EXPERIMENTAL AND DATA-DRIVEN APPROACHES TO RAILWAY BALLAST DEGRADATION UNDER CLIMATE-INDUCED FLOODING SCENARIOS

ABSTRACT The resilience of railway infrastructure is increasingly challenged by the impacts of climate change, particularly flooding and extreme rainfall events that accelerate ballast degradation and compromise track stability. In Turkey, where railway transport has expanded rapidly with an 85.6% increase in passenger volume in 2022, the need for robust design and monitoring strategies is urgent. Similar vulnerabilities have been observed internationally, such as the Conwy Valley line in Wales where ballast was washed away during Storm Ciara. Addressing these issues requires civil engineering solutions grounded in controlled experimentation and data-driven modeling.

This study, a collaboration between the University of Huddersfield and Akdeniz University, focuses on developing an experimental framework to study ballast degradation mechanisms under climate-induced hydrological stressors. A scaled railway substructure will be constructed within an open-channel hydraulic facility, allowing precise control of flow rates, water levels and flood hydrographs. Adjustable parameters will be used to replicate a range of flood scenarios based on projected climate models. Sensor networks, including ultrasonic, displacement and soil moisture sensors, will provide continuous measurements of scour depth, ballast movement and hydraulic conditions.

The experimental data will form the basis for feature extraction with capable of identifying degradation thresholds and predicting failure patterns. This integrated approach bridges physical modeling and digital analytics, enabling a deeper understanding of ballast discharge mechanisms under extreme events. In the short term, the findings will inform civil engineers on optimal monitoring system design, sensor placement strategies and track maintenance under hydrological loading. In the long term, the outcomes contribute toward establishing digital twin models for railway infrastructure, facilitating predictive maintenance and resilience planning. By integrating hydraulic experimentation with computational modeling, this study advances engineering practice in designing climate-resilient, safe and cost-effective railway systems.