

Physics-informed stochastic Petri nets for the deterioration modeling and maintenance assessment of torrent protection structures

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Mountain territories are remarkably exposed to natural phenomena such as torrential floods, arising due to climate and geophysical environmental changes. Protection structures, such as check dams on torrents, are thus constructed in mountains in order to protect people, properties, and infrastructures exposed to these natural hazards. Such protection structures (in our case, check dams) deteriorate with time due to the harsh phenomena they are subjected to since their construction and their deterioration has negative consequences on the induced level of risk and therefore on the vulnerable asset located downstream. If not regularly maintained, the level of protection offered by these structures will be reduced. Because of limited budgetary resources available for their maintenance, it is essential thus to assess the time-dependent efficacy of check dams and to prioritize maintenance strategies.

In this work, we develop a methodology for maintenance decision-aiding for checks dams. One of the encountered difficulties is that few deterioration data are available on these structures, as they are not easily accessible and not instrumented nor automatically monitored. The proposed methodology integrates physics-based and dependability models for modelling the deterioration state evolution of protection structures and improving the maintenance decision-making process. The modeling approach proposed is based on

1. Defining a new degradation indicator that synthesizes both functional and structural deterioration mechanisms of the dam taking into consideration the dynamic interactions between failure modes;
2. A physics-based modeling that captures the time-dependent evolution of the defined degradation indicator using multi-scale physical and analytical hydraulic models to determine the external stability analysis of the structure. This physics-based maintenance modelling relies on deterministic equations for the involved hydraulic and mechanical phenomena and randomness can be introduced through random events (e.g. rainfalls, rockfalls, ...) that primarily drives the protection structure deterioration. This model is then used to simulate deterioration histories, which allows identifying the probabilistic laws of the transition times between the defined deterioration states of the protection structure depending on its behavior over time;
3. Providing a stochastic model for the temporal evolution of the deterioration, implemented using stochastic Petri nets comprising the different deterioration states identified for the structure and integrating the state transition laws built at the previous step. This stochastic Petri nets model can be used to assess the efficiency of preventive maintenance policies to be applied to the dam and to compare them depending on their cost and their efficiency on increasing the availability time of the dams in non-critical states.

The proposed approach is applied and illustrated on a check dam located within a series of check dams in the Manival torrent in Saint-Ismier, France.

References

N. Chahrour, M. Nasr, J.M. Tacnet, C. Béranger, Deterioration modeling and maintenance assessment using physics-informed stochastic Petri nets: Application to torrent protection structures, *Reliability Engineering and System Safety*, 210 (2021), 107524