Structural Performance Evaluation on Reinforced Concrete Structures with Steel Corrosion Using Finite Element Analysis

Background

Some aged concrete structures in electric power facilities have concerns about deterioration. With a view to evaluating their performance rationally, it has been an important issue to make clear the relationship between deterioration and structural performance. In that case, the structural performance evaluation method based on finite element analysis is effective, so it is necessary to construct material degradation model due to reinforcing steel corrosion.

Objectives

The purpose of this study is to present modeling of material degradation due to reinforcing steel corrosion used in the finite element method and applicability for evaluating load carrying capacity on corroded RC box-culverts.

Principal Results

1. Proposal on modeling of material degradation due to reinforcing steel corrosion

For constructing the material model, reinforcement section area loss and initial tension strain due to reinforcement corrosion, the decrease in bond stress between reinforcement and concrete was employed based on a series of double-action tension tests that were artificially corroded by stay current corrosion.

2. Full-scale loading tests on RC box-culvert specimens with reinforcing steel corrosion

We conducted a series of full-scale cyclic loading tests on RC box-culvert specimens with steel corrosion. These results show that the local material deterioration has a minor effect on structural performance of RC box-culverts and this is characterized as a redundant structure.

3. Verification of this modeling applied to finite element analysis by numerical simulations

The previous loading tests using corroded RC box-culverts were numerically analyzed. As a result, the analyzed crack patterns and load-strain relationships were in close agreement with the experimental results. Then, we showed that this modeling could estimate the load carrying capacity corroded RC box-culverts.

4. Evaluation on influence of steel corrosion based on experimental and analytical findings

A parametric study was carried out for corroded RC box culverts with various sizes, reinforcement ratios and levels of steel corrosion, etc. Then, based on analytical results and various experimental investigations, we developed a practical method using a threshold value, which is determined by structural analyses of RC box-culverts in sound condition and is multiplied by the allowable degradation ratio.

A part of this study was conducted as a collaboration research with electric power companies in Japan. And the obtained results were applied to “Recommendations on evaluation of structural sound function for underground reinforced concrete structures in nuclear power plants”(in Japanese) published by JSCE in July 2008.

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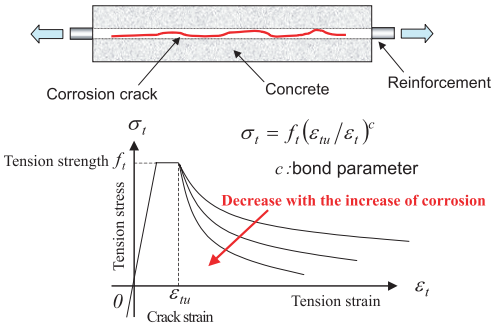
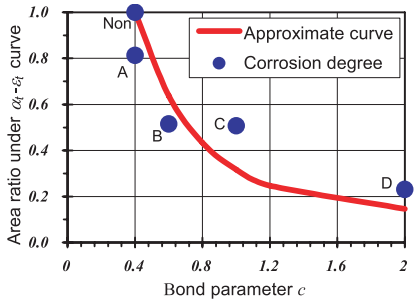
Reference

T. Matsuo, et al., 2008, “Structural Performance Evaluation on Aging Underground Reinforced Concrete Structures” (in Japanese), Modeling of Material Degradation due to Reinforcing Steel Corrosion, Part I, CRIEPI Report N08002, Evaluation on load carrying capacity for RC box-culvert with corroded reinforcing bars, Part III, CRIEPI Report N08023, An estimation method for threshold value in performance verification taking reinforcing steel corrosion into consideration, Part VI, CRIEPI Report N08083.



