NRC Publications Archive
Archives des publications du CNRC

Use of ice landings

Gold, L. W.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/20338248
Internal Report (National Research Council of Canada. Division of Building Research), 1961-08-01

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=3d0f5e5f-9ef5-458e-8992-6d3a0aa6dff1
https://publications-cnrc.canada.ca/fra/voir/objet/?id=3d0f5e5f-9ef5-458e-8992-6d3a0aa6dff1

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada | Conseil national de recherches Canada

NATIONAL RESEARCH COUNCIL

CANADA

DIVISION OF BUILDING RESEARCH

USE OF ICE LANDINGS

by

L. W. Gold

Internal Report No. 229

of the

Division of Building Research

OTTAWA

August 1961

PREFACE

This report is one of several reports and papers which have been prepared by the Snow and Ice Section of the Division as a contribution to the safe use of ice covers for transport and for pulp wood landings. As is often the case in engineering applications, there is much to be learned from careful study of field experience. The Division has been privileged to have very substantial co-operation from the Canadian Pulp and Paper Association and in particular from some of the member companies in the collection and submission of field information, some of which is now presented and analyzed.

The author, a research officer with the Division, is head of the Snow and Ice Section, and has devoted much time to studies of the strength of ice.

Ottawa
August 1961

N. B. Hutcheon
Assistant Director

USE OF ICE LANDINGS

by

L. W. Gold

A Survey on Loads Placed Successfully on Ice Covers

In the fall of 1958 the Snow and Ice Section of the Division of Building Research, in co-operation with the Canadian Pulp and Paper Association, and through the Associate Committee on Soil and Snow Mechanics of the National Research Council, undertook a survey on the failures of ice covers that occurred during the construction and use of ice landings for wood storage by pulp and paper companies. The observations obtained in the winters of 1958-59 and 1959-60 have been reported (1). These observations showed that many of the vehicles broke through ice that would normally have been considered thick enough to support the loads applied. This indicated that factors other than ice thickness were probably responsible for some of the failures that occurred in the course of normal operations on the landings. To obtain further evidence on this point, a study was undertaken in the winter of 1960-61, of the loads which pulp and paper companies successfully placed on frozen lakes and rivers, and of the associated ice thicknesses.

Rose and Silversides estimate that some 10 to 15 million tons of pulp wood are placed on ice covers each winter (2). To attempt to record all this activity would be unrealistic. With the assistance of the Canadian Pulp and Paper Association, arrangements were made for 4 companies to each record, on special forms, details concerning the ice cover and the wood placed on one landing. During the winter, other companies indicated their willingness to participate in the survey and contributed observations. Table I records the approximate size of the landings observed, the approximate weight of the wood placed on the landing, and the number of trips required to place the wood.

Besides a complete record for one landing one company submitted a partial record of the wood placed on 6 additional landings. This record, summarized in Table II, included the total number of cords of wood placed, the associated number of trips, details on ice thickness and sample observations of the daily traffic. These observations were not complete enough to be included in the general analyses but samples of daily traffic indicate that they support the general conclusions obtained from the observations in Table I.

When completed, the survey had recorded over 64,000 loads for a total of over 850,000 tons of wood placed on ice covers. Twelve breakthroughs only were reported during the placing of this wood. Eight companies placed their wood without any failures. Some of these companies have operated their landings for 2 or more years without accident.

OBSERVATIONS

A special form was prepared and distributed to the companies participating in the survey (Fig. 1). This form was used daily to record the total weight of wood placed on each landing, the number of trips required to place this wood, the type of vehicles used, the weight of the largest load placed, the thickness of the ice cover and the thickness of the white ice. From observations on the number of trips and the total weight of wood placed, the average weight per trip on ice of given effective thickness could be calculated. Information on the maximum loads would indicate the spread in size of the loads allowed on the ice during the period for which average loads were calculated.

