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Socio-economically sustainable civil engineering infrastructures by optimization

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Abstract

Sustainability is an important requirement for civil engineering infrastructures, technically and financially. The financial aspects are discussed. It is proposed to select a design and maintenance strategy where structures are systematically renewed by reconstruction or repair. An appropriate objective function for cost-benefit analyses based on a renewal model is established. An intergenerationally acceptable discounting scheme is proposed. As infrastructures also involve risk to human life and limb a socio-economic acceptability criterion to be added as a constraint to cost-benefit analyses is derived. Various renewal models for deteriorating structures including multiple failure modes are discussed. The paper includes various examples illustrating the developed theory.

Keywords: Structural safety; Sustainability; Discounting; Renewal model

1. Introduction

The notion of life cycle engineering probably has emerged in the military field where, apart from first installation, inspection and maintenance and, finally, removal and replacement of a sys-

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tem formed the major cost. Later, it was also used in civil engineering when societies recognized that the infrastructure in a country or region had not only to be built but maintained and finally renewed because failures occurred not only due to extreme external events but primarily due to wear out, deterioration and, in some cases, obsolescence. The strategies adopted by engineers to manage the life cycle of a structure were widely technical, i.e. by improving reliability and durability and by proposing design solutions which should enable a longer time span of full use, possibly with other uses than initially foreseen. This is, no doubt, an important aspect of life cycle engineering. But not the only one and, most likely, not even the most important one.

In addition, there is growing awareness of the fact that our world is a limited world in the sense that it has only limited non-renewable natural resources, even limited renewable resources like water and limited arable land, for example. This lead the so-called Brundland Commission [9] to conclude in 1987 in their famous report "Our Common Future" that a sustainable development is a development "that meets the needs of the present without compromising the ability of future generations to meet their own needs". In the mean time one can say that this statement has widely become a new ethical standard. The immediate implications for the planning, design and operation of civil engineering infrastructures are clear: Save energy, save non-renewable resources and find out about re-cycling of building materials, do not pollute the air, water or soil with toxic substances, save or even regain arable land, do not interfere into the natural water household to an extent disproportionate to the adverse effects of such an interference, and much more.

For civil engineering infrastructures, but not only for those, there is a third aspect and that is the financial aspect. It is assumed that civil engineering infrastructures are financed by the public via taxes, public charges or other. It is in any case the citizen who pays and, of course, also enjoys the benefits derived from their existence. More precisely, intergenerational equity is the core of the new ethical standard the Brundland Commission has set; here we consider this standard with particular reference to the financial aspects of planning, designing, maintaining and replacing civil engineering infrastructure. Our generation must not leave the burden of maintenance or replacement of too short-lived structures to future generations, it must not use more of the financial resources than are really available. It can use only those which are available and affordable in a sustainable manner and discounting with its many myopic aspects must be done with utmost care. In this sense, civil engineering structures should be optimal not only from a technological point of view but also from a sustainability point of view.

The paper will first review a renewal model for setting up suitable objective functions for cost-benefit analysis. After presenting the basic model it is extended to different failure modes and obsolescence, to deteriorating facilities and to a simple case of inspection and maintenance. Then, some recent socio-economic considerations for public risk acceptability are summarized and some thoughts about sustainable and intergenerationally acceptable public interest rates are given. A sustainable, intergenerationally acceptable and affordable public risk acceptance criterion is derived. This is the basis for developing some optimization tools. Several examples illustrate the theory.

2. Cost-benefit optimal technical facilities

Already in 1971 Rosenblueth and Mendoza [50] proposed optimization with respect to benefits and cost as the final goal of setting up structural codes but also for direct design and operation of structures. A technical facility is financially optimal if the following objective is maximized: