

Preliminary insights on REST: Road and Environmental Safety Toolkit

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Highlights

- Forecasting potential for aquaplaning occurrence on porous roads.
- Coupling shallow water equations with infiltration in porous asphalts.
- Stormwater pollution transport and fate in porous asphalts.

Introduction

Water-pavement interaction is one of the most challenging road safety problems. In order to prevent aquaplaning and provide sufficient skid resistance, the layer of water on a pavement surface must be carefully managed in inclement weather conditions (e.g. during rainfalls). Efficiency of pavement surface drainage depends on road geometry (cross grades, longitudinal grades, superelevation concepts and pavement width), rainfall intensity and duration, pavement hydraulic properties (pavement texture – roughness, hydraulic conductivity, and effective porosity for porous pavements), drainage conditions in the upstream section etc. On the other hand, pollution from paved surface is moved with water in the process of “build-up and wash-off”, which depends on similar factors as pavement surface drainage additionally complex due to its dependence on traffic load, antecedent dry period, pavement state in terms of clogging (specially for porous pavements) etc.

Potential solution for efficient pavement surface drainage is the use of porous asphalts which are open graded (OG) asphalt mixtures with up to 25% of air voids. These materials are not perfect, as they are prone to clogging over a relatively short period of time and their service life is only 7- 10 years (Ferguson, 2005), however they may substantially improve the overall road safety. To forecast aquaplaning occurrence and with-it related road safety on real roads with incoming rainfall rates requires development of complex models that consider rainfall, (shallow) surface flow and infiltration together with road geometry. Such forecasts may be used on road section with Variable Message Signs to alert drivers and reduce traffic speed (to decrease possibility of traffic accidents). However, potential benefits of the use of porous asphalts go beyond traffic safety, and such material can be more attractive to road designers and decision makers, if the extent to which they can mitigate stormwater runoff pollutions is known and can be forecasted – a topic still under intensive research (e.g. Antunes, 2020).

This paper presents the main methodology of a new research project RESAFE aimed at coupling the effects of porous asphalts on both road and environmental (flooding, pollution transport and fate) safety in a unique Road and Environmental Safety Toolkit (REST). REST can be used at different scales: 1) “zoomed in” to design critical road section prone to aquaplaning and check its surface runoff pollution mitigation potential and 2) “zoomed out” for real-time forecasting of aquaplaning occurrence using AI surrogate model. The project is in its initial stage, which is why part of methodology still needs to be developed but is presented here to fully understand the process.

Methodology

REST

To understand and simulate pavement surface runoff water dynamics, two-dimensional effects should not be neglected. For porous pavement surfaces, infiltration into the pavement and flow within the porous structure must be adequately addressed and coupled with surface flow. However, to produce real time forecasts of water-pavement interactions, it is necessary to have a robust and fast i.e. surrogate model of

the road section. This is why REST is being developed to consist of two components (models) (Figure 1) and can be used at two different scales (for different purposes). The first one is a complex numerical model that will be able to address the full complexity of the pavement runoff flow dynamics and this component developed, calibrated, and validated with data from (1) a real road section and (2) small experimental catchment. The other component is an AI surrogate model, trained and verified with data generated with the complex numerical model.

