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ICE FORCES ON THE YUKON RIVER BRIDGE-1978 BREAKUP

February 1979

Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Structures & Applied Mechanics Division
Washington, D.C. 20590

FOREWORD

This report presents information on FHWA sponsored research on ice forces on highway bridges. The report covers studies relating to the 1978 ice breakup at the Yukon River Bridge, north of Fairbanks, Alaska. The report is being distributed by memorandum to researchers in this field.

Research on ice forces on highway bridges is included in the Federal Highway Administration Federally Coordinated Program of Highway Research and Development Project 5K "New Bridge Design Concepts." Mr. Craig A. Ballinger is the project manager.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16. Abstract

Personnel from CRREL, the University of Alaska and the Alaska Department of Transportation are jointly conducting studies of ice forces on the Yukon River at the haul road bridge site northwest of Fairbanks, Alaska. As part of the 1978 program the authors visited two instrumented sites in central Alberta operated by the Research Council of Alberta, Canada. Both sites use hinged beams to measure ice loads on piers and both have been in operation since the late 1960's. The sites are described in detail. Unfortunately, the ice at both sites melted in place in 1978 and no load data were obtained.

The ice in the Yukon River at the haul road bridge site began flowing on 11 May 1978. Three "Zarling" cells had been installed on pier 5 in anticipation of the breakup and accelerometers had also been installed on the same pier. The normal surge of water in the river did not materialize and the ice deteriorated in place. When the ice could no longer withstand the drag forces of the river, it broke and passed through the bridge. However, low water levels and other factors made it impossible to get ice load or accelerometer data. An augmented and better-distributed instrument package will be installed for the 1979 breakup.

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PREFACE

This report was prepared by Terry T. McFadden and Philip R. Johnson, Research Engineers with the Alaskan Projects Office, U.S. Army Cold Regions Research and Engineering Laboratory, Ft. Wainwright, Alaska. The report consists primarily of a description of the two load-measurement systems used by the Research Council of Alberta at two instrumented sites in Central Alberta and the research program carried out by CRREL, University of Alaska and Alaska Department of Transportation personnel at the Yukon River bridge northwest of Fairbanks, Alaska. 1978 operations at both the Alberta and Alaska sites are described.

Investigators from the Alaskan Projects Office, CRREL, the University of Alaska and the Alaska Department of Transportation began studying the breakup pattern of the Yukon River at the bridge and methods of measuring ice forces exerted on the bridge during the winter of 1975-76. The breakups during 1976 and 1977 were observed and recorded photographically and development work was carried out on equipment to sense and measure ice loads. The Federal Highway Administration developed an interest in the measurement and prediction of ice forces on highway bridges using the Yukon River bridge as a test site and advanced funding to CRREL which partially supported the two studies included in this report. This funding was supplemented by In-House Laboratory Independent Research (ILIR) funding from CRREL, by additional funding provided by the Alaskan Projects Office, CRREL, and by voluntary unpaid labor provided by personnel from all three agencies. Additional funding has been provided by the Federal Highway Administration to conduct a 3-year study on the measurement and prediction of ice forces on highway bridges so that expanded studies will be carried out in the future.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

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The studies at the Yukon River bridge have been carried out jointly by the following:

John L. Burdick, University of Alaska
Philip R. Johnson, CRREL
Dr. Terry T. McFadden, CRREL
Dr. Thomas F. Osterkamp, University of Alaska
Dr. John P. Zarling, CRREL

In addition, during the 1978 breakup studies, David Esch and Richard Jurick of the Alaska Department of Transportation participated in planning and the development of instrumentation. Many CRREL personnel, including J. Buska, D. Dinwoodie, L. Cartwright, F. Fisk, R. Taylor, K. Crane, C. Powell and others contributed in the construction calibration and installation of load-measurement devices, in establishing and operating a camp at the bridge site and in observing and recording the breakup.

The hospitality of members of the Research Council of Alberta, particularly William Lipsett, during the visit to Alberta in April 1978 is gratefully acknowledged.

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INTRODUCTION

General

Ice forces generally control the design of bridge piers and other structures in rivers in the Northern States, Canada and most of Alaska. Such forces may be very high, particularly during breakup when ice sheets and floes are carried downstream at high velocities and water levels. Rafting and jams may occur to increase ice forces. However, despite their importance, the forces exerted on river structures by ice are imperfectly known.

Surface transportation is currently being extended into subarctic and arctic regions. A pipeline haul road was built from the Yukon River in Alaska north to the Arctic Coast in 1974-75 while the Dempster Highway from Dawson City to Inuvik in the Mackenzie Delta area was completed in 1978. While the Dempster Highway uses ferries and ice roads to cross the major streams, the Alaskan haul road bridges the Yukon River northwest of Fairbanks.

Despite the importance of ice forces in bridge design, there is some evidence that bridges have been over-designed in the past. Evidence includes the fact that few bridges, even older ones not built to modern specifications, have suffered ice damage. The Canadians, using data obtained in part from the ice forces studies carried out by the Research Council of Alberta (RCA), have modified their code (which had previously been similar to the AASHTO code used in the U.S.) to allow for reduced ice loads in most cases. The 1974 Canadian code, with some minor changes, was adopted as an interim specification by AASHTO in 1978 so that it is now also in effect in the United States including Alaska.

Actual field measurements of ice forces on river structures, such as bridge piers, are relatively rare. The most extensive series of measurements are those of the Research Council of Alberta which has used hinged beams to measure total ice loads at two sites in Alberta. These data are generally considered to be of the highest quality of any series available. The Alberta program is reviewed in this report together with a description of the installations as observed during a visit to the sites by the authors in 1978.

The Yukon River bridge site promises to provide an extremely good site for field measurements of ice pressures and loads. The Yukon River is a major river in an extremely cold subarctic location. Ice growth in the very extensive Yukon Flats area above the bridge provides large quantities of ice which must pass through the bridge each spring. In four out of the five springs, a surge of snow meltwater has broken the ice loose in the river above the bridge bringing ice downstream that is both relatively thick and not excessively deteriorated. During the 1978 breakup a low snow pack in the headwaters failed to provide the surge of water required to break the ice loose and carry it downstream; consequently, it remained in place until it was sufficiently deteriorated that it was unable to resist the drag forces of the water flowing below it.

The Yukon River site is accessible by road from Fairbanks. Communications are good both by road and by telephone using a communications system installed to service the Trans-Alaskan Pipeline. While not available in the past, it is probable that an airstrip five miles from the site will be available in the future. It is expected that this will prove to be an outstanding site for studying ice-bridge pier interaction and ice forces on bridge piers.

Research Objectives

The research program, of which the work described in this report is an initial part, has several interrelated objectives. The first is to develop equipment and techniques for measuring ice forces on existing river structures, particularly bridge piers. The second objective is to obtain measurements of ice forces on the Yukon River bridge. The third is to use this information to predict ice loads on other river structures.

The 1978 Program

The 1978 program included a visit to inspect the Alberta installations with the visit expected to coincide with breakup in the Pembina and Athabasca Rivers so that these installations and their performance during the breakup could be observed. Unfortunately, neither river experienced a breakup and the ice melted in place. However, the two sites and their instrumentation were examined and discussions regarding the instrumentation were held with RCA engineers and others.

