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Reliability analysis of Reno mattress for canals

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Abstract

In the present work, we develop a probabilistic approach to analyze the failure functions related to the overall stability of a Reno mattress of an open canal. The considered state functions are those related to critical velocity, stability of the channel bottom, deformation effects, traction forces and residual velocity at the underside of the revetment. To take the uncertainties into account, the water flow rate is considered as random variable, generated by Poisson law. For the need of reliability analysis, Monte Carlo simulation method is used. Also, the Matlab© software is used for generating random draws. The developed method in this work is applied to a practical example which is taken from the engineering field.

Keywords: Probabilistic approach, reliability analysis, Monte Carlo simulation, failure functions, Reno mattress,

1. Introduction

The term canal is usually understood to mean an open artificial channel that permits the free flow of water. Canals are used for irrigation, drainage and water supply. The free surface flows in these channels are in contact with its walls which become a characteristic of the flow as well as its geometry. A revetment is often used for canals, such as flexible structures, they have the function of providing the natural soil with mechanical protection against erosion. Among the most widely used flexible structures around the world, and with great success for transport of water in open channels, we have Reno mattress revetments.

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Traditionally, their design is based on deterministic analysis. Safety factors recommended by the design codes are applied to take account of these uncertainties and ensure a sufficiently safe design. However, this approach does not make it possible to evaluate the risks associated with the failure of the flexible revetment structure and therefore its reliability. During the design of the Reno mattress revetment, civil engineers measure and calculate its stability based on a frequential flow rate, in order to optimize the cost of the structure. However, in practice, the evaluation of the frequencial flow is tainted by uncertainties. The change in the flow rate of the water alters the integrity of the structures and must be able to be predicted in order to avoid the accelerated wear of the system by fatigue of the material or even its destruction when the flows exceed a certain limit. It is then easy to understand the importance of establishing reliable models for predicting such behaviors.

Reliability theory based on probabilistic formulation can respond appropriately, however it raises theoretical, numerical and application difficulties since it requires, in particular, the modeling of uncertainties by laws and statistical parameters. The simplest and most general probabilistic theory is that of the Poisson process which applies to any accidental phenomenon (not predictable by deterministic laws) with extreme values such as: rainfall and project flood.

Nomenclature

$G_1 \ldots G_5$ Limit state functions
τ_b Shear stress asserted on the revetment of the canal bottom
τ_c Shear stress at the critical condition of the canal bottom
τ_m Shear stress in the revetment of the canal banks
τ_s Critical shear stress in the revetment of the canal banks
V Average velocity in the current cross section of the canal
V_C Critical velocity
Δz Height difference between the highest and lowest rock surface within a mattress compartment
t Thickness of the mattress
d_m Average size of the stone fill
V_e Velocity that the soil can withstand without being eroded
V_b Velocity at the interface of the Reno mattress and the base material

2. Probabilistic analysis of failure risk of an open channel

To quantify the failure risk of an open channel, by loss of the overall stability of a Reno mattress at the ultimate limit state, it is appropriate to define the different limit state functions $G(\{X\})$, which define their behaviour. These functions define the failure and the safety domains. A limit state function $G(\{X\})$ can be written as follows (Lemaire, 2005):

$$G(\{X\}) = R(\{X\}) - S(\{X\}) \tag{1}$$

Where, $G(\{X\})$ is the limit state function of the structure ($G>0$: safety domain, $G=0$: limit state function, $G<0$: failure domain), $\{X\}$is a random vector constituted by random variables xi, $R(\{X\})$ is the strength of the structure related to a considered failure mode, and $S(\{X\})$ is the active loading.

The collapse of the structure is related to the exceeding of the limit state $G(\{X\}) =0$, and reliability analysis consists to calculate the probability of failure defined by:

$$P_f = P(G\{X\}) \leq 0 \tag{2}$$

The probability of failure is defined by: