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Design and sensitivity analysis using the probability-safety-factor method. An application to retaining walls

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Abstract

This paper presents a new method for designing engineering works that makes the classical approach, based on safety factors, and the modern, probability-based, approach compatible, and includes a sensitivity analysis. The method consists of a sequence of classical designs, based on given safety factors, that (a) minimize cost or optimize an alternative objective function, (b) calculate the different failure mode probabilities or their upper bounds, and (c) update the safety factors to satisfy both the safety factors and the failure probability requirements. The process is repeated until convergence. As a result, an automatic design of the engineering work, the safety factors and the corresponding probabilities of failure for all failure modes are obtained. A double safety check is used and the correspondence between safety factors and probabilities of failure for the different modes are easily understood. An advantage of this approach is that the optimization procedure and the reliability calculations are decoupled. In addition, a sensitivity analysis is performed using a method that consists of transforming the data parameters into artificial variables and using the dual associated problem. The method is illustrated by its application to a retaining wall design.

Keywords: Level II and III; Optimization; Probability of failure; Reliability analysis; Safety factors; Sensitivity

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1. Introduction

There are two principal ways of dealing with the design of engineering works:

1. *The classical approach*. This is based on safety factors, which are used to guarantee the required safety of the structures to be designed. The engineer, when faced with the problem of designing an engineering work, identifies all possible failure modes and chooses the design variable values for the corresponding engineering work to make it reasonably safe with respect to these modes. The greater the damage associated with the failure mode, the greater the level of safety required for this mode (see EUROCODE [11], ROM [24]).
   A classical design fixes the values of the safety factors and chooses the values of the design variables to satisfy these safety conditions. All the variables involved are assumed to be deterministic.
2. *The probability-based approach*. This works with probabilities of failure. Normally, a global probability of failure is used as the basic design criterion. However, working with failure probabilities is difficult because (a) it requires the definition of the joint probability of all variables involved, and (b) the evaluation of the failure probability is not an easy task. The problem becomes even more difficult if several failure modes are analyzed, because the failure region is the union of the different failure mode regions, and regions defined as unions are difficult to deal with because of their irregular and non-differentiable boundaries (see Melchers [21]). As an alternative design criterion, the probabilities of failure for the different modes can be used. Nevertheless, one may easily obtain an upper bound for the global failure probability by summing all the failure mode probabilities.
   A probability-based design checks that the selected design leads to failure probabilities below given upper bounds. Some or all the variables involved are assumed to be random (see Rackwitz and Fiessler [22], Wirsching and Wu [30], Wu, Burnside and Cruse [31], and Ditlevsen and Madsen [10]).

Nowadays, both approaches are questioned: the classical approach because it does not give a clear idea of how far we are from failure, and the probability-based approach because it is very sensitive to the assumed joint distribution and tail assumptions (see Castillo [5], Castillo, Solares and Gómez [7], [8], [9], and Galambos [13]).

Defenders of the classical and probabilistic approaches have serious difficulties in working together because they speak different languages. In this paper, we defend the coexistence of safety factors and failure probabilities and present a method that solves this problem, limiting both safety factors and probabilities of failure for the proposed designs. The method consists of a sequence of optimal (in the sense of minimizing the cost or an alternative objective function) classical designs, based on sets of safety factors bounds, that are adequately modified in each iteration to satisfy both the safety factors and the failure mode probability bound requirements.

Several authors have previously used optimization techniques to deal with engineering design, as for example, Lorenz [18], Kim and Adeli [16], Adeli [1], Bhatti [2], Sarma and Adeli [27,28], and Ringertz [23], Royset, et al. [26], etc. However, in this paper we deal with a new methodology that simultaneously considers safety factors and probabilities of failure. In addition, a sensitivity analysis procedure is presented. A sensitivity analysis adds quality to a design and supplies very important information on the work being designed from the view point of cost and reliability.