Based on the experience of two previous springs, three load cells were fabricated, calibrated and installed on pier 5 of the Yukon River bridge. Accelerometers were obtained and installed on the same pier. Instrumentation was obtained and placed to record both load cell data and accelerometer data. However, as mentioned above, the snow pack in the upper Yukon was low, the expected surge of water down the river did not materialize and the ice mostly melted in place. Since water levels did not reach the load cells that were installed, no load cell data were obtained. In addition, slushy ice accumulated upstream from the bridge between the instrumented pier and the north bank of the river so that the pier was shielded from any ice being carried downstream by the river. As a result, no accelerometer data were acquired.

THE RESEARCH COUNCIL OF ALBERTA ICE FORCES PROGRAM

Background

The Province of Alberta includes the western part of the Canadian Great Plains, and the southern half of the Province extends westward to the divide of the Rocky Mountains. Numerous rivers rise in the Rocky Mountains and flow eastward or northeastward across the prairie. In the southern portion of the Province, the Saskatchewan system flows eastward to the Winnipeg Basin and on to Hudson Bay. In the central and northern portions of the Province, the Athabasca and Peace River systems flow easterly and then northerly to ultimately reach the Arctic Ocean as the Mackenzie River. The prairies of Alberta are called upon to carry both the waters rising in the Rocky Mountains and those which rise on the prairies themselves. As a result, Alberta has numerous prairie rivers ranging from small to large. These rivers have required bridges that have been subjected to the normal hazards of flooding and, during the spring breakup, to ice. Some bridges have been lost to the ice and the Province established a program to study ice forces on bridge piers. This study is carried out by the Research Council of Alberta.

Two bridges in Central Alberta are instrumented with hinged beams, the Hondo site on the Athabasca River and the Pembridge site on the Pembina River. The two locations are shown in Figure 1.

The Hondo Site and Program

The Athabasca River and the Hondo bridge are shown in Figure 2. At this site the Athabasca River, which rises in Jasper National Park, west of Edmonton, is approximately 850 ft (250 m) wide and confined by banks around 30 ft (10 m) high. Of the three piers shown in the figure, the instrumented pier is the second from the right. The pier is shown in more detail in Figure 3 and the details of the hinged beam, built

into the pier, are shown in Figure 4. The pier is 7.5 ft (2.29 m) wide and the battered nose is inclined 23° from the vertical. The strain gauge system at the top of the beam is accessible through the access shaft shown in Figure 4. The top of the pier can be reached from either bank of the river using a catwalk in the steel supporting structure underneath the bridge deck.

Data from the load cell strain gauges are acquired using a single-channel FM magnetic tape recording system. Simulataneous photographic coverage is obtained from above, from the side and from a position looking upriver using super-8 movie cameras. The site is lighted for night photography. The photography is used primarily to determine the height of impact of the ice on the pier [thus the 3 ft (0.9 m) stripes painted on the load cell]. Water levels are also obtained from a recording gauge installed in the float well. Other analysis which can also be carried out from the photography after the breakup includes scaling of the ice thickness from ice blocks whose sides are visible to a camera.

Load cell data have been obtained from the Hondo installation since 1967, except apparently for 1968. During the 1967 and 1969 studies, an improvised load cell was used, but in 1970, it was replaced by a high-quality commercial load cell which has worked very well. It is necessary each spring to free the hinged beam from the ice between it and the pier to ensure that the ice does not interfere with the beam. The data for some of the more recent years had not been analyzed as of July 1978.

The Pembridge Site and Program

The Pembina River and the Pembridge site are shown in Figure 5. The hinged beam is a vertical steel cylinder filled with concrete and placed upstream of the central pier system. The beam is shown in Figure 6 and the mechanical arrangement is shown in Figure 7. Again, a strain-gauge load cell is used at the top of the beam; this can be seen in Figure 8.

The Pembridge installation is operated much like the Hondo one. An FM tape recorder is used to record strain gauge data. The site is lighted for night operations and super-8 cameras are used to photograph the ice-pier interactions. Water and ice levels can be determined from photography of the vertical beam, and in addition, a water level recording gauge is located at the bridge. The Pembina River is much smaller than the Athabasca River at the Hondo site, being about 250 ft (75 m) wide. The Pembina River flows into the Athabasca River some distance above the Hondo site.

The Pembridge installation was first put into operation for the 1969 breakup and has operated since, except for the 1970 season. Originally the 3-ft-diameter vertical steel pipe lacked the concrete. However, ice damaged the pipe and it was filled with light-weight concrete to stiffen and strengthen it. This beam is much less stiff than the one at the Hondo site. There is some suspicion that the data obtained from the site may include the structural response of the long slender hinged beam as well as the imposed ice loads.

CRREL researchers visited the Pembridge site in 1972 with a device to measure the in situ resistance of the ice to the penetration of a small circular pile driven horizontally through the ice using a hydraulic ram. This work is reported by Haynes et al. (1975).

Like the Athabasca River at the Hondo site, the Pembina River at Pembridge did not experience an ice run during the 1978 breakup. Instead, the ice melted in place. No data were obtained at either RCA site.

The Hondo and Pembridge installations are very good examples of the use of hinged beams to measure ice loads. Since each has been in operation about a decade, the bugs have been worked out of the

mechanisms and the operational techniques. The authors agree with others that these installations have obtained the best ice-forces data in North America and perhaps the world.

Results of the Alberta Studies

The Research Council of Alberta, the University of Alberta and various investigators have published numerous papers based, in large part, on the results of the Alberta studies. A partial list of these papers is found at the end of the report. The most significant is Neill (1976) which is the current state-of-the-art paper on the subject of dynamic ice forces on riverine structures. The Alberta publications have been used by many others investigating various aspects of ice loading in rivers.

The most significant use of the data was in encouraging the Canadians to revise their specification for the evaluation of ice loads in the design of highway bridges in 1974. By adopting a much more rational method of estimating ice loads and by reducing most design loads for bridge construction, the Canadian specification undoubtedly reduced the cost of new bridges and led to a better understanding of ice loads among bridge designers. In 1978, AASHTO issued an interim specification on the calculation of ice loads on bridges which is almost identical with the 1974 Canadian specification. This will also provide the Northern States and Alaska with the same benefits as were experienced by the Canadians.

The Canadian studies have also provided a great deal of information regarding the modes of ice failure, the maximum loads that are experienced, the oscillatory characteristics of ice forces, the effect of battering or inclining the nose of a pier and other important matters in the area of dynamic ice loads. While numerous theoretical and model studies of ice loads have been carried out, few field measurements of actual ice loads have been carried out and none with the duration and quality of the Alberta studies.

As a long-term program, the Alberta studies may have some limitations. It must be recognized that their installations are on two prairie rivers, one small and one medium, in central Alberta. Although the two instrumented sites are manned each year, the returns which accrue each year tend to drop with the early information of the greatest value. As years of data accumulate, the body of knowledge grows, but in the long term, the additions tend to be of statistical value, not new and interesting information. The usefulness of hinged beams is recognized but some limitations exist -- these are discussed below. Whether the ownership of sites instrumented with hinged beams prevents RCA from undertaking studies with other types of instrumentation is a subject the authors are unable to discuss. However, it is felt in Alaska and elsewhere that other options are possible and may have advantages.

