Worst-case design of structures using stopping rules in k-adaptive random sampling approach

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Abstract

In the practical design process, uncertainty in the parameters should be appropriately taken into account. In particular, our interest focuses on design problems with dynamic analysis under uncertainties. For example, earthquakes are essentially uncertain phenomena. Lack of taking uncertainties of the seismic motions into consideration may cause severe damage in building structures. It is known that transient dynamic analysis is not suitable for conventional design optimization owing to the high computational cost, the difficulty of sensitivity analysis and non-smoothness of the response functions. Furthermore, the uncertainty of the inputs makes matters worse. It is highly desired to establish a design method for robust optimization which is applicable to problems with time-consuming dynamic analysis under uncertain parameters.

For such purpose, one of the authors presented a worst-case design of structures based on a random sampling approach, in which constraints are assigned on the worst values of the structural responses. In this case, the optimization problem turns out to be a two-level problem of optimization and anti-optimization. It was shown in the numerical examples that a good approximate optimal solution is found by the method with relatively small number of analyses when compared with Genetic Algorithm (GA) and Tabu Search (TS). Key concept of the method is estimation of the worst value by Random Search (RS) with order of the function values.

The RS is the simplest and most obvious search method; however, there are still several important issues to deal with. One of them is how we choose the stopping rule. An approach is to estimate the closeness of the current record value of the objective function to its worst value, where the maximum value among the observations is referred to as a record value. It has been also pointed out that RS is impractical or less efficient. Indeed, the theoretical average waiting time of a better record is infinite and by discarding other record values we lose an enormous amount of information. One of the reasons is the difficulty of predicting the exact extremes from only the small samples. We may not need such exact extremes and prefer to know approximately good solution quickly in many practical situations. A sophisticated approach is to estimate the confidence intervals for it by statistical procedures.

We present a clear definition of the approximation of the worst values based on the k th order statistics and proposed a framework of anti-optimization with new stopping rules of random sampling approach. We investigated the behavior of the stopping rules through a numerical example. The distribution-free tolerance interval is used as a stopping rule of random sampling approach for solving anti-optimization problems. It is not needed to know the distribution of the samples to apply the method. The numerical result indicates use of relatively small samples is enough to predict the large number of future samples even for two-level problem with the complicated dynamic analysis under uncertain parameters.