ANALYSIS OF THE OBSERVATIONS

Theoretical considerations show that the maximum stress, S, produced in an ice cover is directly proportional to the applied load, P, and inversely proportional to the square of the effective thickness, h; i.e.,

$$S = C \frac{P}{h^2}$$

where C is a proportionality factor that depends on the properties of the ice, the geometrical configuration of the load, the location of the load with respect to cracks in the cover and the nature of these cracks. The effective thickness was obtained by adding one-half of the measured thickness of white ice to that of good clear ice. With a good ice sheet and moving vehicles whose wheel geometry does not change very much from one vehicle to another, C can be considered constant. The ratio $\frac{P}{h^2}$ = S/C is called the "ice loading" in this report.

From the records, the observed values of the average load, $\bar{P}$, and the maximum load Pm for each landing were determined for effective ice thicknesses in steps of 1 in. In Fig. 2, $\bar{P}$ in lb is plotted against effective ice thickness h, in in. Shown in the same figure for reference are the lines defined by $P=50h^2$ and $P=250h^2$. All breakthroughs reported to date have occurred for loads greater than $P=50h^2$ (1). $P=250h^2$ defines approximately the upper safe limit that has been recommended in the literature for those situations where some risk is acceptable. The ratio of $\overline{P}$ and Pm to the square of the effective thickness of the ice was calculated. In Fig. 3, $\overline{P}/h^2$ is plotted against the ice thickness along with $Pfail/h^2$ obtained from the breakthrough reports received to date. $\overline{P}/h^2$ is plotted against Pm/h^2 in Fig. 5. Figure 4 shows the observed number of loads placed on the ice during the ice use survey for each ice thickness in steps of 1 in. In the same figure is shown the number of breakthroughs recorded since the fall of 1958.

It could be argued that the calculation of effective ice thickness in the manner done in this report is not justified. The rule of giving to white ice an effective thickness of half its measured thickness is one which has been adopted by a number of authors. It probably originated from investigations made by the Russians prior to 1939. Its continued use is not an indication of its validity but rather of the lack of knowledge on the strength properties of white ice. This rule was used in (1) and has been adopted in this report for the following reasons:

(1) The quality of the white ice formed on the landings is variable. The mechanical properties of this ice depend upon its quality.

(2) The bonding strength between successive layers of white ice is variable. Some breakthrough observations indicate a failure of the cover between such layers.

(3) It is unlikely that properly prepared white ice has a strength as low as one-half that of good clear ice (5). Assuming that it does have a strength equivalent to one-half its thickness of clear ice will ensure that the resulting prediction of the bearing capacity will be on the safe side.

(4) Assigning to white ice this effective thickness will draw attention to the fact that the strength of such ice is less than that of good clear ice and that it depends upon the quality and thus upon the techniques used in preparing the landing.

Calculating the effective thickness in this way will normally change the measured thickness by no more than 25 per cent and usually less than 15. Changing thicknesses by this amount will not greatly affect the limits on the bearing capacity of ice covers obtained from the present surveys, nor will it significantly modify the general conclusions that were obtained from the study on the use of ice landings.

DISCUSSION

Figures 2 and 3 show that many of the reported ice failures occurred for loadings that are normal for operation of the Pulp and Paper Industry. This confirms the observation that factors other than ice thickness must be responsible for these failures.

To define more precisely some of the factors that could be contributing to the ice failures, a revised breakthrough report was prepared and distributed in the fall of 1960. Besides the specific information deemed important from earlier breakthrough observations, an opinion as to the cause of the failure was requested. The breakthrough observations obtained during the winter of 1960-61, combined with the observations of previous years, confirmed that vehicle speed is one contributing factor. For ice thicknesses and water depths normal for landings, vehicle speed should be kept below 5 mph to ensure that the cover will not be unduly stressed by this effect.

Reports showed that some failures may be associated with a drop in temperature sufficient to cause thermal cracks in the ice. Observers commented on the very brittle nature of the ice under this condition. This brittle behaviour may be due to the presence of thermal stresses. Such observations suggest that extra precaution be taken when placing loads on ice covers following a marked drop in temperature, and in particular to keep vehicles well away from any cracks.