It was undoubtedly discouraging during the 1978 breakup when the two sites were manned by about four persons each for about a month and the ice melted in place so that no data were obtained. Members of the group report that this situation exists about every fifth year and 1978 proved to be one of those years.

Ice-Thickness Radar at the Hondo Site

The Applied Research Branch, CRREL, sent an ice-thickness radar and operator to the Hondo site in both 1977 and 1978. Reportedly no data were obtained in 1977 because the operator was not present during the short and unpredictable period of ice run. Again, no data were obtained in 1978 since there was no ice run. Consequently, the utility of the device in measuring ice thickness while ice loads are being measured during breakup has not yet been demonstrated. The authors helped install the radar at the Hondo site during their visit to Alberta in April 1978 and had the opportunity of examining the equipment and seeing it in operation on ice which was not moving.

The equipment used was a Geophysical Survey System, Inc. (GSSI) broad-band radar unit. By using a broad-band pulse, the system is able to obtain a number of returns simultaneously. At some frequencies, returns will be received from the upper surface of the ice, at other frequencies, returns can be received from the ice-water interface, from the bottom of the stream and from other interfaces. The radiated average power output of 5 mW is centered at 100 MHz with a 3-db bandwidth of 100 MHz. The antenna is pulsed at a rate of 50 kHz and has a pulse width of 3 ns. The system consists of a control unit, a strip chart recorder, a magnetic tape recording system and an antenna-transceiver system. It is described by Dean (1977), although the antenna used at the Hondo bridge was different from the one described in Dean's report.

At the Hondo site the control unit, strip chart recorder and magnetic tape recorder were housed in a small space between bridge structural elements and enclosed with a plywood floor and tarpaulin cover. Electrical power was available at the site to operate the equipment. The antenna was slung from the bridge structure to a point 10-12 ft above the ice. The operator and the strip chart recorder are shown in Figure 9. The control unit is beyond the operator and the magnetic tape recorder is near his feet. The antenna, as slung from the bridge, is shown in Figure 10.

The authors are currently withholding judgment on this unit. There is no question but that the unit will give returns from the various interfaces and perhaps provide returns from well into the streambed. The depth of each interface can be determined using distances measured on the chart and the velocity of travel in the different mediums. However, the raw data are not normally used and a computer technique is used to modify the data by a signal averaging noise reduction routine which reduces continuous noise in the data. In examining the raw data (the computer was not available at the site) the authors were unable to identify the various

interfaces, such as the top and bottom of the ice, with confidence. They have not yet been able to examine the processed data with an experienced interpreter. It is planned to bring this radar unit to the Yukon River bridge for the 1979 breakup for further testing and evaluation. It has not been used at the Yukon bridge in the past.

Hinged Beams for Measuring Ice Loads

The Alaska group conducting field studies of ice forces on the Yukon River considered using a hinged beam on the Yukon bridge and decided not to use this type of load measuring device. Hinged beams have been used in many of the significant programs of measuring ice forces including the measurement of ice forces in Cook Inlet and the Alberta work; they are simple devices and generally can provide unambiguous information. However, some problems may exist in the data from hinged beams in that the normal ice-pier interaction is replaced by an ice-beam-pier interaction and the structural response of the beam may become important. This may not be important with a short rigid beam such as that at the Hondo site, but it may be important with a long relatively limber beam such as that at the Pembridge site.

The Yukon River site would require a long massive hinged beam. The river bed is at elevation 240 ft MSL. Ice first starts to flow at a water elevation of around 270 ft MSL and continues to flow to an elevation of around 290 ft MSL. The tops of the piers are at 310 ft MSL. The hinged beam, if running from the river bed to the top of the pier would be 70 ft long. Ice loads used in the bridge design were 2600 kips either on the nose or the side of a pier. A hinged beam device would have to be very strong and securely held to resist the ice forces. However, due to the great length of the beam, it would also be relatively limber and the data obtained from it would be affected by the structural properties of the beam.

The costs of fabricating, installing and instrumenting a hinged beam on the Yukon bridge were never accurately estimated. One of the authors (Johnson) suggested that a hinged beam would require $1,000,000 and three years. While this was an estimate, it at least indicates the order of magnitude of the cost and time that would be required. In contrast, one pier was instrumented with Zarling cells for less than $10,000.

Hinged beams also suffer from an additional problem which places limits on the accuracy of the data obtained. They do not sense the point or area of ice impact. Impact elevation is obtained using the auxiliary methods of personal observation, movie photography and records of water stage in the river. Observations at the Yukon River during breakup suggest several sources of uncertainty regarding the point of ice loading and possible resulting errors:

1. The thickness of ice passing under a bridge is not measured at the Canadian sites. Efforts to measure ice thickness have led to CRREL efforts to use an ice-thickness radar in conjunction with the hinged beam apparatus at the Hondo site in Alberta. In some cases, ice thickness can be scaled off the photographic record but such cases are random and cannot provide a continuous record. Errors result from these uncertainties.

2. Ice properties, such as compressive strength, are often not uniform through an ice sheet. It is common to have the upper portion of the ice candled with very low strength. When such ice sheets or floes strike a hinged beam, the real load is imposed on the beam at some point below the apparent one. As a result, the total load calculated from the data will be underestimated and the unit pressure will also be underestimated.

3. When broken ice is coming downstream, floes often pile on each other. Three levels have been observed

at the Yukon River but two are probably more common. A larger floe may be totally submerged by a smaller one riding it. Often the larger submerged floe will be the one to strike the pier. Since this is not visible, there will be no information regarding the ice thickness, the elevation of the point of contact or the size of the floe.

4. During the 1977 breakup, a substantial number of ice floes with sand and gravel frozen to the bottom of the floes were observed. These floes were barely floating and yet were thick floes of good-quality ice and were armed, on the bottom of each floe, with frozen material which would be stronger, harder and more abrasive than ice. The problems described above in determining the point of impact, the total loads and the unit pressures would also be in play under these conditions.

It can also be pointed out that each hinged beam is custom designed and fabricated for a particular installation. It becomes a permanent installation although it may have served all useful functions after three or four seasons. A decision must be made at the end of its useful life whether it should be abandoned or removed and such a decision may be difficult to make.

In the case of the short-term (3 year) research program at the Yukon River bridge, it was decided to develop load cells which could be installed on existing structures. Furthermore, in some cases, such devices are designed so that they give an indication or measurement of the point of load application and possibly of the dimension of the load.

THE 1978 YUKON RIVER BREAKUP AND STUDY

Introduction

To provide access north of the Yukon River while building the Trans-Alaskan Pipeline, a bridge was built across the Yukon River about 95 air miles (140 road miles) northwest of Fairbanks, Alaska. The bridge was completed and opened to traffic in October 1975. The bridge provides a very favorable site to study ice forces since 1) the Yukon River is a major subarctic river, 2) a tremendous ice factory exists in the Yukon Flats above the bridge and 3) winter temperatures in the Flats and at the bridge site approach or equal the continental lows. Very large quantities of the river ice pass through the bridge each spring at breakup. Figure 11 shows the location of the bridge.

