A laboratory investigation of river shore-line ice jam forces
by Douglas Malcolm Stewart

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
Montana State University

Abstract:
This thesis presents the experimental results of a laboratory project to construct a measurement system in a refrigerated, hydraulic flume to measure the normal and tangential forces transmitted to a river shoreline due to a floating, fragmented ice cover. Two materials were used to model the floating, fragmented ice cover; real ice and a commercially available polyethylene with the same specific gravity as ice. Two block sizes of each material were used. The experimental results of the thrust exerted by the model ice covers on a floating retention structure, called a boom, are also presented.

The results of the studies of the boom thrust show that the boom thrust attains a maximum value when the length to width ratio of the ice cover reaches a certain value. This relationship is of the form (Formula not captured by OCR) The normal and shear force exerted by the ice cover on the shoreline was shown to generally have maximum values at the downstream edge of the cover and decrease in the upstream direction. The normal force was in the range of two times the shear force at all conditions tested. The normal and shear forces exerted on the shoreline, at any one point, were normally less than the thrust exerted on the boom.

The two model materials, ice and plastic, showed slightly different results. The real ice data always had much more experimental . scatter. The forces developed by the plastic blocks were generally larger than for the ice blocks under the same testing conditions. It is theorized that this is due to differences in surface tension effects of the two materials. Friction coefficients were found for the jams consisting of the two model materials against the river shoreline. The friction coefficient for the jams consisting of plastic blocks was an order of magnitude higher than for jams consisting of real ice blocks.

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Signature Douglas M. Stewart

Date May 27, 1980

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ABSTRACT

This thesis presents the experimental results of a laboratory project to construct a measurement system in a refrigerated, hydraulic flume to measure the normal and tangential forces transmitted to a river shoreline due to a floating, fragmented ice cover. Two materials were used to model the floating, fragmented ice cover; real ice and a commercially available polyethylene with the same specific gravity as ice. Two block sizes of each material were used. The experimental results of the thrust exerted by the model ice covers on a floating retention structure, called a boom, are also presented.

The results of the studies of the boom thrust show that the boom thrust attains a maximum value when the length to width ratio of the ice cover reaches a certain value. This relationship is of the form

$$F_B = C\ (1 - C_o e^{-\frac{L}{B}}).$$

The normal and shear force exerted by the ice cover on the shoreline was shown to generally have maximum values at the downstream edge of the cover and decrease in the upstream direction. The normal force was in the range of two times the shear force at all conditions tested. The normal and shear forces exerted on the shoreline, at any one point, were normally less than the thrust exerted on the boom.

The two model materials, ice and plastic, showed slightly different results. The real ice data always had much more experimental scatter. The forces developed by the plastic blocks were generally larger than for the ice blocks under the same testing conditions. It is theorized that this is due to differences in surface tension effects of the two materials. Friction coefficients were found for the jams consisting of the two model materials against the river shoreline. The friction coefficient for the jams consisting of plastic blocks was an order of magnitude higher than for jams consisting of real ice blocks.

Chapter 1

INTRODUCTION

In northern climates, ice jams in rivers have been historical events. However, it has only been in recent years that the study of the mechanics and hydraulics of river ice jams has been undertaken. Although various theories on the mechanics of river ice jams have been proposed and analogies with theories from other fields have been drawn, very few field or laboratory investigations have been undertaken in this area and quantitative data is very scarce.

Hydraulic engineering projects on rivers are playing an ever-increasing role in our expanding technological society. Ice jams are an extremely important feature of river engineering in cold regions. It is well to recall when defining the geographical limits of cold regions such events as the ice jam in 1899 in the Mississippi River at New Orleans! (Gerard, 1980) Design engineers for hydraulic structures seriously lack the data with which to evaluate the effect of forces exerted by river ice jams. Quantitative measurements of forces exerted by river ice jams are almost non-existent, due mainly to the difficulty of obtaining such measurements in the field. Recent literature has shown a beginning in the area of measurement of river ice jam forces through attempts at instrumenting bridge piers and piles in northern rivers which experience ice jams. However, much additional work needs to be done in order to provide information needed for cost effective design and operation of civil works projects.

