A NONLINEAR FINITE ELEMENT ANALYSIS OF CONCRETE RAILWAY SLEEPER DAMAGED BY ICE EXPANSION

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ABSTRACT

Cracks formed in concrete railway sleeper were investigated in this study. A three dimensional nonlinear finite element analysis was conducted to find out the reason for the damage of the sleepers based on the comparison with the field investigation and experimental result. It is found that the cracks were caused by the freezing force of water unexpectedly penetrated into the inserts of the fastener hole used in the sleeper. In addition, the effect of position of insert hole, initial fastening force, and compressive strength of concrete on freezing force was investigated. The freezing force in the inner insert hole is slightly greater than that of the others. The freezing force increases as the compressive strength of concrete increases and the initial fastening force decreases.

Keywords: Concrete railway sleeper, Slab track, Ice expansion, Fracture, Finite element analysis

1. INTRODUCTION

The slab track system for high speed railway system was adopted in Kyengbu railway in Korea. There are 153,394 concrete sleepers placed for the construction from 2007 to 2009. Some of them were found damaged. A conical crack was formed near a fastening bolt of a sleeper as shown in Figure 1. It initiated from the top of the insert was extended to the top of the sleeper. In this paper, a three dimensional finite element analysis was used to probe into the reason for this crack forming and compared with experimental results for verification.

Figure 1: Cracks developed in the railway sleeper

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2. DEVELOPMENT OF THE FINITE ELEMENT MODEL

A three dimensional nonlinear finite element model was implemented to a widely used commercial code, ABAQUS(Hibbitt, Karlson & Sorensen, 2005). Because of the symmetry in the longitudinal direction, half of sleeper was only modeled as shown in Figure 2. The crack growth was simulated by the crack band model(Bazant and Oh, 1985). The size of elements in the region where the crack would cut through was fixed as the characteristic length which is defined as cube root of element volume. The characteristic length was set to five millimeters in this study.

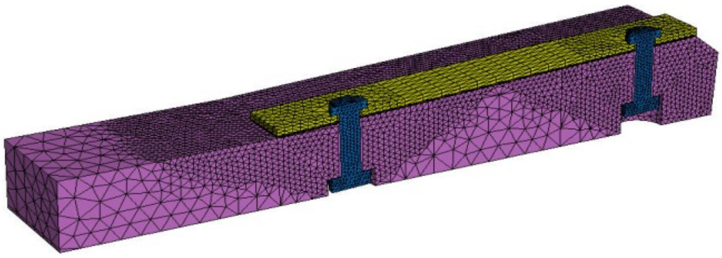

Figure 2: Finite element mesh using tetrahedral elements

Concrete was modeled with a softening plastic material that the strength decreases as the strain increases. We used the cohesive crack model with bilinear cohesive law which is based on CEB-FIP(Fib, 1999)

3. FAILURE ANALYSIS BY ICE EXPANSION

It is found that the crack was caused by unexpectedly ice expansion of freezing water leaking into the inserts of the fastener hole. A sleeper has been applied two types of loads: (1) ice expansion caused by water leaked inside the insert, and (2) fastening force applied to the bolts. The loading sequence in failure analysis was as follows. At first, the fastening force was applied to the bolt. And then, the expansion of ice was applied. The fastening force was carried by the strain decreases, and the ice expansion was modeled by upward displacement at the bottom surface of the nut. The contour of principal strain when the ice expansion was applied is shown in Figure 3.

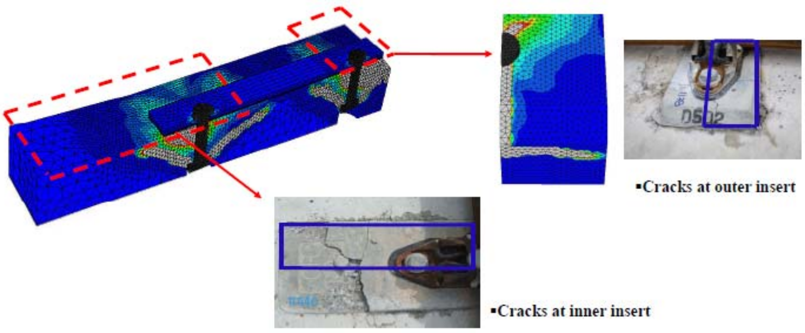

Figure 3: Distribution of the principal strain

The effect of position of insert hole, compressive strength of concrete, and initial fastening force on freezing force was investigated with several analysis.

