

INTEGRATING MACHINE LEARNING CLASSIFICATION WITH THERMAL INTEGRITY PROFILING FOR CONCRETE PILE ASSESSMENT

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ABSTRACT

Thermal Integrity Profiling (TIP) is a non-destructive monitoring technique used to assess the integrity of concrete piles and foundations by analysing hydration temperature data for defect detection. Currently, TIP is limited by manual interpretation, which can lead to inconsistencies and errors in distinguishing between defects and normal temperature variations. By integrating this new ML approach with TIP, defects can be more accurately classified for any concrete composition, improving the reliability of the assessment.

The thermal analysis model consists of a 2D plane strain concrete pile simulated using COMSOL Multiphysics. The heat of hydration was estimated using the model proposed by [1]. Curing temperatures are recorded every 0.025 days over 5 days from pouring, through 8 sensors (probes) placed radially 75mm away from the pile edge. A wide range of geometric and material parameters was considered for this study, including pile radius, defect size and location, thermal conductivities and volumetric heat capacities of concrete, soil and bentonite as well as the concrete hydration parameters. These were generated using a random Latin hypercube sampling algorithm. A randomly generated bentonite defect is included in half of the dataset samples, reflecting real-world situations where defect presence is unknown.

Hydration temperature data from 100,000 pile samples was used to train an ANN classifier for defect prediction. Features include pile radius, cement content, average and maximum temperatures per probe, times when maximum temperature occurs, and average thermal differences across the 8 probes. The label determines the presence or absence of a defect. Defect samples with an area smaller than 2% of that of the concrete pile were excluded, as they are undetectable and can be assumed to have negligible effect in real-world applications.

The ANN, implemented in Keras, uses a 70-15-15 dataset split for training, validation and testing. The network was comprised of four hidden layers of 2500, 1000, 250 and 100 layers. Common regularization techniques such as cross-validation, dropout, learning rate reduction or early stopping were applied to minimise the overfitting. Normal random noise, representing a $\pm 0.1^\circ\text{C}$ error due to instrument accuracy [2], was added to all temperature readings to enhance model robustness and generalisation. The model achieved an accuracy

of $R^2 = 0.963$. Most mislabelled samples correspond to false negatives associated with defects of very small area positioned close to the pile axis.

The presented model demonstrates high predictive accuracy for defect detection within concrete piles in the context of TIP. Implementing the ANN in real-world projects can enable the detection of construction defects in near real-time, benefiting the safety of concrete foundations and the overall efficiency of construction.

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