The Yukon River Bridge

The bridge is shown in Figure 12. It is a six-span continuous orthotropic-deck bridge 2295 ft (700 m) long. Five piers in the river are subject to ice forces. The deck, which has a slope of 6% downward toward the north due to the elevation differences of the two banks, is carried by tall steel frames placed on the piers. The piers and abutments are numbered from one to seven, beginning at the south (high) end. Figure 13 shows pier 1 (the south abutment) and pier 2, the first pier in the river. Figure 14 shows piers 4, 5, 6 and 7 in order of increasing distance in the photo. Pier 5 is the instrumented pier while pier 7 is the north abutment. The water was high (about 277 ft MSL) when the two photos were taken so that the relative massiveness of the piers is not evident. The piers are tied into concrete footings, placed on bedrock and held in place by 12 or 14 (depending on pier number) rock anchors 60 ft (18 m) long and prestressed to 800 kips (3,550 KN) each. Since the piers are firmly anchored and since the bridge deck and the steel frames will provide little restraint to pier movement, the piers will perform as almost pure cantilever beams.

The bridge deck, shown in Figure 15, consists of a 30 ft (9 m) roadway with guard rails running along both sides of the deck. The deck has not been permanently paved and is currently covered with wood planking. Cantilevered out from the deck supporting structure, below the deck level, are pipeline supports on each side of the bridge. The east (upstream) pipeline support carries the 48 in. Trans-Alaskan Pipeline now carrying about 1.2 million barrels of oil per day from the Prudhoe Bay oilfields to the port of Valdez. Figure 16 shows this pipeline leaving the east support structure at the south end of the bridge. The west pipeline support, which may be used for a second pipeline in the future, is currently unoccupied and can be used by the research project on the bridge through the courtesy of the Alaska Department of Transportation. This pipe carrier can be seen in Figure 17.

Water Elevations at the Bridge Site

The 1,979-mile Yukon is a major river. Only the combined Mississippi-Missouri and the Columbia Rivers in the United States have greater flow. It drains 330,000 square miles in area , of which 200,000 square miles are upstream from the bridge site. The "Standard Project" flood, the highest possible water flow which might occur at the bridge, is estimated to be 1,600,000 cubic feet per second (cfs)(150,000 m^3/s), which will provide 81 ft of water at the bridge site. The 50-year flood is 1,018,000 cfs (95,000 m^3/s) which will provide 65 ft of water.

The streambed at the bridge site is at about 240 ft mean sea level (MSL) and the piers extend up to 310 ft MSL. The normal pattern of water level at the bridge is for the level to drop to a winter minimum of around 258 ft in February-March. Snowmelt begins to add to the river flow in late April or early May and the river level begins to rise slowly. The rate of rise is moderate for a week or so and then begins to accelerate.

As the water level reaches or passes 270 ft MSL, the ice begins to move and breakup occurs. The water level continues to rise rapidly during breakup and will reach a peak toward the end of May. After receding from this peak, water levels will remain at 270 - 280 ft during the summer. With the approach of fall and freezeup, the water levels will begin to fall and normally will fall slowly but continuously until the winter low is reached.

Breakup in the Yukon normally progresses downward from the headwaters to the Bering Sea. Breakup at the bridge can be predicted, with some confidence, by watching the water level and the progress of the breakup upstream. Water rise in the Yukon Flats is moderate since this is a broad flat expanse of land with numerous river channels. However, 18 river miles above the bridge, the Yukon enters a narrow channel between mountains and is constrained to a single channel, often only about 2,000 ft (600 m) wide. In this narrow channel, water level changes are great.

Objectives of the 1978 Study at the Yukon River Bridge

The objectives of the 1978 study at the Yukon River bridge were to

1. Manufacture, calibrate, install and monitor one or more "Zarling cells" on the Yukon River bridge.
2. Observe ice conditions in the immediate vicinity of the bridge. This would include the measurement of ice thickness whenever this was possible.
3. Determine the influence of a log jam frozen into the ice at the nose of pier 4 and, if possible, the ice loads exerted on the bridge.
4. Photographically record the ice breakup and, if possible, key the photography to the ice load data.

Zarling Cells

A major effort has been made during the past several years to develop, calibrate, install and monitor load cells on the bridge. Since the hinged beam concept was rejected, the investigators selected several types of smaller load cells for development and testing. One is the "Zarling cell," developed by one of the project investigators and designed for mounting on the 90° nose of a pier. It is Alaskan practice to install bridge piers with vertical faces with a 90° nose. Since the nose of the pier is the first part of the pier to experience a floating ice sheet, it was decided to first develop a load cell which would measure such loads.

The parts of a Zarling cell are shown in Figure 18. It consists of base plate which is welded on the nose of the pier, a reaction beam which is instrumented with strain gauges to measure strains which can be converted to moments and then to loads, and a nose piece with a shape similar to that of the nose of the pier. Leads from the strain gauges are carried up the pier to an instrumentation point on the west pipe rack. It is possible to determine where the equivalent load is placed on a Zarling cell by examining the output from the two sets of strain gauges so that the device will provide some data as to the point or area of loading. By using a number of relatively small cells, one above the other, it is hoped to secure good information regarding the areas of ice loading at any time. The theory of the Zarling cell is too lengthy to include in this report, but is being prepared for later publication.

Three Zarling cells, each 3 ft long, were fabricated and installed on pier 5 of the Yukon River bridge before the 1978 breakup. Prior experience had indicated that ice would begin to move at a water level of 273 and 282 ft MSL.

Installation of the Zarling cells was performed from scaffolding on the ice with support provided from the pipe rack and bridge about 120 ft above. When the work was begun, the water and ice levels were near 260 ft, so standard scaffolding was placed on the ice and used to gain easy access to the work site. As the water rose, the scaffolding also rose, changing its position relative to the work zone. Figure 19 shows the scaffolding in place.

Based on experience obtained during the 1977 breakup, the principal problems were to securely attach the load cells to the nose of the pier, to adequately waterproof the strain gauges and to protect the electrical leads leading from the load cells to the top of the pier. The common base plate of the three load cells was firmly welded to the nose of the pier. However, because of distortions of the base plate which had been subjected to heavy welding, it did not fit snugly to the nose of the pier. The void was filled by drilling and taping the plate in a number of areas, installing Alemite fittings and forcing a special low-temperature epoxy grout into the void.

The strain gauges used were obtained from Micro-Measurements, Romulus, Michigan. Attempts were made to obtain weldable strain gauges but only a few were available. The balance of the fittings required were converted from adhesive-type to weldable by securing 0.005 in. stainless steel shim stock and adhering the strain gauges to the shim stock. The shim stock was then spot welded to the reaction beams. All strain gauges were then well protected from water and ice by a series of coatings and coverings. The leads from the strain gauges were firmly attached to the reaction beams and then carried up to the instrumentation point on the west pipe carrier. Protection was afforded the wiring by welding angle iron to the nose of the pier and running the leads under the angle iron. Above the highest anticipated ice level, the wires were bundled, tied to the top of the pier and then led up to the pipe carrier where they were firmly attached. All load cells are still in place, all circuits proved

good in late September and it is planned to use these load cells during the 1979 breakup. Figure 20 shows the three load cells in place.

A Brush 6-track recorder was leased to obtain load cell data. Due to the low water levels and the formation of an ice jam between the instrumented pier and shore, no data were obtained.

