Performance-based Design using Optimization and Probabilistic Tools

G.I. Schuëller
Professor
University of Innsbruck
Innsbruck, Austria, EU
Mechanik@uibk.ac.at

G.I. Schuëller, born in Salzburg, Austria, EU, is Chair Professor at the University of Innsbruck, Austria, and Director of its Institute of Engineering Mechanics, a position he has held since 1981.

M.A. Valdebenito
Research Associate
University of Innsbruck
Innsbruck, Austria, EU

M.A. Valdebenito, born in Santiago, Chile, is a doctoral student at the University of Innsbruck, under the supervision of Prof. G.I. Schuëller.

Summary

This contribution investigates the application of tools for optimization and probability assessment within the context of performance-based design of structural systems under seismic risk. An application example illustrates the advantages of the proposed approach.

Keywords: Performance-based design; non linear static analysis; reliability analysis; simulation techniques; reliability-based optimization.

1. Introduction

The basic objective of Performance-based Design (PBD) is providing a rational approach for design with emphasis on the expected behaviour of a structure during its lifetime, i.e. taking into account the complete spectrum of loading that could act on a particular building as well as the expected performance under these loads, quantifying the possible economical losses that would arise from a loss of serviceability or structural damage of the facility, etc. A major difficulty for the rational quantification of the expected behaviour of a building is that loadings, structural properties and deterioration processes (among many other factors) are highly uncertain, thus making rational planning considerably more involved. Therefore, this contribution investigates the application of reliability-based optimization (RBO) for the optimal design of steel frames in view of seismic risk. In particular, the aim is minimizing the costs of construction and damage due to seismic events. To achieve this goal, a novel approach for RBO considering discrete design variables is presented. In order to quantify the structural response, non linear static analysis is applied. Moreover, damage and economical losses are accounted for by means of a simplified procedure introduced in [1].

2. Performance-based Design: Basic Concepts

PBD aims at replacing the current philosophies for design, evaluation and construction of civil engineering structures. The objective is introducing new approaches to conceive structures which exhibit a more predictable and reliable behaviour under common and extreme loading events (e.g., wind loading, earthquakes). The need of this new approach for projecting civil engineering facilities comes in particular from recent earthquakes which have occurred in the U.S. and Japan (Northridge, 1994 and Kobe, 1995), which caused heavy human and economic loses.

Recent works have suggested an approach for the application of PBD based on five basic steps. The first step is concerned with the basic definition of the facility, i.e. location, structural system, occupancy, design life time, etc. In the second step, a probabilistic characterization of the seismic hazard at the specific location of the facility is carried out; this implies, in turn, the construction of design spectra with an associated return period. Then, in the third step, the response of the facility is simulated using appropriate analysis methods, e.g. non linear static or non linear dynamic procedures. The output of the structural analysis phase is a series of engineering demand parameters (EDP). These parameters are then used to estimate damage by means of fragility curves. In the final step, information on damage is used to estimate losses, either in economic terms, deaths or downtime.

https://doi.org/10.2749/222137809796067498
Distributed by structurae

3. Reliability-based Optimization

Reliability-based optimization (RBO) offers the means for performing decision-making under risk, as it allows determining an optimum design solution (w.r.t. some predefined criterion) while explicitly accounting for the effects of uncertainties. Therefore, when designing a particular facility, it is possible to use the outcome of the PBD methodology, i.e. losses due to seismic hazard, within the RBO framework in order to determine the best design solution.

The solution of a RBO problem requires the repeated computation of the probability of occurrence of a damage state for several different values of the design variables; in turn, the computation of each probability can be demanding. In order to reduce numerical costs, a feasible approach is to construct an approximate representation of the reliability as an explicit function of the design variables. In this way, the reliability assessment and the optimization step are decoupled [2]. The approximate model of the reliability is constructed using a novel approach proposed by the authors.

4. Application Example

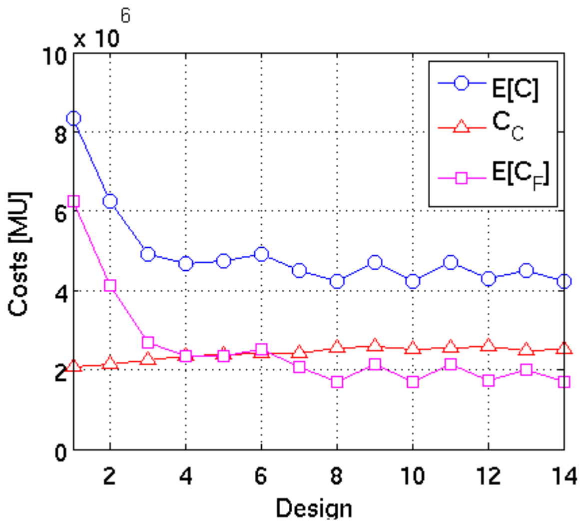

Figure 1: Evolution of total expected costs

In order to illustrate the capabilities of the approach proposed for RBO within the context of PBD, an example involving the optimal design of a 5-storey steel frame structure is considered. The objective is to minimize the costs associated with construction (C_C) and eventual damage due to seismic hazard ($E[C_F]$). The results of the application of the RBO procedure are shown in Fig. 1 (note that $E[C] = C_C + E[C_F]$). It can be seen that in the initial design, the expected damage costs are quite large if compared with the construction costs. However, as the optimization procedure produces successive candidate optimal designs, this situation is reversed. In fact, in the optimum design, the construction costs are superior to the expected failure costs. Finally, it is important to mention that this optimization problem was solved using parallel computing; thus, computation time was reduced considerably, i.e. from more than 12 days to just 15 hours.

5. Conclusions

This contribution has presented an approach for performing PBD within the framework of RBO. In particular, it was shown by means of an application example that it is possible to quantify the expected performance of a structure during its life time and determine an optimized design by means of advanced simulation algorithms for reliability assessment, efficient optimization strategies and parallel computing. The example also showed that for an optimal design of a structure, it is not sufficient to consider just the construction costs, as the costs associated with partial damage play a significant role.

6. Acknowledgements

This research was partially supported by the Austrian Research Council (FWF) under Project No. P20251-N13. This support is gratefully acknowledged by the authors.

7. References

[1] WEN Y.K., and KANG Y.J., “Minimum building life-cycle cost design criteria. I: Methodology”, *Journal of Structural Engineering*, Vol. 127, No. 3, 2001, pp. 330-337.

[2] SCHUËLLER G.I., and JENSEN H.A., “Computational methods in optimization considering uncertainties - An overview”, *Computer Methods in Applied Mechanics and Engineering*, Vol. 198, No. 1, 2008, pp. 2-13.