Some of the failures occurred on the access roads from the shore under conditions that suggest erosion of the ice from currents or a bridging effect between the shore and the floating ice cover, a possible result of lowering the water level. A number of failures were associated with multi-layered ice covers, i.e. ice layers separated by a pocket of water or air. Such defects in the cover may be caused by a changing water level or poor flooding practice.

During a visit to one of the landings, the foreman described another source of failure confirmed later by one of the breakthrough reports. If the loads are large enough to crack the ice under the vehicle, then continuous use of a road by vehicles carrying such loads can cause severe cracking and a considerable depression of the ice in the immediate vicinity. This deterioration of ice by traffic can be controlled by moving the road at least one truck width about every two hours, depending on the traffic.

An interesting fact which the survey revealed was the marked decrease in the ratio $\overline{P}/h^2$ as the thickness of ice increased. The reason for this is obvious. For each landing there is a particular increase in ice thickness with time and so the ice thickness axis in Figs. 3 and 4 can be visualized as a time scale. At a given ice thickness, usually about 16 in. for most landings, loads are allowed on the ice. Experience has determined the size of the load that can be placed on the ice at this time. For a five ton truck this is usually 8 to 10 tons, a little over $\frac{1}{2}$ the capacity of the truck, giving a gross weight of about 20 tons. As quickly as possible, the loads are increased to the full capacity of the truck. This loading of 20 to 25 tons is usually achieved by the time the ice is 20 in. thick. For ice thickness greater than 20 to 25 in. the factor limiting the size of the load placed on the ice is the capacity of the truck and not the thickness of the ice. When the maximum loading of the truck has been reached, the ice loading decreases with increasing ice thickness (Fig. 3).

At any time the maximum load on the landings under observation was usually within 20 per cent of the average load (Fig. 5). This is probably because there was normally not a very large variation in the capacity of the trucks used on each landing and each carried the greatest possible load. A notable exception is shown by the observations plotted as circles where the maximum loads greatly exceed the average loads, particularly for the higher loadings. It is of interest that 5 of the 12 breakthroughs recorded in the ice use survey occurred on this landing.

It is a common field observation that cracking occurs in the immediate vicinity of a vehicle when the ice loading, P/h^2, is about 150 lb/in^2. This indicates that the ice loading for collapse of the ice cover is probably less than 300 lb/in^2 (3,4). The maximum load reports contained in this report and in (1) show that the ice loading for the collapse of a good ice cover must be greater than 250 lb/in^2. The limiting value for P/h^2 is thus probably between 250 and 300 lb/in^2. This indicates as shown in Fig. 3, that during the early part of the season, when the effective ice cover is less than 20 in., the reserve of strength in the cover is often less than 100 per cent of the applied load. As the season progresses, the situation improves. When the ice thickness is 25 in. or greater, the reserve of strength is often 200 to 300 per cent of the average load being placed on the cover.

The way in which companies have naturally taken advantage of this fact in practice is shown in Fig. 4 where the intensity of the traffic gradually increases with increasing thickness (or the equivalent, decreasing $\overline{P}/h^2$) so that most of the wood is placed on the ice when there is a comfortable margin of safety. This fact is reflected in the breakthrough observations where the majority of failures occur for ice thickness less than 20 in., whereas most of the wood is placed on the ice when the thickness is greater than 20 in. (Fig. 4).

Although many ice failures occur for ice loadings that are quite normal, the studies indicate that they are confined primarily to the construction period of the landing (Fig. 4). This suggests that the ice cover is more sensitive to the additional factors that contribute to breakthroughs when its thickness is less than 20 in. Stressing and cracking of the ice by naturally occurring temperature changes would produce such behaviour.

CONCLUSIONS

The study on the loads placed successfully on ice covers by pulp and paper companies show that factors other than ice thickness must be responsible for many of the failures occurring during normal operations on ice landings. Breakthrough observations indicate that these additional factors are probably -

(1) vehicle speed;
(2) crack formation and the development of thermal stresses by naturally occurring temperature changes;
(3) fatigue of the ice cover through repetitive loading;
(4) formation of multiple ice layers separated by air or water pockets; and
(5) erosion or bridging of the ice cover near the shore.

