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Optimization and risk acceptability based on the Life Quality Index

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Abstract

Optimization techniques are essential ingredients of reliability-oriented optimal designs of technical facilities. Suitable objective functions are presented for different replacement strategies for structural facilities. Within FORM/SORM structural reliability analysis can be reduced to an optimization task and some simple algebra. However, instead of a optimization of cost on top of a optimization for the reliability task, a one-level optimization is proposed by adding the Kuhn–Tucker conditions of the locally stationary reliability problem to general cost-benefit optimization. For locally non-stationary failure phenomena a bi-level optimization must be used. A rational basis to account for the cost of saving lives based on the recently proposed Life Quality Index is presented. Several examples illustrate the methodology. © 2002 Published by Elsevier Science Ltd.

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1. Introduction

Traditionally, target reliabilities in engineering have been set implicitly by calibration at past and present practice. It is tacitly assumed that past practice is already nearly optimal although the development of present rules has been widely by trial and error and most frequently in terms of safety factors, cautiously selected nominal or representative design values, as well as suitable quality assurance rules and not in terms of rational reliability measures. The profession agrees that this cannot give totally wrong numbers because those developments for appropriate targets had already a long history. Explicit probabilities or reliabilities of satisfying structural behavior have then been inferred backwards from deterministically looking codes of practice. Doing such calibration analyses surprisingly reveals that there is great variation between different structural members, materials and design practices in terms of probabilities. Most of these variations are extremely difficult to interpret. It is also recognized that for new, extraordinary buildings the

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argument of a long empirical history might not apply. Further it is obvious that some structural components may be grossly overdesigned while others are underdesigned. In summary, it is difficult to believe that past and present practice produce structures which are economically optimal and, simultaneously, "safe enough".

More modern approaches define a so-called ALARP-region (As Low As Reasonably Practicable) between a region which is considered acceptable and another region which is no more acceptable. Usually this is defined in a log-log plot of the occurrence probability of adverse events versus their consequences. Those regions are mostly determined from data on failures. It is noted that different industries tend to define different ALARP-regions reflecting their experiences and also their special demands. The empirical nature of this approach is also evident.

More recently, two important concepts found increased interest. The first concept requires explicitly that technical facilities should be economically optimal (see, for example, [22]). Designing, erecting, maintaining and replacing structural facilities is viewed as a decision problem where maximum expected benefit and least cost are sought and the reliability requirements are fulfilled simultaneously at the decision point. In what follows the basic formulations of the various aspects of the decision problem are outlined making use of some more recent results. A renewal model proposed as early as 1971 by Rosenblueth/Mendoza [28], further developed in [5,26] and extended in [22] is presented in some detail. The second concept introduces a special social indicator, which helps to quantify the necessary investments into structural safety, i.e. the investments to save human lives [16]. This social indicator is rather general. It is applicable for the investments by the public into health care, into road traffic safety, into fire protection systems and, of course, to structural safety. The public does such investments either by itself or via codes, programs or regulations. More specifically, the recently proposed Life Quality Index (LQI) [16] is discussed and applied to structural facilities in the context of expected value optimization. Since all quantities of interest are expressed in monetary terms and time is involved some remarks are made about appropriate discount rates. The theoretical developments are followed by some illustrative examples.

2. Optimal structures

A structural facility is optimal if the following objective is maximized (see Fig. 1):

$$Z(\mathbf{p}) = B(\mathbf{p}) - C(\mathbf{p}) - D(\mathbf{p}) \tag{1}$$

Without loss of generality it is assumed that all quantities in Eq. (1) can be measured in monetary units. $B(\mathbf{p})$ is the benefit derived from the existence of the facility, $C(\mathbf{p})$ is the cost of design and construction and $D(\mathbf{p})$ is the cost in case of failure. $\mathbf{p}$ is the vector of all safety relevant parameters. Statistical decision theory dictates that expected values are to be taken [17]. In the following it is assumed that $B(\mathbf{p})$, $C(\mathbf{p})$ and $D(\mathbf{p})$ are differentiable in each component of $\mathbf{p}$. It is reasonably assumed that $B = B(\mathbf{p})$ and that $C(\mathbf{p})$ increases whereas $D(\mathbf{p})$ decreases in each component of $\mathbf{p}$. This is illustrated in Fig. 1. The cost may differ for the different parties involved, e.g. the owner, the builder, the user and society. A structural facility makes sense only if $Z(\mathbf{p})$ is positive within certain parameter ranges for all parties involved. The intersection of these ranges defines reasonable structures (public or other subsidizing excluded).