8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineeering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

Reliability-based optimization of RC structures

*** Michalis Fragiadakis[1] and Manolis Papadrakakis[1]**

[1] Institute of Structural Analysis & Seismic Research
National Technical University of Athens
Zografou Campus, Athens, GR-15780, Greece
mfrag@mail.ntua.gr, mpapadra@central.ntua.gr,

Key Words: *Structural Optimization, Reinforced Concrete, Evolution Strategies, Reliability-based optimization.*

ABSTRACT

The conventional trial-end-error seismic design process for reinforced concrete structures is replaced by a structural optimization algorithm resulting to a fully automated methodology based on nonlinear response history analysis. The optimum design is achieved in the framework of a reliability-based optimization problem. Compared to the usual practice of employing deterministic criteria, the reliability-based approach is a more rational procedure since more meaningful design criteria, that correlate better with the performance-based concept, can be adopted. In order to assess a candidate design, the use of deterministic criteria is compared to the practice of using the mean annual frequency of exceedance of a limit-state.

A discrete reliability-based optimization (RBO) is formulated as follows:

$$\begin{array}{lrl} & \min \mathcal{F}(\mathbf{s}) & \\ \text{subject to :} & g_i(\mathbf{s}) \geq 0 & i = 1, \ldots, \ell \\ & s_j \in R^d & j = 1, \ldots, m \\ & h_k\left(\nu_{EDP}(\mathbf{s}) \leq \nu_{EDP}^{lim}(\mathbf{s})\right) & k = 1, \ldots, n \end{array} \tag{1}$$

where $\mathcal{F}$ is the objective function to be minimized and g_i are the ℓ deterministic constraints. R^d is a given set of discrete values from which the design variables s_j take values and h_k are the n probabilistic constraints. More specifically, ν is the mean annual frequency of exceedance of the k^{th} performance level, while EDP denotes a chosen Engineering Demand Parameter. If the last set of probabilistic constraints of Eq. 1 is omitted, the resulting problem is a deterministic-based optimization problem (DBO) [1]. The objective function of the optimization problem is the total cost, considered as the sum of the total cost of concrete and the total cost of reinforcing steel. Unlike steel structures, for reinforced concrete buildings the formulation of the optimization problem is more complicated due to the presence of the reinforcement, where a large number of possible combinations of section dimensions and reinforcement amount exist.

The "analysis" phase of the methodology proposed consists of three steps. Initially the design problem is formulated as an equivalent "steel-structure" problem, where tables of RC beam and column sections are generated. The next step is to check the structure against load combinations that do not contain seismic actions, e.g. gravity loads, live loads, etc for the non-seismic load combinations. If all the constraints are satisfied, the capacity of the structure against seismic loads is subsequently assessed. In order to efficiently handle the large size of the section database, the concept of cascade optimization is adopted, where a single optimization problem is tackled within a number of autonomous stages.

The process of calculating the mean annual frequencies (MAFs) of exceedance of a limit-state uses data obtained through structural fragility analysis which are integrated with information available from the site hazard analysis. Therefore, the mean annual frequency (MAF) of exceeding a limit-state refers to the annual rate that an engineering demand parameter (EDP) exceeds a given demand level (*edp*) and is calculated using the total probability theorem:

$$\nu\left(EDP > edp\right) = \int_0^\infty \left[1 - P(EDP > edp \Big/ IM = im)\right] \left|\frac{d\nu(IM)}{dIM}\right| dIM \qquad (2)$$

In order to calculate $P(EDP > edp \Big/ IM = im)$ multi-stripe analysis is adopted [2]. In multi-stripe analysis each dynamic analysis is characterized by two scalars, an intensity measure (IM) and an engineering demand parameter (EDP). For moderate period structures an appropriate choice for the IM is the 5%-damped, first-mode spectral acceleration, $S_a(T_1, 5\%)$, while the maximum interstorey drift (θ_{max}) of the structure is the chosen EDP. The IM and the EDP are evaluated for a small number of limit-states (at least three) and then appropriate interpolation functions are fitted to obtain the median and the standard deviation for the whole range of limit-state states. For a deterministic optimization approach, the constraints are applied directly to the engineering demand parameter. However, for the probabilistic case, the limit-state constraints are applied on the annual rate of exceedance of the drift capacity. The threshold annual rate is expressed as the reciprocal of the return periods of the limit-state capacities: 72, 475 and 2475 years for the three performance objectives specified by the FEMA guidelines [3].

The proposed methodology is applied to a six-storey reinforced concrete frame. The frame is designed following both the deterministic (DBO) and the reliability (RBO) performance-based design approaches. Compared to the current design practice, both formulations lead to structures of improved seismic performance and reduced total cost. However, the implemented probabilistic formulation allows more elaborate design criteria to be taken into consideration, like the minimum return period of a limit-state state being exceeded and can, potentially, lead to further economy compared to deterministic approaches.

REFERENCES

[1] Fragiadakis, M., Lagaros, N.D. and Papadrakakis, M.“Performance based earthquake engineering using structural optimization tools”. *International Journal of Reliability and Safety*, Vol. **1-2**, 59–76, 2006.

[2] Jalayer, F. “Direct probabilistic seismic analysis: Implementing non-linear dynamic assessments”, *Department of Civil and Environmental Engineering*, Stanford University, CA, PhD thesis, 2003.

[3] FEMA-356 “Prestandard and commentary for the seismic rehabilitation of buildings”. *Federal Emergency Management Agency*,Washington DC, 2000.