. The ultimate goal of conventional building codes is life safety, or providing protection to occupants until they can safely and orderly exit the structure. These codes do not carefully consider the degree of damage that may occur, and if the structure can reasonably be repaired. Thus the performance objective beyond life safety is not clear: the building may be useable, needing only minor repairs, or it may be a total loss, necessitating demolition. More likely, the building's condition will be

somewhere between these extremes, requiring extensive repairs and having to be vacant for many months, causing disruption to the tenants and owner.

Earthquake damage states and performance levels are well defined in the Vision 2000 document published by the Structural Engineers Association of California. The damage states of Negligible, Light, Moderate, Severe, and Complete describe the level of damage experienced by a building during a specific seismic event. These damage states can be roughly compared to five performance levels: Fully Operational, Operational, Life Safe, Near Collapse, and Collapse. These damage states and performance levels are then related to site seismicity and probabilistic studies including recurrence rates for earthquakes of various sizes at the site. Graphics in the paper and Vision 2000 combine these factors with various occupancies in a logical manner.

The structural implications of PBSD can be quite significant. There are a variety of current building codes and standards that include material detailing requirements to achieve basic life-safety performance in an occasional or rare earthquake. This assumes the building is built on a suitable site without potential surface faults, liquefaction, or seismic induced landslides affecting the site. For higher performance objectives structural systems must be selected that have historically performed well in the most severe earthquakes. In general, more rigid structural systems tend to deflect less and experience less overall damage. Building configuration is exceedingly important, as regular buildings tend to outperform irregular or unusually shaped buildings. Seismic load paths need to be direct and well detailed. Structural detail must be carefully selected and detailed for proper performance, based on all our knowledge of inelastic response of structures. The design must be consistent and of high quality, and should be thoroughly peer reviewed by suitable knowledgeable engineers. Then the construction must be well executed, with thorough competent inspection to ensure that the completed building will perform as intended when the earthquakes occur. PBSD is also quite applicable to existing buildings and structures. It has also become routine in California to strengthen deficient existing buildings for improved seismic performance, generally for life safety and to prevent possible collapse or potential collapse. But usually, with some additional work or a different approach, an existing building can be strengthened to a higher performance objective. This is also becoming somewhat common where businesses assess their potential risk or loss of business or manufacturing capability and decide to strengthen some of their facilities to a higher performance objective.

The nonstructural implications of PBSD are perhaps more challenging and difficult to achieve than the structural issues. The nonstructural issues include not only preventing the collapse of ceilings and partitions and sliding or overturning of equipment and furniture, but also the operability of critical building systems such as electricity, water, sewage, and other utility services.

Since no consensus standards or guidelines exist for the higher performance levels of PBSD, a considerable effort will be needed to develop such guidance. Toward this end in the United States, the Earthquake Engineering Research Institute recently developed an Action Plan for the U.S. Federal Emergency Management Agency. The Action Plan outlines all the steps needed to achieve consensus guidelines for attaining PBSD. The program is outlined as a multiple-task effort, which will probably require ten years to complete. The program not only addresses the technical issues, but also the stakeholder and educational agendas, which will need to be addressed.