The majority of failures reported occur for ice thicknesses less than 20 in. For these thicknesses, the ice loading for the year is greatest and the ice cover is likely most sensitive to temperature changes. Most of the wood is placed on the landings when the ice thickness is greater than 20 in. By giving careful attention to the factors listed above, it should be possible to reduce the frequency of occurrence of vehicle breakthroughs without reducing the average weight of the loads now placed on ice covers. In some cases, it should be possible to increase this average weight.

ACKNOWLEDGMENTS

The author is indebted to the following pulp and paper companies for their contribution to this study on the use of ice landings: Abitibi, Canadian International Paper, Consolidated Paper, Donacona Paper, Dryden Paper, Great Lakes Paper, Huron Forest Products, K.V.P., Price Brothers, St. Lawrence Corp., and Spruce Falls Power and Paper. He would like to express his sincere thanks to the individuals in these companies who made and recorded the observations. The author wishes also to acknowledge the very considerable co-operation and assistance received from the Canadian Pulp and Paper Association in establishing and conducting the studies on the breakthrough of vehicles and the use of ice landings.

REFERENCES

(1) Gold, L. W. Field study on the load bearing capacity of ice covers. Woodlands Rev., Pulp and Paper Mag. of Canada, Vol. 61, (5), May 1960, p. 11-15.

(2) Rose, L. B. and C. R. Silversides. The preparation of ice landings by pulp and paper companies in eastern Canada. Trans. Eng. Inst. Can., Vol. 2 (3), 1958, p. 101-107.

(3) Meyerhof, G. G. Bearing Capacity of floating ice sheets. Proc. Am. Soc. Civil Eng., Jour. Eng. Mech. Div., EM-5, October 1960, p. 113-145.

(4) Gold, L. W. Discussion to "Bearing capacity of floating ice sheets", by G. G. Meyerhof. Proc. Am. Soc. Civil Eng., Jour. Eng. Mech. Div., EM-2, Part 1, April 1961, p. 83.

(5) Butkovitch, T. R. Ultimate strength of ice. Research Paper No. 11, Snow, Ice and Permafrost Research Est., Wilmette, Ill., 1954.

TABLE I

WEIGHT OF WOOD AND NUMBER OF TRIPS ON LANDING

Approximate area covered with wood	Approximate weight (tons)	Number of truck trips	Average weight wood per trip (tons)
115	166,364	8,577	19.4
544	168,341	10,193	16.5
22.6	10,861	1,045	10.4
8.4	760	171	4.5
48	71,184	4,136	17.2
39	37,250	2,493	14.9
16	12,810	872	14.7
14	14,443	1,121	12.9
8	5,569	365	15.3
30	28,113	3,003	9.4
110	113,765	7,411	15.4
97	78,288	3,522	22.2
	707,748	42,909	

TABLE II

WEIGHT OF WOOD AND NUMBER OF TRIPS ON LANDING

Approximate area covered with wood	Approximate weight (tons)	Number of truck trips	Average weight wood per trip (tons)
27	25,500	3,550	7.2
29	29,100	3,594	8.1
17	20,600	3,754	5.5
38	22,700	3,076	7.4
28	28,200	3,569	7.9
32	24,800	3,896	6.4
	150,900	21,439	

Report on the Use of Ice Landings

Company ______________________ Name of River or lake ______________________

Location of landing ______________________

Total area of landing ______________________ Acres.

Date	Ice thickness in.		Total for day		Means of transport	Weight of largest load for day (vehicle plus load, lbs.)
	Total	Whitec	No. of loads	Weight of wood or No. of cords	ie.20 loads horse plus sleigh, 14 loads 4 ton truck	

Gross area of landing covered with logs at last date ______ Acres.

Reamrks(If loads given in cords, give average weight of 1 cord.)

____

____

This form when completed to be returned to -

Secretary,
Subcommittee on Snow and Ice,
Associate Committee on Soil and Snow Mechanics,
National Research Council,
Ottawa, Ontario.