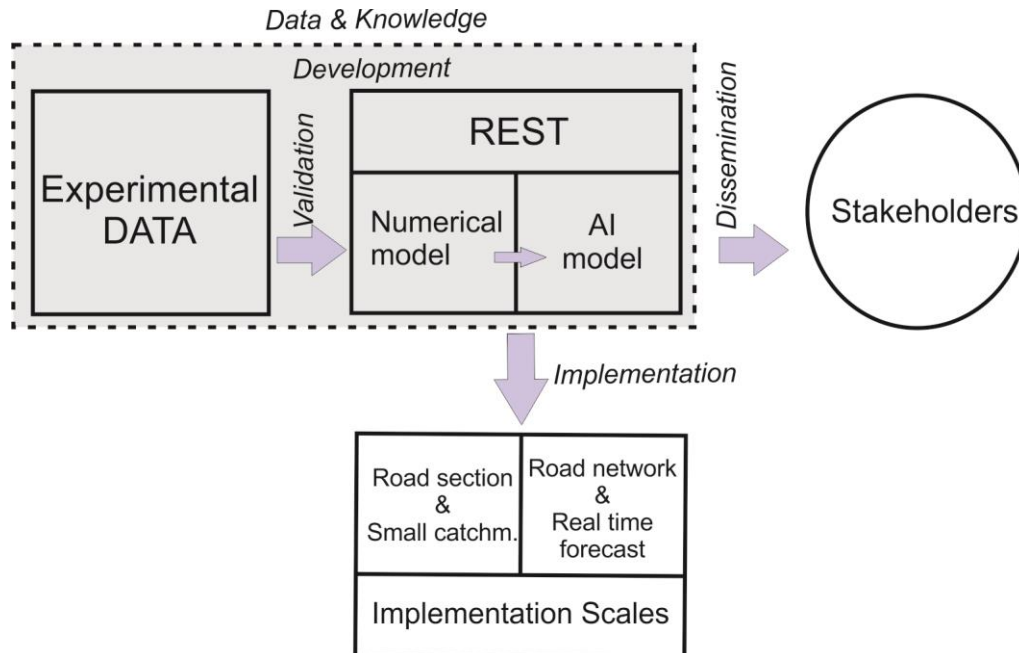


Figure 1. Basic concept of the RESToolkit

Numerical model

More recent studies use two-dimensional shallow water equations to simulate the surface runoff (e.g. Aranda, 2021), and these are rarely coupled with infiltration models to account for porous pavement hydrology. Even when coupled (e.g. Eck et al., 2012), these infiltration models assume saturated flow, which can be rather significant (Stanic et al., 2023 showed the order of magnitude of 10^{-2} m/s) and unreal i.e. with thin water film above the porous pavement it is unlikely that the porous material will be saturated. This is why the numerical model in REST is based on a two-dimensional surface flow and porous pavement unsaturated infiltration based on depth-averaged shallow flow equations and porous media filtration. The model is based on the finite volume approach with staggered arrangement of the flow variables, and it is capable to simulate the flow on irregular surface topography. The model enables predictions of water depths, depth-averaged flow velocities and related parameters relevant for contaminant build-up and wash-off, such as surface shear stresses. The model includes the clogging effects of porous pavement.

AI surrogate model – future developments

Since complex, finite volume numerical hydraulic model implemented in REST requires significant computational resources and has long run times, it is unsuitable for implementation on a road network scale. This is why REST will be upgraded with faster, surrogate AI model. The AI surrogate model will be trained, tested and verified on suitable synthetic datasets produced by using the complex, finite volume numerical model. Several machine learning algorithms (Artificial neural networks, Deep learning, Random Forest) (Silva et al., 2021) will be developed and compared to select the best one for the desired outcome, satisfactory precision and fast prediction. In order to select the most appropriate model architecture it is necessary to select proper hyperparameters. Process of searching for the ideal model architecture, referred to as “hyperparameter tuning”, will be carried out in this task. On the trained and validated model sensitivity analysis of input parameters significance will be conducted. Finally, selected model will be deployed and tested for real-time application on at least two road section of existing road network.

Experimental work

Validation of the numerical model in REST is based on data collected from the experimental urban catchment of Djukić et al. (2018). This experimental catchment is modified in two separate parts with two different porous asphalt mixtures and contains section of the old/standard asphalt.

Preceding the field experiments, a series of laboratory test will be conducted on developing and testing of porous asphalt mixtures PA8 and PA11 with polymer-modified bitumen, fibers and antistripping additives, including lime. The mixture design will include a series of performance tests to evaluate the resistance of a PA mixture to rutting, cracking, ravelling, moisture susceptibility, and drain down, while still maintaining an air void structure that provides adequate permeability; testing of component materials, mixture volumetric composition including the air voids percentage, Indirect Tensile Strength and resistance to water, resistance to permanent deformation. In addition, Cantabro test for determination of particle loss and permeability will be determined. Furthermore, laboratory investigations will include temporal changes of hydraulic properties, with results directly embedded into the numerical model of REST. Synthetic mixtures of stormwater spiked with road runoff pollutants will be used in investigations of selected asphalt mixtures, and the tests will include intensive controlled wetting and drying cycles and leaching tests, while increased water film surface retention will indicate decreased skid resistance.

Two porous asphalt mixtures with favourable physical-mechanical properties, as well as permeability, will be selected for field testing at the urban catchment site. Testing will include testing of pollutant build-up (wet vacuuming technique, sample characterization), testing of pollutant wash-off, testing hydraulic performance and properties of asphalt surface over time. Experiments will include simultaneous collection of meteorological data from the existing instruments located in the catchment. Testing results will enable establishment of pollutant build-up and wash-off relations under specific climatic conditions, as well as hydraulic performance of porous pavement in real-life conditions.

Main outcomes

Development of the new numerical model of REST will contribute in increasing the accuracy of water flow length calculations for various superelevation concepts, especially in “S” curves inflection zones, which are prone to aquaplaning occurrence. AI methods will be used for reliable aquaplaning occurrence assessment in the real road network. Inclusion of clogging effects of porous pavement and analysis of contaminant buildup and wash-off would provide more realistic and environmentally oriented results.

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