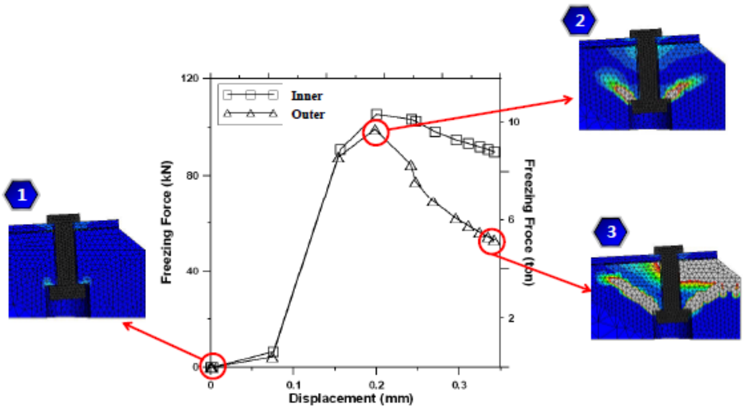

Figure 4: Evolution of the damage on different levels of softening

The development of the crack at different points of the force-displacement diagram is shown in Figure 4. As expected, the initial fastening force introduced a high stress gradient near the insert hole. At the peak, almost half of the height of the sleeper was damaged. Beyond the peak, the crack growth became spontaneous if a freezing force is applied by a pressure.

4. PARAMETRIC STUDY

In order to evaluate the effect of location of the frozen insert holes and concrete compressive strength, a parametric study using the finite element model was performed.

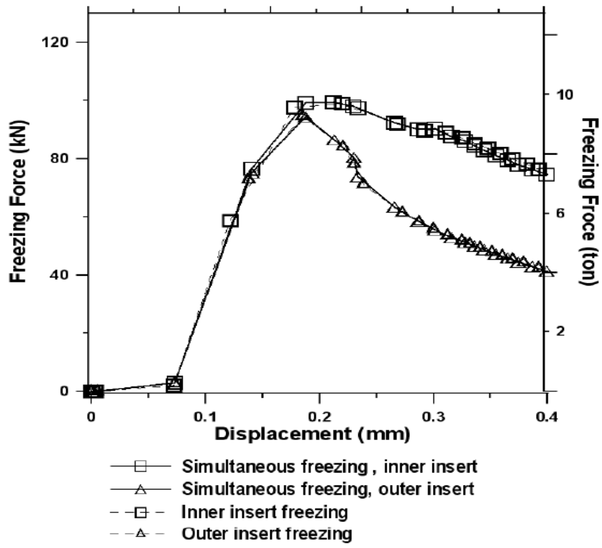

Figure 5: Behavior of the inner and outer insert holes

The freezing of the two inserts could take in place independently or simultaneously, which was considered as a variable. The freezing force-displacement diagram is shown in Figure 5 for different locations of frozen inserts. It was found that there is no difference in the behavior between the curves of simultaneous and independent freezing. The maximum freezing force of the inner insert hole was larger than that of the inner insert hole. It is because the inner insert hole is confined by surrounding concrete.

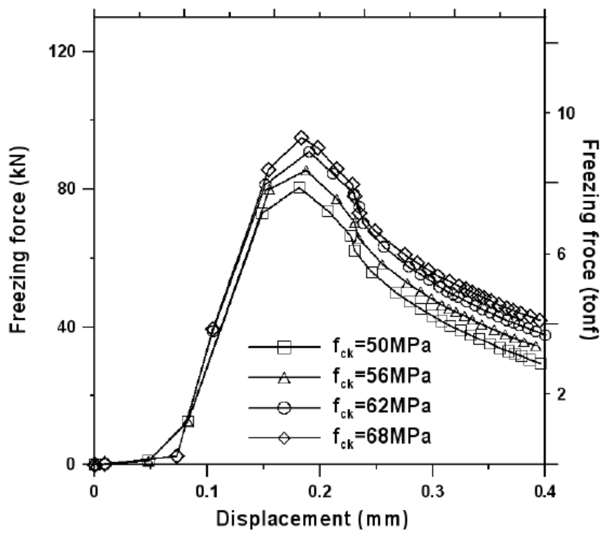

Figure 6: Influence of the concrete compressive strength

Figure 6 shows the influence of the concrete compressive strength to the resistance of the sleeper. The resisting force increases as the compressive strength increases as expected.

5. CONCLUSIONS

The conical crack which was formed near a fastening bolt of a sleeper is investigated in this study. It is found that the failure of sleeper was caused by unexpectedly ice expansion of freezing water leaking into the inserts of the fastener hole. A three dimensional finite element model is developed to analyze the behavior of failure, and the effect of parameters for the maximum freezing force.

6. ACKNOWLEDGMENTS

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