Ice jams and ice accumulations may take many forms but there are fundamentally three basic modes of the accumulation process. In relatively low velocity flow the first mode of accumulation occurs. Under this condition the ice jam progresses upstream by mere juxta-positioning of ice floes. As the velocity in the reach of the jam formation is increased the ice jam thickens. The second mode of accumulation occurs in a "hydraulicly narrow" river section, defined as the hydraulic reach in which the ice cover thickens by floe entrapment under the jam from underturning of the ice floes at the leading edge of the cover. This thickening will continue until the head loss created by the deposition of the entrapped floes raises the upstream water level to the point at which the velocity becomes low enough to allow a new upstream progression of the ice cover.

A "hydraulicly wide" river section, in which the third type of accumulation will occur, is defined as the hydraulic reach in which the jam thickens when the thrust on the cover exceeds the internal strength of the ice cover. A folding or collapsing of the jam occurs which thickens the jam until the internal strength can resist the external forces applied, namely the shear force of the flow applied to the jam on the undersurface of the cover and the gravity component of the weight of the ice in the streamwise direction. When a new equilibrium is restored the upstream progression of the cover will continue.

Each of the modes of the accumulation process are dynamic.

A given river reach may during the course of the formation of a jam act as either hydraulicly wide, hydraulicly narrow, or juxtapositioning of the ice floes may occur, depending upon the changing hydraulic conditions and the integrity of the ice floes.

Objectives

When a fragmented ice cover comes to rest within a given river reach the hydrodynamic forces exerted on the cover are either absorbed internally in a crushing failure of the cover or are transmitted to the shoreline throughout the length of the cover. The river shoreline will see this force in three components, a force normal to the bank face, a force tangential to the bank face, or a force which is in the vertical plane of the bank face. The objectives of this thesis are to present the results of a laboratory project to construct a measurement system in a refrigerated, hydraulic flume to measure the normal and tangential forces transmitted to a river shoreline due to a floating, fragmented ice cover and to present the results of a limited number of experiments conducted with this measurement system using two materials to model the floating, fragmented ice cover: real ice and a commercially available polyethylene with the same specific gravity as ice.

Chapter 2

LITERATURE REVIEW

The objective of this section of the thesis is to present a brief overview of the theoretical and experimental studies that have been conducted on the forces exerted on river ice jams. All of the river ice jam theories presented include a postulation of the stress distribution within the fragmented cover. A brief description of the assumptions involved in each is presented. A summarization of the laboratory and field investigations of the forces exerted by a floating, fragmented cover on a floating retention structure, normally called a boom, is also presented. To the knowledge of this author, this study is the first attempt at the measurement of the forces exerted by an ice jam on a river shoreline.

Many of the accepted theories of the distribution of stresses in a fragmented ice accumulation have stemmed from analogies with gravity flow of granular media through two dimensional hoppers and bins and from the theories of pressure distribution in granular soils. A floating, fragmented ice cover is assumed to act as a granular material with respect to the interaction of the particles in the mass, in all the present theories.

Pariset and Hausser (1961) have formulated a theory for the formation of ice covers and ice jams in rivers based on Janssen's (1895) theory for grain pressure in a silo. Michel (1970) has followed Caquot's (1956) theory from the field of soil mechanics which assumes that the total thrust on the granular mass is transmitted to the edges by an arching action of the material.

Sodhi and Weeks (1979) have developed a one-dimensional theory governing ice pressure in a straight channel for a stationary fragmented ice cover based on Cowin's (1977) derivation of static loads in bins.

Uzuner and Kennedy (1976) have developed a theoretical model of a river ice jam in a straight, rectangular channel using an eulerian control volume approach and assuming that the stress within the ice cover is distributed to the banks according to the coulomb friction law.

Tatinclaux (1977) has presented a theoretical model similar to that of Uzuner and Kennedy and correlated this with a large number of flume experiments conducted with plastic and ice blocks. Tatinclaux's model concentrates on the equilibrium thickness of the jam accumulation and avoids the hydraulicly wide river case.

