Abstract of Dissertation

Chloride Transport Coupled with Moisture Migration in Non-Saturated Concrete Exposed to Marine Environment and Application to Cracked Concrete

(海洋模擬環境に暴露された不飽和コンクリートの塩化物イオンおよび水分連成解析とひび割れコンクリートへの適用)

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Concrete is a composite heterogeneous artificial stone made of mineral aggregates and water-base cementitious paste. It lacks or is deficient of some crucial strength properties such as compactness and homogeneity; toughness and ductility; and impermeability and hindrance to ingress of deleterious substances like chloride ions. Yet concrete is in abundance use for construction of normal and mega structures. Its durable service life is most sought after these days. The development of reasonable methods for predicting the chloride penetration into concrete is very important to determine the durable service life of reinforced concrete structures.

In this research, material and environmental modeling has been carried out simultaneously for non-saturated cracked and un-cracked concrete exposed to marine environment. Since the main concern is the non-saturated concrete, therefore, specific experimentation and modeling has also been done on moisture migration. Primarily semi submerged structures, which represent exposure to tidal, and splash zones are the main concern.

Detailed modeling of moisture transport in a typical marine environment, for alternate wetting and drying as well as single long wetting exposures is done in a laboratory controlled environment. Both humid and liquid wetting environment modeling is carried out by DuCOM- Concrete Durability Simulator Program developed at Concrete Laboratory, Department of Civil Engineering, The University of Tokyo. The vapor transport model is verified and liquid conductivity model is enhanced for sorption absorption of water by concrete. To model the continuous alternate wetting and drying marine environments, hydraulic pressure method is used. The hydraulic pressure method

is very effective to determine strong sorption flux, which is triggered after prolonged drying and for environments with short wetting and long drying.

This enhanced moisture migration model proposed and verified for sorption is then implemented to predict the chloride penetration profiles under cyclic wetting and drying environments. For this, various alternate wetting and drying hygral cycles were designed in the laboratory controlled environment comprising of 1hr wetting in 3days, 9hr wetting in 3days and 33hr wetting in 3days and completely submerged case for bench marking. The chloride prediction analysis has been carried out by modeling the sorption behavior and coupling it with the chloride transport model of DuCOM. This kind of analytical approach is highly advantageous for very short wetting exposures such as splash zone.

The experimental results verify the DuCOM chloride transport model coupled with enhanced moisture migration model (applied with hydraulic pressure at the surface element) under varying wetting and drying environments. The enhanced moisture migration model is then applied on blended cements. Analysis and experimentation has been carried out for fly ash and blast furnace slag with varying replacement of cement, for different alternate wetting and drying hygral cycles. The modification made in liquid conductivity model has been verified successfully for BFS and FA cements.

At the end the chloride transport in cracked concrete is modeled by introducing void elements in the cracked zone, and enhancing the chloride transport model for chloride diffusivity through voids. From 2D chloride penetration profiles along crack, it is clear that chloride transport is very rapid along and across the crack boundaries. To treat this phenomenon, the crack boundary can be modeled as exposed to the environment, but then self-healing effects cannot be modeled. In void element crack methodology the self-healing effect can be nicely imbibed in the analysis along with the effect of discrete and smeared cracks. For this modeling, the chloride diffusivity along the crack length is enhanced by considering the effect of chloride transport through voids with a constrictivity parameter independent of bound chlorides. The constrictivity parameter for void is made a function of crack width in such a way as to distinguish the hair line micro-cracks from that of large cracks, which can be seen by the naked eye.

In this research a systematic approach has been adopted in dealing with the complicacies which are involved in chloride migration processes in marine environment. To start with the moisture migration in wetting and drying environment is modeled both for wetting as well as humid environment. The enhanced moisture migration model is then applied with the chloride transport model to predict the chloride profile under alternate wetting and drying. Both the experiment and analysis show the strong coupling between moisture migration and chloride transport. The same approach is then extended for blended cements with fly ash and slag as admixtures. To make this research more useful for application to real structures, where concrete is not always sound, and crack free, modeling is carried out for un-sound concrete (cracked concrete) on parallel lines as for sound concrete by modeling relevant parameters.

In short, this study is an attempt with scientific approach to hit upon and evolve much wanted research on chloride transport coupled with moisture migration in marine environment in sound and cracked concrete. In this research work, every effort is made to present the chloride transport phenomenon, in the marine environment in its totality, and well integrated form, which can be useful for scientists and engineers dealing with durability problems in off-shore and on-shore concrete structures.