

**RAIN-INDUCED WETTING-DRYING AND ITS IMPLICATION ON
THE DURABILITY DESIGN OF CONCRETE**

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**RAIN-INDUCED WETTING-DRYING AND ITS IMPLICATION ON
THE DURABILITY DESIGN OF CONCRETE**

by

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Department of Civil Engineering

Submitted

in fulfillment of the requirements of the degree of

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CERTIFICATE

This is to certify that the thesis entitled “**Rain-induced Wetting-Drying and its implication on the Durability Design of Concrete**”, being submitted by **Mr. Kaustav Sarkar** to the Indian Institute of Technology Delhi, India, for the award of the degree of “**DOCTOR OF PHILOSOPHY**” in Civil Engineering, is a record of original bonafide research work carried out by him under my guidance and supervision. To the best of my knowledge, the thesis has reached the requisite standard. The material contained in this thesis has not been submitted, in part or full to any other University or Institute for the award of any degree or diploma.

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ABSTRACT

Concrete is the most widely used construction material of modern era. Thus, the necessity to engineer its application for the development of sustainable infrastructure cannot be overemphasized. An aspect of significance to this end is the ability of cast elements to resist the action of ambient environment and deliver durable performance over the desired period of service. The currently adopted approach to cater to the necessity relies heavily on the implementation of prescriptive measures which often lead to unsatisfactory results leading to the premature serviceability failure of structural elements. A solution to the problem lies in rationally analyzing the influence of factors which contribute towards the pertinent degradation phenomena and in constituting design guidelines to contain the concomitant impact within acceptable limits. Of special significance in this context is the analysis of moisture transport phenomena in concrete which plays a pivotal role in regulating the evolution of almost every degradation process. It is thus critical to account for those exposure conditions which affect the state of moisture within the porous matrix of concrete.

This work focuses on the study of wetting-drying phenomena manifesting in consequence to the occurrence of intermittent rains. The considered exposure condition is of particular relevance to tropical climatic zones where a substantial period of the year conjures conspicuous rains and the rest remains primarily dry. The condition invariably induces a state of unsaturation which is conducive for the initiation and propagation of reinforcement corrosion in concrete, known as the most prevalent cause of durability distress in concrete structures. In relation to the delineated problem, the work carried out in this study is along the following lines:

- Statistical characterization of the wetting-drying phenomena induced by intermittent rainfall in tropics

- Experimental estimation of hydraulic diffusivity of concrete for steady state drying and artificially created rainfall wetting
- Numerical assessment of moisture distribution profiles in concrete subjected to typical wetting-drying conditions
- Numerical evaluation of sensitivity of moisture penetration to the characteristics of rainfall manifestation.

To enable a comprehensive evaluation of the phenomena under diverse tropical conditions, the study has been undertaken to encompass the instances of five Indian meteorological stations, each representing a distinct climatic zone within the tropical expanse of the subcontinent. Stations considered for the study include, Jodhpur (Hot-Dry), Madras (Warm-Humid), Bangalore (Temperate), Kodaikanal (Cold) and New Delhi (Composite). The analysis has been carried out using fifteen years of relevant climatic data, obtained from the archives of the Indian Meteorological Department, to characterize the traits of annual wet and dry spells. The derived probability characteristics have been subsequently utilized to design typical rainfall scenarios for each of the identified stations.

A non-linear Finite Element analysis scheme has been developed using a modified diffusion equation implementing dimensionless terms to facilitate the simulation of moisture distribution in concrete corresponding to the designed scenarios. The obtained results have been evaluated to determine the durations during which saturation levels remain conducive to corrosion at different depths from exposed surface. The numerical model has also been implemented to study the sensitivity of moisture intrusion to variations in the magnitudes of rainfall intensity, duration and the level of initial saturation.

An experimental study has also been carried out using ordinary concrete of three water-to-cement ratios viz., 0.4, 0.5 and 0.6 to aid the estimation of hydraulic diffusivity for

wetting and drying conditions. The drying tests have been carried out for steady state conditions of 20°C and 40°C and a relative humidity of 60% in both the cases. The wetting tests, on the other hand, have been carried out using a specially designed artificial rainfall simulator. The gravimetric measurements made during the course of experiments have been utilized to fit moisture distribution profiles. Hydraulic diffusivity values corresponding to different levels of saturation have been subsequently determined through Boltzmann's analysis. The derived values have been used to fit hydraulic diffusivity as a function of moisture content – exponential for wetting and a S-shaped curve for the case of drying. The fitted models have been subsequently incorporated in the numerical model for the analysis of isothermal moisture transport phenomena. Independent observations for wetting and drying have been used to validate the constituted numerical scheme prior to its application for simulation exercise.

The thesis records an initial endeavor made towards the durability design of reinforced concrete elements under tropical climatic conditions. The work provides an insight into the phenomena of wetting-drying concomitant to intermittent rains; outlines a method to facilitate the design of wetting-drying scenarios; devices and implements an artificial rainfall simulator to facilitate the study of rain induced moisture ingress; constitutes models for hydraulic diffusivity using gravimetric observations and studies the evolution of moisture distribution for typical scenarios using a robust numerical model to assess the prevalence of moisture conditions conducive to corrosion.

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