Several experimental investigations have been conducted on the thrust developed on a boom by a floating, fragmented accumulation. Latyshenkov (1946) conducted a study in a small natural channel, 1.6 m wide, with a single layer cover of ice floes. Refer to Figure 1. The thrust exerted on the boom by the ice cover was shown to attain a maximum when the cover length was 2.5 to 3.0 times the channel width. Figure 1 plots the boom thrust normalized by the maximum

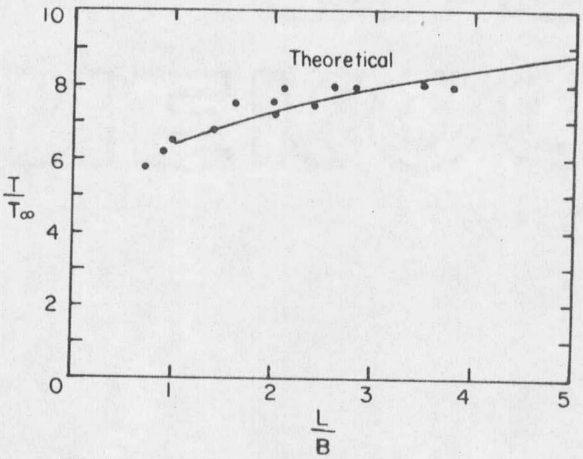

FIGURE 1. Results of tests with ice floes. Latyshenkov (1948)

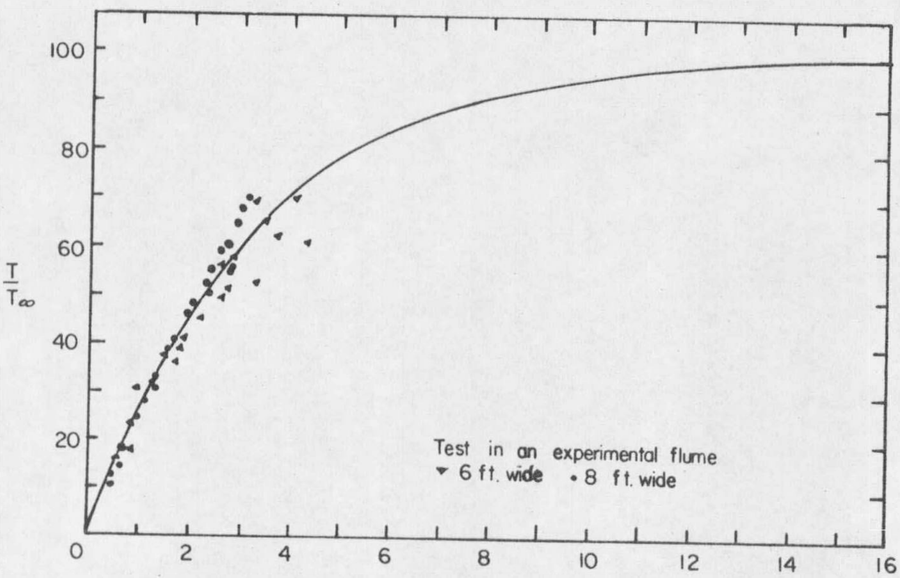

Figure 2. Forces on a boom caused by a model log jam. Kennedy (1956)

thrust seen on the boom against the length to width ratio ($\frac{L}{B}$).

Figure 2 shows the results of flume tests conducted by Kennedy (1956) with model wooden logs. Kennedy's data is plotted in the same form as Latyshenkov's data. The experimental data was limited due to model length at the length to width ratio ($\frac{L}{B}$) equal to 4.0. The correlation between model results using wooden logs and ice jam behavior may be of questionable value, due to differences in the material interaction and differences in material shapes.

Delagrave (1966) conducted tests in a 2 meter wide flume with polyethylene pieces used to model ice floes. Refer to Figure 3. Thick covers were modeled in these tests, simulating river ice jam conditons. The jam thickness to flow depth ratio (h/Y) ranged from 0.2 to 0.3. The boom thrust is plotted against $\frac{L}{B}$ showing the leveling off of the boom thrust as the ice jam is increased.

This study will extend the experimental work conducted on forces exerted by river ice jams. This is the first attempt to investigate the forces exerted on a river shoreline by an ice jam. Further experiments measuring the thrust on a boom from a river ice jam covering a wider range of conditions will be presented. Two model materials will be used to model the ice jams and resulting forces. It has not been shown in the literature that polyethylene can be successfully substitued for real ice in force model. Comparative data for the two materials will be presented. Data will be presented for the evaluation of