Accelerometers

The question of whether useful data can be obtained by measuring accelerations on a pier has not yet been answered but studies are underway. During the 1977 breakup, working without funding, investigators on the project secured two geophones and a 2-pen recorder from University of Alaska sources, and records of pier movement were obtained. Although data from the geophones was not analyzed, they provided evidence that good measurements of bridge accelerations could be obtained. For the 1978 breakup, two accelerometers were leased and installed on the top of pier 5. The 2-pen recorder was again borrowed from the University of Alaska and preparations were complete to measure pier response. However, apparently due to the low water and the configuration of the river bottom, slushy ice jammed along the north bank from the bank out to, and covering, pier 5 and no ice forces were felt by the pier. Consequently, no data were obtained in 1978.

Plans have been developed to carry out further accelerometer studies during the 1979 breakup, perhaps on two piers.

Chronology of the 1978 Yukon Breakup

Breakup on the Yukon River generally starts upstream and progresses downstream. The following chronology of the breakup shows that this general pattern is interrupted at some major tributaries such as the

Tanana. Time sequences of ice movement at specific locations give useful information for predicting the time of first movement of ice and the subsequent "ice run" at the study site. A summary of the chronology of the 1978 breakup is given below.

Monitoring of the breakup at the river began on 25 April. Weather had been unseasonably warm and the snow was disappearing approximately 7 days earlier than normal in the Fairbanks region. Data were obtained from the following stations:

1. Dawson City, Yukon Territory, Canada, 485 river miles* upstream from the study site.
2. Eagle, Alaska, near the U.S.-Canadian border 370 miles upstream from the study site.
3. Fort Yukon, Alaska, 175 miles upstream from the study site.
4. Tanana, Alaska, 175 miles downstream of the study site.

25 April 1978: Eagle, Alaska, reported quite a bit of overflow on top of the ice. The ice appeared rotten but solidly in place. Dawson City, Canada, also reported overflow on the ice along with open water along the shore.

29 April: Mr. David McFarland of the U.S. National Weather Service flew the river from Eagle to below the Yukon bridge study site and reported that no ice was moving and everything looked solid and firm. He also reported that the Tanana River looked solid and it appeared that it would be 3 or 4 days before the ice would go out. However, on 30 April, the Tanana River ice went out at Nenana.

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* All river miles were measured from a USGS Alaska map (scale 1:1,000,000).

1 May 1978: Eagle reported that the ice was rotten but still in place with overflow. No report was received from Dawson City.

2 May 1978: The ice at Fort Yukon was reported to be solid by Mr. Donald Nelson, Manager of radio station KJNP, at North Pole, Alaska. Eagle reported both in the morning and the afternoon that the ice was still solidly in place with overflow.

3 May 1978: Fort Yukon reported that the ice was still solid. No work was received from Eagle. Dawson City reported that breakup on the Klondike River, a tributary to the Yukon, had occurred on 2 May, but that the ice was still in place at Dawson City.

4 May 1978: The ice started to move at approximately 1400-1500 hours at Eagle Village, which is 2½ miles upriver from the town of Eagle. The ice did not move at the bluff next to the town.

5 May 1978: The morning report from the town of Eagle stated that the ice had stopped moving at the village and was still in place at the town. A report that the Yukon River at Tanana had started to break up was received. This was five days after the ice went out at Nenana. The Tanana River was then clear of ice from Nenana to Tanana, a distance of 170 river miles.

6 May 1978: At approximately 1500 hours the ice started to move at Eagle.

7 May 1978: By afternoon, the river channel was clear of ice from Eagle for approximately 80 miles downstream. The river stage was low and ice continued to hold in the channel beyond 80 miles downstream through 8, 9, and 10 May.

11 May 1978: At 1630 hours, ice started to move at the Yukon River bridge study site. Ice had moved downstream near Tanana and Galena during the preceding days, but was still holding in the channel at Fort Yukon.

12 May 1978: Ice continued to move intermittently at the bridge (Figure 4) with some large jams forming between the bridge and Steven's Village (30 miles upriver from the study site).

13 May 1978: The river was clear of ice by noon.

1978 Ice Conditions and Breakup

No studies of the freeze-up of the Yukon River or the character of the ice at the bridge site had been carried out at the Yukon River bridge prior to April 1978 due to lack of funding. However, CRREL personnel had developed a hot-wire ice thickness gauge during the winter of 1977-78. Eight units of a redesigned gauge were taken to the Yukon River on 13 April 1978 and installed in the ice. One string of five was in a line across the river about one-half mile (1 km) above the bridge. Ice thicknesses ranged from 35 to 52 in. (0.9 to 1.3 m). Three gauges were placed approximately 300 ft (100 m) above the bridge and ice thicknesses ranged from 50 to 57 in. (1.3 to 1.4 m). A hanging dam of old frazil ice was found in two of the latter sites with the slush under the ice going to a depth of 9 ft (3 m).

The river was next visited on 2 May 1978 and the gauges were examined. Small streams were bringing snow meltwater onto the ice in the area of the five gauges and made the gauges difficult to approach. They were not read at this time. By 7 May the ice around the poles had melted, the poles were tilted and some were dropping into the river. Little information was obtained from these experimental gauges after they were installed.

One of the gauges was installed near pier 5 and was convenient to read while personnel were working on the ice nearby. Ice thicknesses were:

14 April	54 in. with frazil to 9 ft	(1.37 m)
4 May	48 in.	(1.22 m)
8 May	36 in.	(0.91 m)
9 May	34 in.	(0.86 m)

However, more important than the decrease in thickness was the decrease in quality as the upper surface candled and the candling went deeper and deeper. No quantitative data were obtained on this matter -- it is one that will require further work.

The hot-wire ice thickness gauge program was not particularly successful. One problem was that the distance to the river made it difficult to visit the site. With funding available, it may be feasible to charter a ski-equipped aircraft at times to visit the site and take readings.

The 1978 breakup was different than others for which we had information (1974 and 1975) or had observed (1976 and 1977). The lack of an adequate surge of water downstream from the headwaters left most of the ice in the river at the bridge and upstream to melt in place. Warm days, windy weather and clear skies thinned and deteriorated the ice pack until the ice weakened to the point where it was unable to resist the drag of the current. The ice moved at 1632 hours on 11 May 1978. J. Buska, a CRREL civil engineer who was monitoring breakup at the bridge, reported the initial breakup as follows:

> "We were on the nose of the pier when it began to move. Cracks began to appear with water and slush welling up through the cracks. Then right next to the pier on the south side there was a large upheaving of the ice just as the whole ice sheet began to move. Total time from the time we first noticed the cracks to ice sheet movement was 3 minutes."

At 1732 hours he reported:

> "Most of the ice passing the pier is slushy, candled and weak. A large floe has been captured between piers 5 and 6 and an ice ridge is building up from the nose of pier 5 to the ferry landing. Most of the ice is now hitting the side of pier 5. The river stage is well below the load cells so data cannot be collected."

At 2200 he reported that some grounded ice was measured from shore. The ice was 31 in. thick with 26 in. of candled ice.

Figure 21 shows the elevation of the river during the 1978 breakup.

Ice Collars

Ice collars were observed around the concrete piers of the Hondo bridge in Alberta. At the time of our visit, the ice was badly deteriorated and little quantitative information could be obtained. However, the texture of the ice showed that they had been present and may, in some years, be a factor to consider. They can be seen in Figure 2.

