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Editorial Open Access

Performance Based Seismic Design

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Editorial

Performance based seismic design (PBSD) is a cogent design approach that allows engineers to design structures with a predictable seismic performance for a specified level of hazard. In contrast to the conventional limit state or strength and serviceability based design in which a structure is designed to withstand severe load combinations and be functional under normal load conditions, PBSD goes beyond just safety and serviceability and addresses different structural performance expectations under various hazard levels. An important component of PBSD is the selection of a design criterion stated in the form of one or more performance objectives. A performance objective specifies a desired seismic performance level for a structure. Based on the Applied Technology Council report (https://www.scribd.com/doc/37801847/ATC-40), typical performance levels can be defined as follows:

Operational: At this performance level, limited or no structural damage is expected for the main force resisting system. The structure should retain nearly all of its pre-earthquake strength and stiffness, and non-structural elements are generally in place and functional.

Immediate Occupancy: Structural elements are expected to perform just like those under the operational level, but non-structural components may not be functional.

Life Safety: Noticeable damage to the structure is expected, but without experiencing total or partial collapse. Injuries may occur, but the risk of life-threatening injury should be low. Repair may not be economically feasible. Considerable damage to non-structural components and systems may occur, but collapse that may result in serious bodily injuries is prevented.

Collapse Prevention: Extensive damage to the structure is expected, which may include significant stiffness and strength degradation of the lateral-force resisting system resulting in large permanent deformation, and limited deterioration of vertical-load-carrying capacity. Significant risk of injury exists. Repair may not be technically practical.

For these performance levels to become an integral part of the PBSD procedure, they need to be quantified. This can be achieved by (1) defining some engineering demand parameters (EDP) that can be computed using well-established structural analysis techniques. Examples of these engineering demand parameters are peak interstory drift, plastic rotation experienced by essential structural elements, cumulative strain energy, a combination of these EDP, etc., and (2) either specifying the limits for one or more of these EDP that fall within each performance level, or identifying the proper performance level through the use of damage indices. It should be noted that the type and limits of EDP and the value of damage indices are structural system specific, and extrapolation from one system to another should not be attempted without a thorough understanding of system behavior. Descriptive deformation states for collapse prevention, life safety, and immediate occupancy performance levels for several types of lateral-force resisting systems can be found in FEMA-750 (https://www.fema.gov/media-library-data/20130726-1730-25045-1580/femap_750.pdf) and efforts to advance PBSD are summarized in FEMA-445 (https://www.fema.gov/media-library-data/20130726-1600-20490-1237/fema445.pdf).

Another component of PBSD is to define the ground motion levels that are expected to occur at the site of interest. These hazard levels are often characterized in terms of the probability that a specific earthquake will be exceeded in 50 years or the estimated return period of an earthquake assuming earthquake occurrences can be modelled using a Poisson process. The most common hazard levels considered are:

Service Level Earthquake (SLE): This level of hazard represents ground motions that are expected to occur more frequently, with a 50% probability of being exceeded in 50 years, or an average return period of about 72 years.

Basic Safety Earthquake I (BSE-I): Also known as the design level event, earthquakes at this hazard level have a 10% probability of being exceeded in 50 years, or an average return period of approximately 474 years.

Basic Safety Earthquake II (BSE-II): This level represents the maximum considered earthquake (MCE) at the site, which may be necessary for use in the design of critical structures. Earthquakes at this hazard level have a 2% probability of being exceeded in 50 years, or an average return period of roughly 2475 years.

Hazard maps for BSE-I and BSE-II are available online at the U.S. Geological Survey (USGS) website (http://earthquake.usgs.gov/hazards/hazmaps/).

An alternative to these seismic hazard maps is the risk-targeted probabilistic based maximum considered earthquake maps (ASCE/SEI 7-10, ftp://ftp.consrv.ca.gov/pub/oil/SB4DEIR/docs/GEO_ASCE_2010.pdf), which take into consideration the probability of structural collapse. These risk-targeted maps correspond approximately to a 1% chance that the structure will experience collapse in 50 years. The advantages of using these maps are that the effects of soil conditions and risk levels can be accounted for relatively easily through the use of simple modifying factors.

Using these performance and hazard levels as guides, a design criterion that corresponds to a performance objective can be defined. If the design has more than one performance objective, it is called a multi-level performance design.

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The third component of PBSD is structural analysis. Several methods are available to estimate the seismic responses of existing buildings. FEMA-750 categorizes these analysis methods into four main groups as well as specifies specific limits for the use of each procedure, and FEMA P-1050-1 (https://www.fema.gov/media-library-data/1440422982611-3b5aa529affd883a41fbdc89c5ddb7d3/fema_p-1050-1.pdf) provides details of their implementation. Among these analysis methods, the linear static (e.g., equivalent lateral load analysis) and linear dynamic (e.g., elastic response spectrum or linear time-history analysis) methods are the easiest to perform, despite their limited applicability to just regular buildings where torsion and high-mode effects are negligible. In applying these methods, it is assumed that the estimated displacements using linear equivalent elastic stiffness is approximately equal to displacements that may occur under the design loads. The other methods, nonlinear static (e.g., nonlinear pushover) and nonlinear dynamic (e.g., nonlinear time-history) methods, are applicable for all structural types, except that the nonlinear static procedure cannot be applied to buildings where higher mode effects are significant.

The fourth component of PBSD is damage analysis and assessment. Damage analysis pertains to quantifying the degree of damage to a structure after an earthquake event. Damage analysis can be carried out subjectively by using FEMA damage assessment operations manual (http://www.fema.gov/media-library-data/1459972926996-a31eb90a2741e86699ef34ce2069663a/PDAManualFinal6.pdf); deterministically by employing damage indices, often expressed as a function of one or more engineering demand parameters (EDP); or probabilistically by utilizing fragility curves, which are plots of a structure's cumulative probability of exceeding various damage states for a given EDP against a ground motion parameter (e.g., peak ground acceleration or spectral acceleration).

The fifth component of PBSD is loss analysis. Losses can be associated with structural damage or non-structural damage such as casualties, direct/indirect economic costs, and downtime. A rather comprehensive treatment of loss estimates, including economic loss and social impact, can be found in https://www.fema.gov/hazus, which is FEMA's risk assessment and loss estimation tool as a result of a hazard event.

Although PBSD methodology is well-established for buildings, its implementation to bridges is still at a nascent stage, and research as outlined in NCHRP Synthesis 440 (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_440.pdf) is on-going. Nevertheless, the framework developed for PBSD is wide-ranging. With continued research and experimentation, it is expected that the application of PBSD concept to structures other than buildings and bridges will become a reality in the foreseeable future.