Characteristics of Sea Ice floes Run-up caused by Tsunami Considering Ice Jams and Ice Pile-ups around Structures

Shinji Kioka
Civil Engineering Research Institute for Cold Region, Sapporo, Japan

Takahiro Takeuchi
Hachinohe Institute of Technology, Hachinohe, Japan

Yasunori Watanabe
Hokkaido Univ., Sapporo, Japan

ABSTRACT

We performed model experiments on the inundation flow of tsunamis with ice floes. After the collision force imparted by the ice floes acts on structures, the tsunami flow is dammed by the formation of ice jams between the structures, and a large static force also acts on the structures because of the water level rise in front of the structures and because of hydrostatic pressure between the structures due to the ice-jam, and this steady state remains for some time. We developed a simple theoretical model for estimating the water depth and the tsunami force, and we verified the validity of the model.

KEY WORDS: Tsunami, Pile-up, Ice jam, dam-break wave, Collision, inundation flow

INTRODUCTION

Tsunamis that carry sea ice can harm life and property more severely than conventional tsunamis can. Sea ice carried to land by tsunamis has been reported to cause serious damage to private houses and bridges from the impact of the ice floes (e.g., in the 1952 Tokachi-Oki Earthquake). The run-up of sea ice to the shore and of river ice along rivers and some minor damage to land structures caused by ice collisions were also confirmed during the 2011 Great Tohoku Tsunami on the coast of the Kuril Islands (Kaistrenko et al., 2012). Also, in Japan, the run-up of sea ice to the shore, the collision of river ice against a sluice gate and the water level rise due to the formation of ice jams have been also confirmed (Kioka et al., 2013, Yoshikawa et al., 2012). Therefore, there is an urgent need to take considerations and measures regarding inundating tsunami flows accompanied by ice floes in urban areas. We have performed model experiments on the tsunami run-up (inundation flow) with ice floes considering ice jams and ice pile-ups around structures, we have examined the tsunami force acting on those structures and the run-up water depth in front and behind those structures with and without ice floes (Kioka et al., 2013), and we have examined the collision force acting on a structure and the fracture mechanisms of an ice floe by medium-scale tests and numerical calculations (Kioka et al., 2010, 2012).

In this study, while we performed model experiments under various conditions, we introduced just one parameter, that of “open ratio ($\xi = \Sigma B/(2\Sigma W + \Sigma B)$, and see Fig.5-6)”, instead of structure width ($W$) and pitch ($B$), and we developed a simple theoretical model that uses the open ratio for estimating the water depth and the tsunami force in steady state for the case of some prism-shaped structures arranged in a row on land.

MODEL EXPERIMENT ON TSUNAMI RUN-UP WITH ICE FLOES

Focus Points Addressed in this Experiment

Various additional risks in comparison with conventional tsunamis can be assumed due to the existence of sea ice floes such as collision by ice floes to buildings/structures, just like tsunami debris, and the formation of ice jams and ice pile-ups. Ice jams could dam the inundation flow between onshore structures to increase the water level and to cause greater force to act on the structures. In the past, the ice jams that formed between the legs of jacket type oil platforms caused the platforms to collapse from the increase in drag force (Wang, 1983). At the time of 2011 Great Tohoku Tsunami, many ice fragments piled up to jam a river channel and the water level upstream of the jam increased over several days) (Yoshikawa et al., 2012). Also, an ice pile-up can exert great static force on structures just as earth pressure does. This study aims to focus on the additional risks from such ice-jams and ice pile-ups at the time of tsunami run-up (inundation flow).

Experimental Methods and Conditions

As shown in Fig.1., a tsunami was generated by the sudden -opening of a water gate as in a dam-break, under the condition where sea ice floes drifted ashore, and then ran up to level land after propagating on an uniform slope (scale: 1:100). The water channel (19 m long by 0.8 m wide) was steel with glass-sides and it was rectangular in cross-section. A uniform slope of 1/20 started from 2.2 m downstream of the water gate to connect to level land. Several prism-shaped structures were arranged in a row on land at 0.8 m from the starting point of the level land (a position hereinafter referred to as “the changing point of the slope”). Table 1 shows the main experimental conditions. While the