FIGURE 1. FORM USED TO REPORT THE USE OF ICE LANDINGS

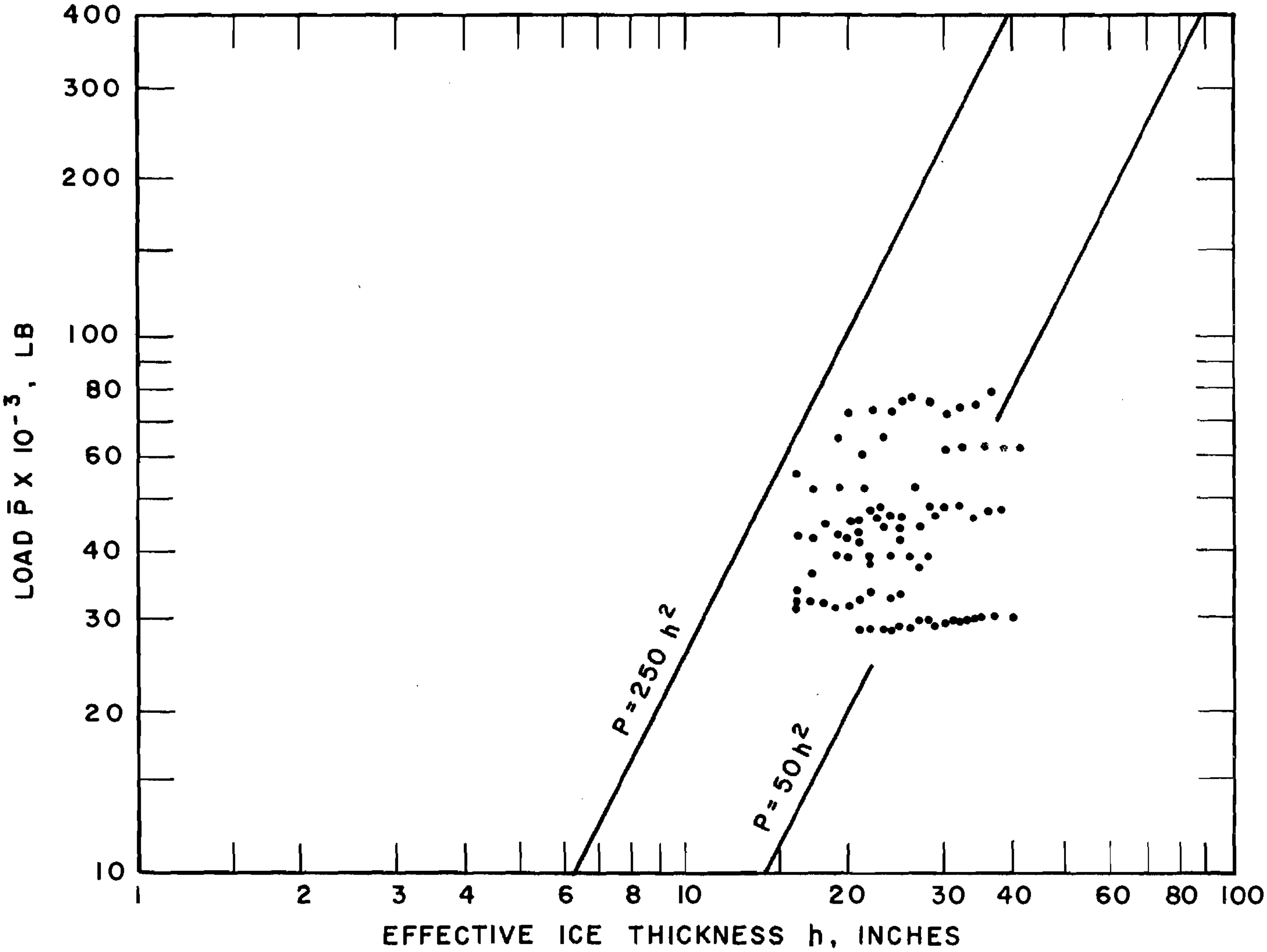

FIGURE 2

AVERAGE LOAD $\bar{P}$ FOR GIVEN EFFECTIVE ICE THICKNESS h