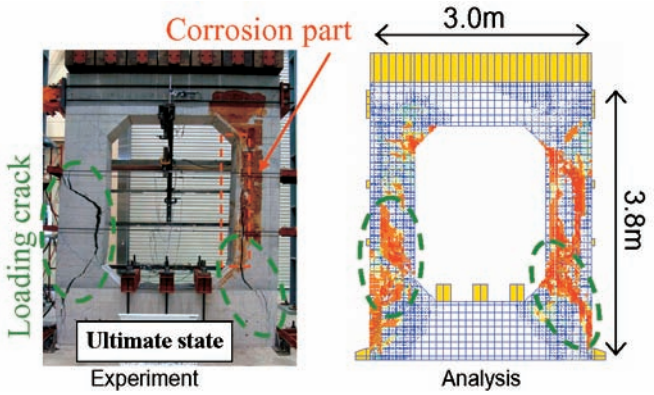
(a) Tension softening model for concrete



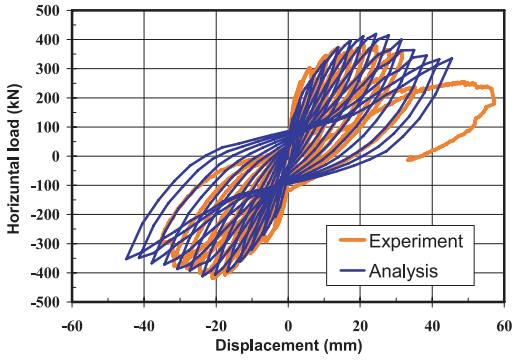
(b) Relationship between bond parameter and corrosion degree

Fig.1 Modeling of bond degradation between reinforcement and concrete

In this analysis, the effects of steel corrosion were taken into account by adjusting the bond parameter c as well as reduction in steel area. For the bond parameter c, 0.4 and 2.0 were adopted in the effective bond zones as recommended for deformed bars, and in the plain concrete portions to reflect the brittle behavior after cracking, respectively.



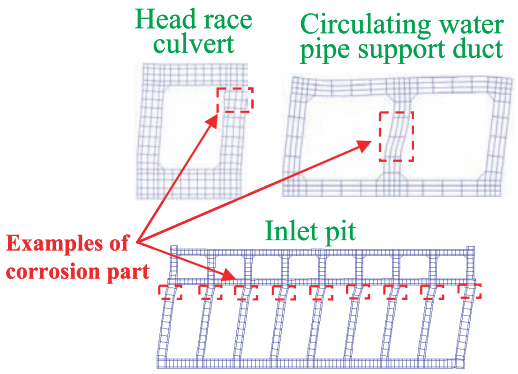
(a) Crack patterns



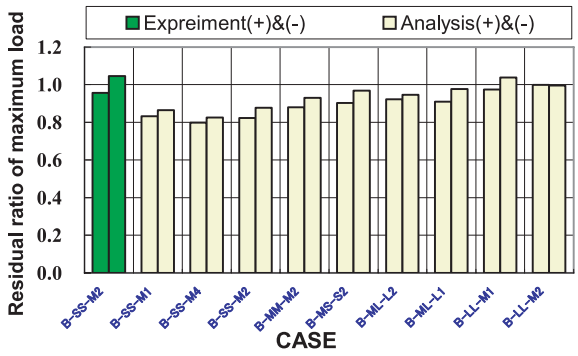
(b) Load-displacement relationship

Fig.2 An example of FEM simulations for experiments

In this experimental result, maximum strength of the box-culverts with steel corrosion shows slight decrease and the local material deterioration has minor effect on ultimate strength of RC box-culverts. It was because plastic hinges were developed if steel yielding or shear cracks occurred around the corner parts and the loads were redistributed from the damaged parts to the other parts. Furthermore loading tests were numerically analyzed. As a result, the analyzed crack patterns and load-strain relationships were in close agreement with the experimental results within the maximum corrosion ratio 15% of primary reinforcement.



(a) Corroded RC structures



(b) Experimental and analytical results

Fig.3 Some results of parametric study in consideration of reinforcement corrosion

A parametric study was carried out for corroded RC box culverts of various sizes, reinforcement ratios and levels of steel corrosion, etc. And, as an application of analytical results and various experimental investigations, we suggested allowable degradation ratios for a modification of the threshold value, which corresponds to the chloride induced deterioration progress that is widely accepted in maintenance practice for civil engineering reinforced concrete structures.