Ice collars on the Yukon bridge piers were observed during 1978 as during the previous two breakups. In all cases the ice at the bridge was unable to move until the ice collars were able to spread and pass the piers. During the 1978 breakup the collars split along the axis of the piers but the ice was only able to move a slight distance. As downstream ice forces increased, the collar components were forced downstream and sideways but the ice sheet between piers resisted the downward and sideways movement. Ultimately the ice sheet between piers buckled from the sideways forces, the ice collars spread and the ice in the river was now able to begin passing through the bridge.

Ice collars at the Yukon River bridge form as a result of two separate phenomena. The first is due to the fact that, early in the winter, ice forms and freezes to the pier while the river level is dropping. At some time the first sheet of ice breaks and a new plate begins to form at a new water level. This process may recur several times during the early winter. At the same time, the pier, built of concrete and steel, is a good conductor of heat. Carrying heat from the wetted area to the

open air, it tends to freeze an ice collar around itself that projects downward into the water for some distance.

Figure 22 shows a mature ice collar in early May 1977. The cracked upper surface can be seen. The dirt on the collar is from the bridge above. Figure 23 shows an ice collar when the ice is first starting to move.

Since the collar has melted loose from the pier, it has been free to rise up the pier as the river rose. However, as described above, it was unable to spread so that it could slip past the pier until the ice sheet between the piers buckled or yielded enough to allow the collar to split and slide sideways to clear the pier. Figure 24 is another view of this collar showing the downstream end of the pier a short time later.

Driftwood Reinforcement of the Ice on a Pier Nose

Driftwood collected on the nose of pier 4 of the Yukon River bridge before freezeup during the fall of 1977 and was incorporated into the ice sheet in the area. The host of other tasks underway made it impossible to observe the ice breakup at this pier. However, it was observed that the driftwood was broken by the ice before the ice at that pier passed the pier. It will be necessary to develop methods of measuring ice forces in such cases before it will be possible to estimate the importance of this factor.

CONCLUSIONS

Despite the disappointing breakup of 1978, the Yukon bridge remains an outstanding site for ice forces measurement. It will be important in the future to pay careful attention to the snowfall in the headwater area to estimate the characteristics of the breakup that can be expected. It may be possible to secure assistance from the National Weather Service and its counterpart in the Yukon Territory (or from other sources) each winter and spring to develop our predictions.

Instrumentation should be installed on pier 4 as well as pier 5. Pier 4 is well out in the main river channel and is a better pier to use than pier 5. It receives more of the sweep of water and ice than pier 5. There is currently no means of reaching the top of the pier from the bridge and a ladder or other system will have to be installed. Piers 4 and 5 are sufficiently close 410 ft (125 m) that power and instrumentation at both piers can probably be handled from the same site on the west pipe carrier.

It will be necessary to map the contours of the riverbed above the bridge. There is shallow water between the north bank and pier 6. There is a possibility that shallow water extends on out toward pier 5.

An expanded program of instrumenting piers with accelerometers is required for the 1979 breakup. Probably both pier 5 and pier 4 will be instrumented.

Ice thickness and quality information must be obtained during breakup. Two prospects for securing such data are ice-thickness radar and the use of devices such as the Zarling cell, which indicate where loads are applied. Further study will be given to this matter and perhaps other instrumentation can be developed.

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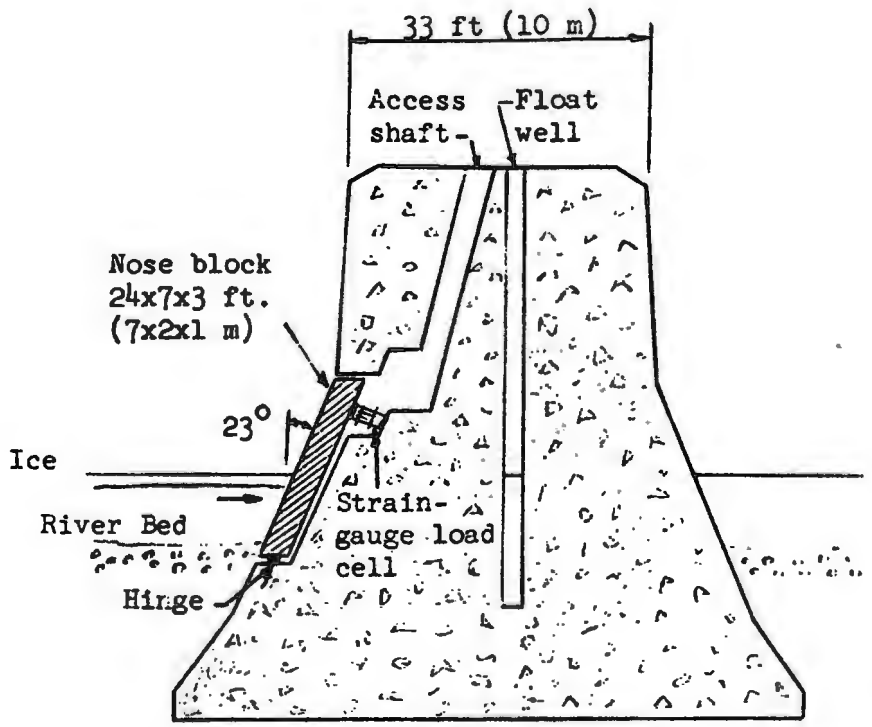
Fig. 1. Location of the Alberta sites.

Fig. 2. The Athabasca River and the Hondo bridge.

Fig. 3. The instrumented Hondo pier (courtesy of Alberta Department of Highways and Research Council of Alberta).

Fig. 4. Diagram of the Hondo pier and hinged beam (from Watts and Podolny 1976).



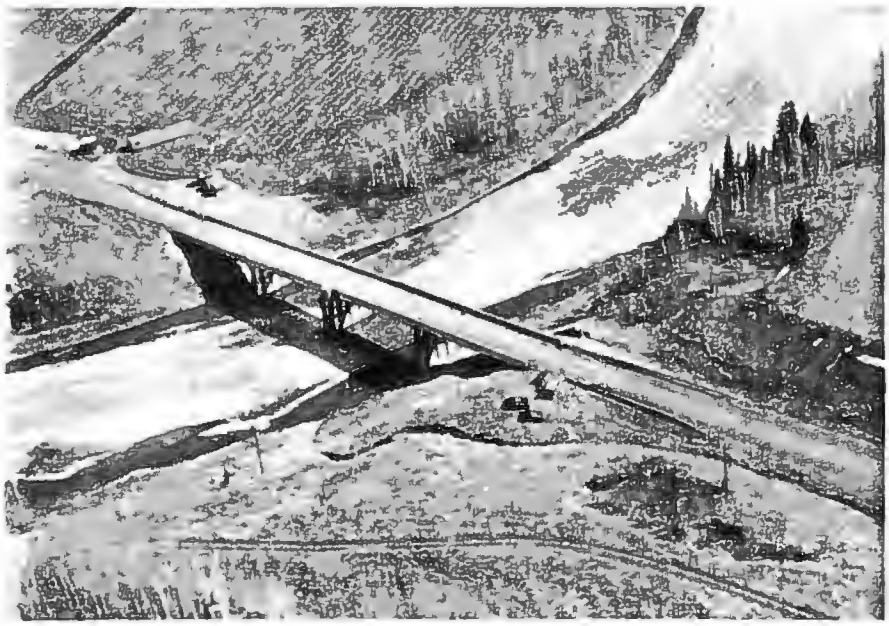


Fig. 5. The Pembina River and the Pembridge site.

