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Abrasion Depth Distribution of a Cylindrical Concrete Structure Due to Sea Ice Movement

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ABSTRACT

The estimation method for the abrasions of a cylindrical concrete structure due to sea ice movement proposed by Itoh et al. (1994) is extended to predict precisely the abrasion depth distribution near the waterline of the concrete structure. The extended distinct element method (EDEM) by Meguro and Hakuno (1989) is applied to evaluate the ice contact pressure distribution on the waterline assuming that the failure modes of the ice sheet are crushing with radial cracking. With a proper adjustment of the material parameters, realistic failure patterns and contact pressure histories can be obtained. We examine the adequacy of our extended estimation method through the field investigation of abrasion on a concrete Swedish lighthouse. It is demonstrated that the abrasion depth distribution of the cylindrical concrete structure would be mainly determined by the ice contact pressure, the ice temperature, the relative velocity between ice and concrete, and the excursion of the broken pieces of the ice sheet near the waterline.

INTRODUCTION

In rivers, lakes and oceans where periodic ice floes occur, concrete structures such as bridge piers, sea walls, wharves, docks, lighthouses and oil production platforms have a belt of deterioration and loss of concrete at the waterline. Huovinen (1990) found that the lighthouses in the Gulf of Bothnia had abrasions of 15 mm to 50 mm at the water level over 22 to 24 years. Past research works and field observations suggest that the concrete deterioration at or near the waterline is due to a combination of cyclic freezing and thawing process plus mechanical loadings from the moving ice sheet (Hoff, 1989). With the recent development of high-strength concrete, the concrete material durable against freezing and thawing has already been developed (Janson, 1987); thus, it is important and useful for the design of concrete offshore structures in arctic regions to accurately predict the ice-sliding concrete abrasion depth distribution around concrete structures.

Many different abrasion test methods to investigate the ice-abrasion resistance of concrete structures have been proposed by Nawwar and Malhotra (1988), Hoff (1989) and Huovinen (1990). Based on our seven years of systematic, laboratory, sea-ice abrasion tests and field observations (Itoh et al., 1988, 1994) we made a scenario of the ice-sliding concrete abrasion and proposed the estimation method for the actual amount of abrasion on offshore concrete structures. As shown in a previous paper (Itoh et al., 1994), the abrasion rate due to sea-ice movement is expressed by an empirical formula as a function of both ice-contact pressure and ice temperature. Hence, the total amount of concrete abrasion is obtained by multiplying the abrasion rate by total excursion of ice floes. The previous method (Itoh et al., 1994) can estimate the spatially averaged abrasion depth but can not estimate the abrasion depth distribution on the waterline of a cylindrical concrete structure, because neither ice-contact pressure distribution nor ice-sliding excursion distribution can be precisely estimated on the circumferential waterline.

The discrete element approach based on the particle representation of mechanical systems was initiated by Cundall (1971), who called it the distinct element method (DEM). An extension of Cundall's method to the study of an aggregate composite structure such as concrete with a large cracking zone was introduced by Zubelewicz and Bazant (1987). Meguro and Hakuno (1989) also improved Cundall's method to an extended distinct element method, which can be used for a complex or heterogeneous material, and they applied it to the problem of fracture of concrete structures.

Jirasek and Bazant (1993) proposed the dynamic particle model for fracture of quasi-brittle material to simulate the impact of a large ice floe in a rigid obstacle. The interaction between two neighboring particles is described by a piecewise linear stress-strain law, in which a tensile post-peak softening branch is related to microfracture energy of the material. They compared their numerical results of contact force with the observed contact force recorded on August 4, 1981 at Hans Island. Since the simulation is limited to the initial stage of failure, only a qualitative agreement of the measured force history can be observed.

In this paper, we apply the extended distinct element method (EDEM) to simulate the dynamic fracture behavior of sea-ice floes crushing into the vertical cylindrical concrete structure. It is demonstrated that the EDEM can follow not only crack formation around the structure at an initial loading stage but also the total fracture process even after the medium becomes discontinuous. The ice-contact pressure distribution and the excursion distribution of crushing ice floes around the structure can be calculated for the Sydostbrotten Lighthouse located in the middle of Bothnia Bay. Combining our empirical formula of the ice-sliding concrete abrasion amount with those calculation results, we estimate the abrasion depth distribution on the waterline, which is compared

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KEY WORDS: Extended distinct element method, fracture analysis, abrasion of concrete structures, contact pressure distribution, excursion distribution of crushing ice.