

論文の内容の要旨

Thesis Title:

Effect of Macro-cell Corrosion on Electrochemical Measurements and Total Corrosion Estimation of Steel in Concrete

(コンクリート中のマクロセル腐食が電気化学的測定および鉄筋腐食推測に及ぼす影響)

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Reinforcement corrosion occurred by chloride ion is one of the main severe deterioration problem in concrete field especially in marine concrete structures. Reinforcement is naturally protected by high alkaline environment available in concrete pore structure; however, the diffusion of chloride ions into concrete reduces the hydroxyl to chloride ion ratio so that the threshold level is exceeded by penetrated chloride ions. Corrosion is a process of metal dissolution at anodic region of the corrosion cell while the cathodic region is connected to the anode to complete the corrosion cell which is necessarily an electrochemical reaction. Depending on how physically separated the corrosion cell is, it is called the macro-cell or micro-cell corrosion. Anodic and cathodic regions are significantly separated to make a macro-cell and this particular separation is occurred mainly by the electrochemical potential imbalance along the steel in concrete. Potential imbalance is generated by many factors; the difference of chloride ions on the steel surface is one of most significant factors. Macro-cell corrosion is severe than the general uniform corrosion because of the small anodic area of the corrosion cell can results a rapid deterioration.

There are several methods to assess reinforcement corrosion or the probability of corrosion. Chloride ion content at steel bar level, moisture content, concrete resistances etc., are used to identify the possibility of corrosion however they are not enough to judge firmly the degree of the ongoing corrosion process. To take the decision about repairing or some other assessment related to corrosion, approximately accurate magnitude and location of active corrosion is necessary. To achieve above, widely used electrochemical

measurements; half-cell potential and the polarization resistance data can be obtained. Half-cell potential measurements itself does not provide the corrosion rate but the probability of corrosion. However, the polarization resistance measurements can directly be converted to the corrosion rate based on electrochemical theories.

Though it is explained that electrochemical measurements can be directly used to estimate the corrosion process, the output is highly dependent on the ongoing macro-cell corrosion along the steel bar. Once the macro-cell corrosion is activated, the cathodic reaction of the corrosion cell misleads the directly measured electrochemical measurements so that the reliability of the output is significantly low; this phenomenon is introduced as the cathodic polarization effect. The main objective of this research is to experimentally observe the cathodic polarization effect by direct electrochemical measurements when macro-cell corrosion along the steel bar is significantly active and to prove it by indirect measurements taking separate macro-cell and micro-cell corrosion in to account. Objective is further extended to the identification of net and gross macro-cell current conceptually as well as experimentally as the cathodic polarization effect can be explained then as author explained.

The polarization effect of cathodically active area (cathodic polarization effect) induced by anodic reaction is identified at both major electrochemical measurements; half-cell potential and the polarization resistance. Therefore, an active corrosion process is detected by external measurements even at the locations with zero amount of chloride ion in concrete. However, as expected, the concrete resistance is not affected by this polarizing effect because the concrete resistance does not directly represent the corrosion process. The total corrosion current converted by direct electrochemical measurements (polarization resistance) further clarifies and confirms the effect of cathodic polarization. To confirm the effect and to show its significance, total corrosion currents are evaluated by indirect method where it is the summation of macro-cell and micro-cell current. Macro-cell corrosion current flow from each and every steel element in the steel bar is calculated by models. Micro-cell corrosion currents are determined by the direct polarization measurements obtained for segmented steel bar when steel elements are at disconnected situation. The summation of the anodic currents of macro-cell corrosion calculated by

models and the currents of micro-cell corrosion produces the calculated total corrosion. Above calculated total corrosion currents are compared with the total corrosion currents obtained by direct electrochemical measurements to prove the effect of cathodic polarization and its significance on the total corrosion output.

Specially prepared segmented steel bar is used (only for experimental purpose) to measure the macro-cell current flow between elements. Macro-cell currents which are experimentally measured and calculated by models are compared to check the accuracy of each method. The tendency proves that models are compatible up to some extent. However, currents by segmented steel bar are significantly deviates compared to models.

To understand the macro-cell corrosion mechanism and to explain the effect of cathodic polarization, a detailed analysis of corrosion is necessary. For this aim, an effective use of the segmented steel bar is necessary. It is conceptually described that directly measured macro-cell corrosion currents represents the net corrosion current which is a combination of both anodic and cathodic corrosion currents. Hence the concept and the importance of gross corrosion currents are explained in detail. To identify gross corrosion current, the measurement of polarization curves are adopted. However, results proves that even a pure macro-cell cathodic current at cathodic element change its own anodic polarization curves which is totally out of the expectation. The result is enough to express about the complexity of the cathodic polarization phenomenon; also, result brings a new concept about the ability to separate macro-cell and micro-cell corrosion for experimental purpose which is different from real situation.

The clarification of the concept of net and gross macro-cell corrosion current is essential to solve the cathodic polarization phenomenon. To achieve the target, macro-cell corrosion current flow is modeled with respect to the distance between steel elements and the chloride content in concrete. To model, the cathodic to anodic area ratio and the relevant current flow are used and the model is carried out considering different ratios. This model is used to simplify complex macro-cell current flow along the steel bar; an example of solution is provided. Simplified macro-cell current flows are to be used for the evaluation of net and gross corrosion currents.

Discussions and conclusions throughout this study are made based on the segmented steel bar and electrochemical measurements. It is proved that the segmented steel bar does not perfectly reflect the real situation compared to model output of continuous bar assuming that electrochemical processes are equally produced. It is explained, in this study, technological facts about measurements, its accuracy and the process of the segmented steel bar and it is still to be used for the further clarification of the cathodic polarization effect which is considered as the driving factor for future succeeding research studies.