Fig. 6. The hinged beam at the Pembridge site.
(from Watts and Podolny 1976)

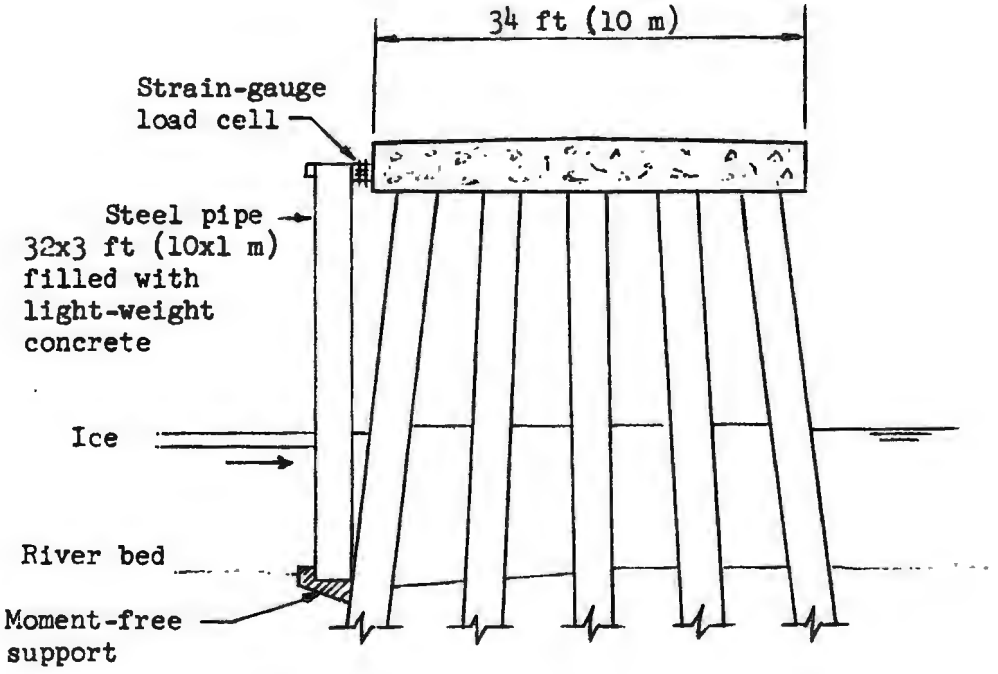


Fig. 7. Diagram of the Pembridge pier and hinged beam. (from Watts and Podolny 1976)

Fig. 8. The Pembridge load cell.

Fig. 9. A CRREL radar operator with the GSSI radar.

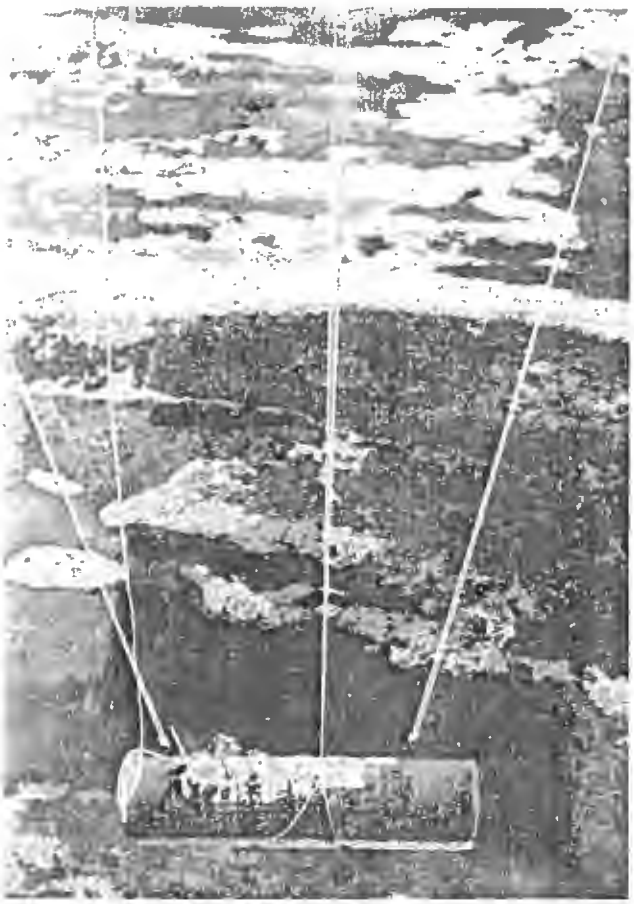


Fig. 10. The GSSI ice-thickness-radar antenna.

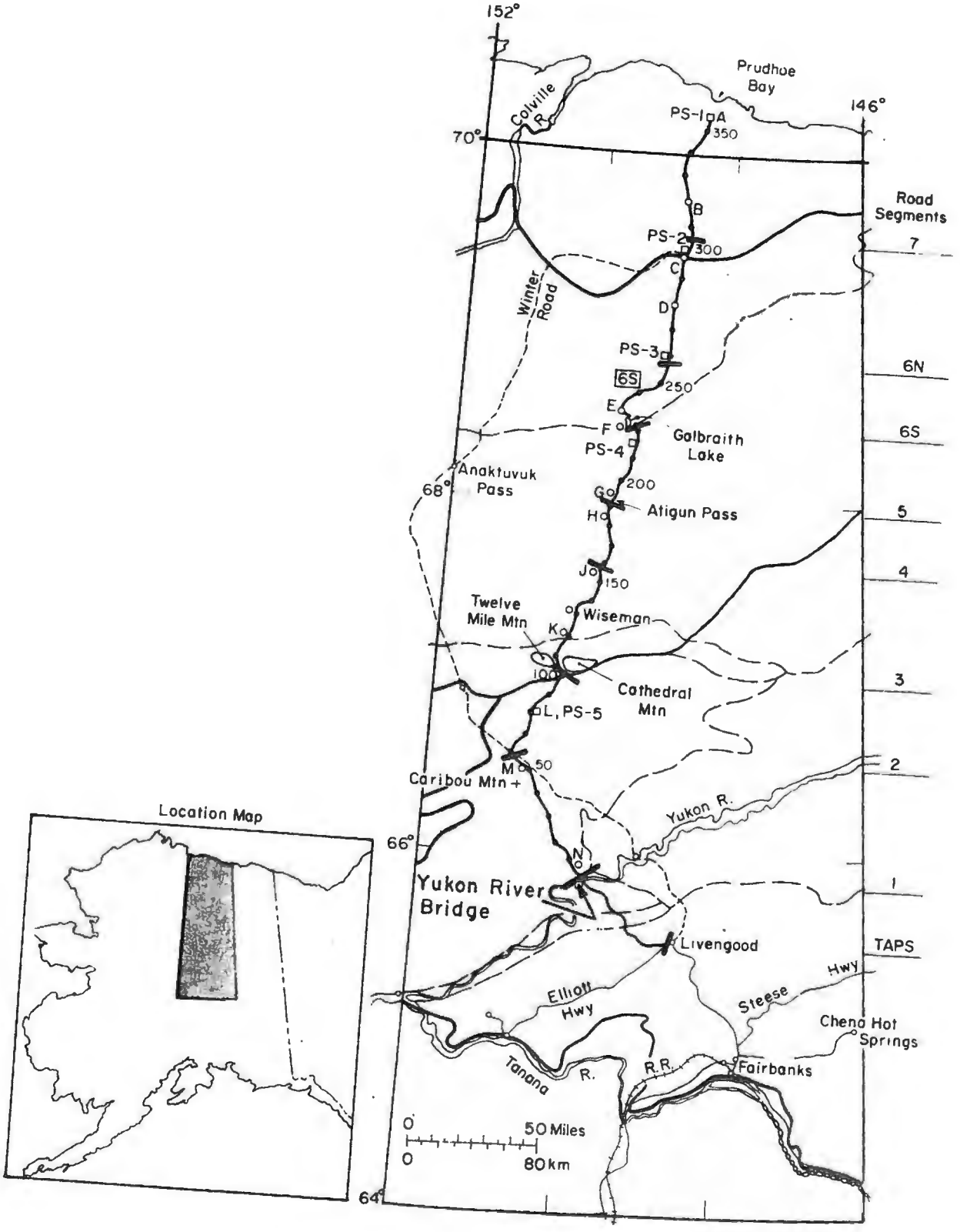


Fig. 11. Location of the Yukon River bridge.

Fig. 12. The Yukon River bridge.

Fig. 13. Piers 1 and 2 of the Yukon River bridge.

Fig. 14. Piers 4 - 7 of the Yukon River bridge.

Fig. 15. The deck of the Yukon River bridge.

Fig. 16. The TAPS pipeline leaving the east pipe carrier at the south end of the Yukon River bridge.

Fig. 17. The west pipe carrier of the Yukon River bridge.

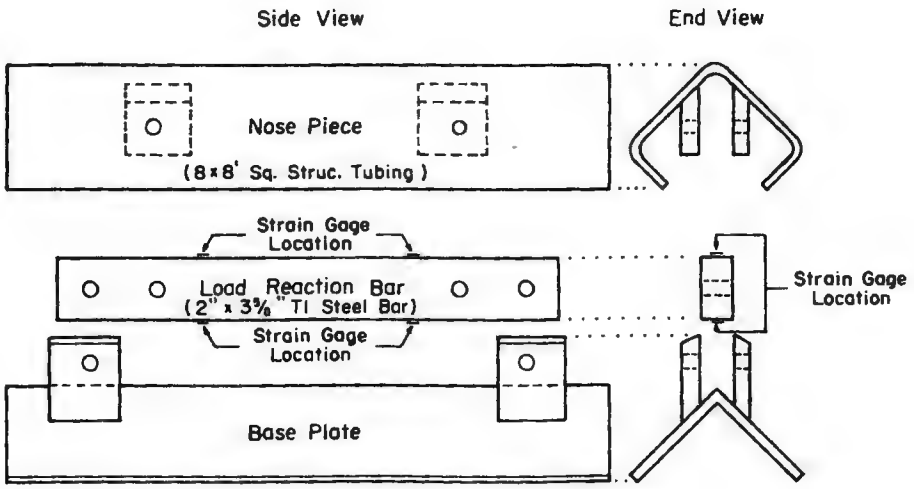


Fig. 18. The Zarling load cell.

Fig. 19. Using scaffolding to install Zarling load cells.

Fig. 20. Three mounted Zarling load cells.

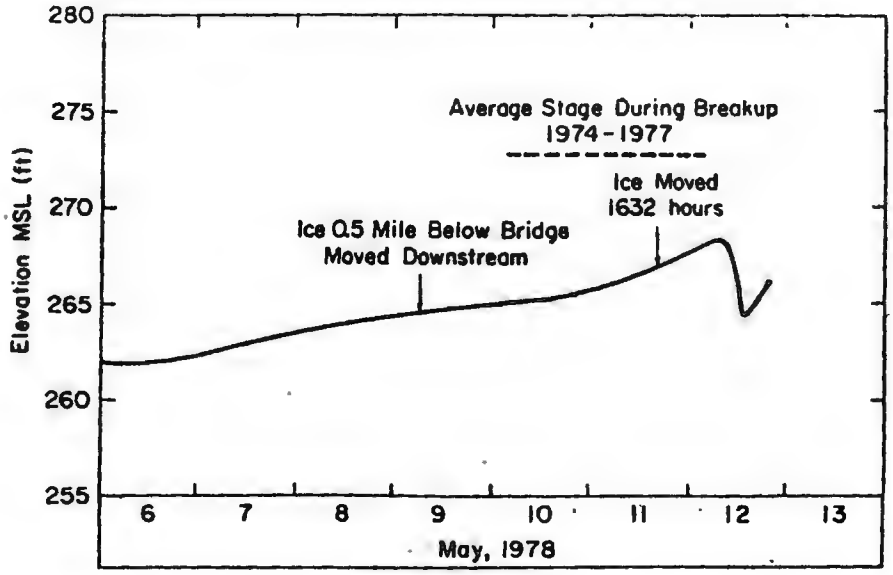


Fig. 21. Water elevations during the 1978 breakup.

Fig. 22. A mature ice collar in place.

Fig. 23. View of an ice collar beginning to pass its pier.

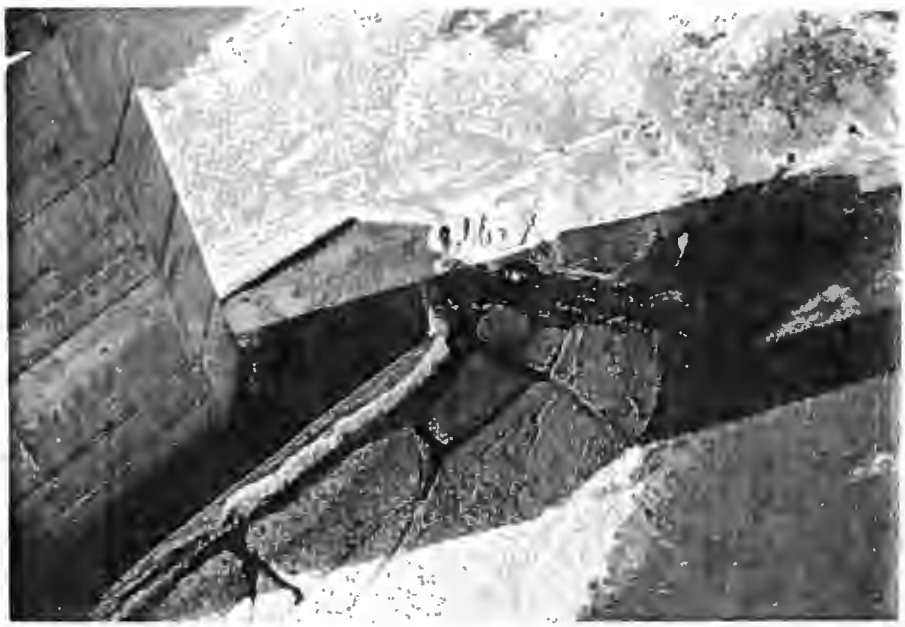


Fig. 24. An ice collar passing its pier.

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway Administration under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by keeping the demand-capacity relationship in better balance through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

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Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

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* The complete 7-volume official statement of the FCP is available from the National Technical Information Service (NTIS), Springfield, Virginia 22161 (Order No. PB 242057, price $45 postpaid). Single copies of the introductory volume are obtainable without charge from Program Analysis (HRD-2), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.