BR 2448-1

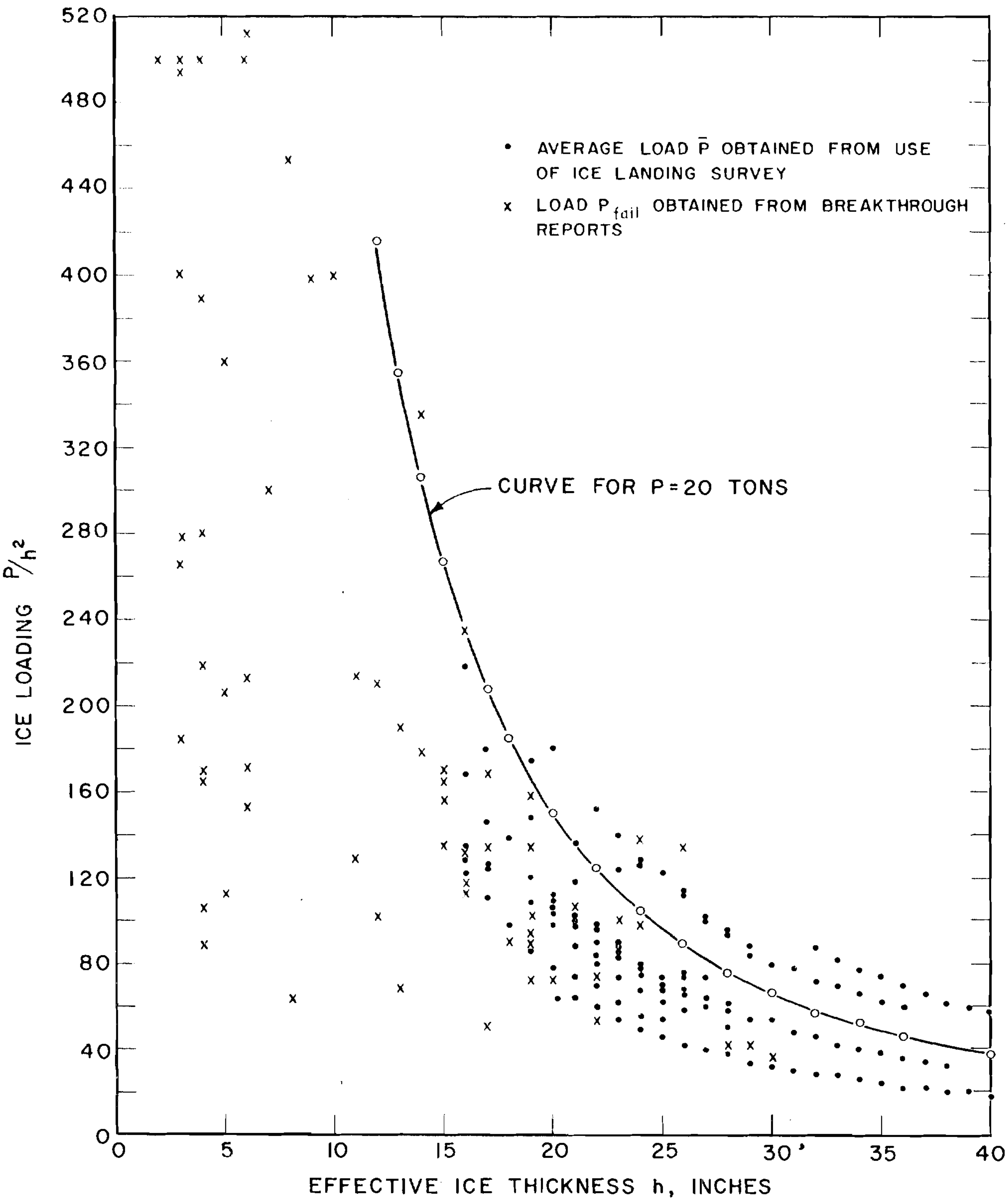

FIGURE 3

OBSERVED LOADING AT GIVEN THICKNESS OF THE ICE COVER, P IN LB, h IN INCHES

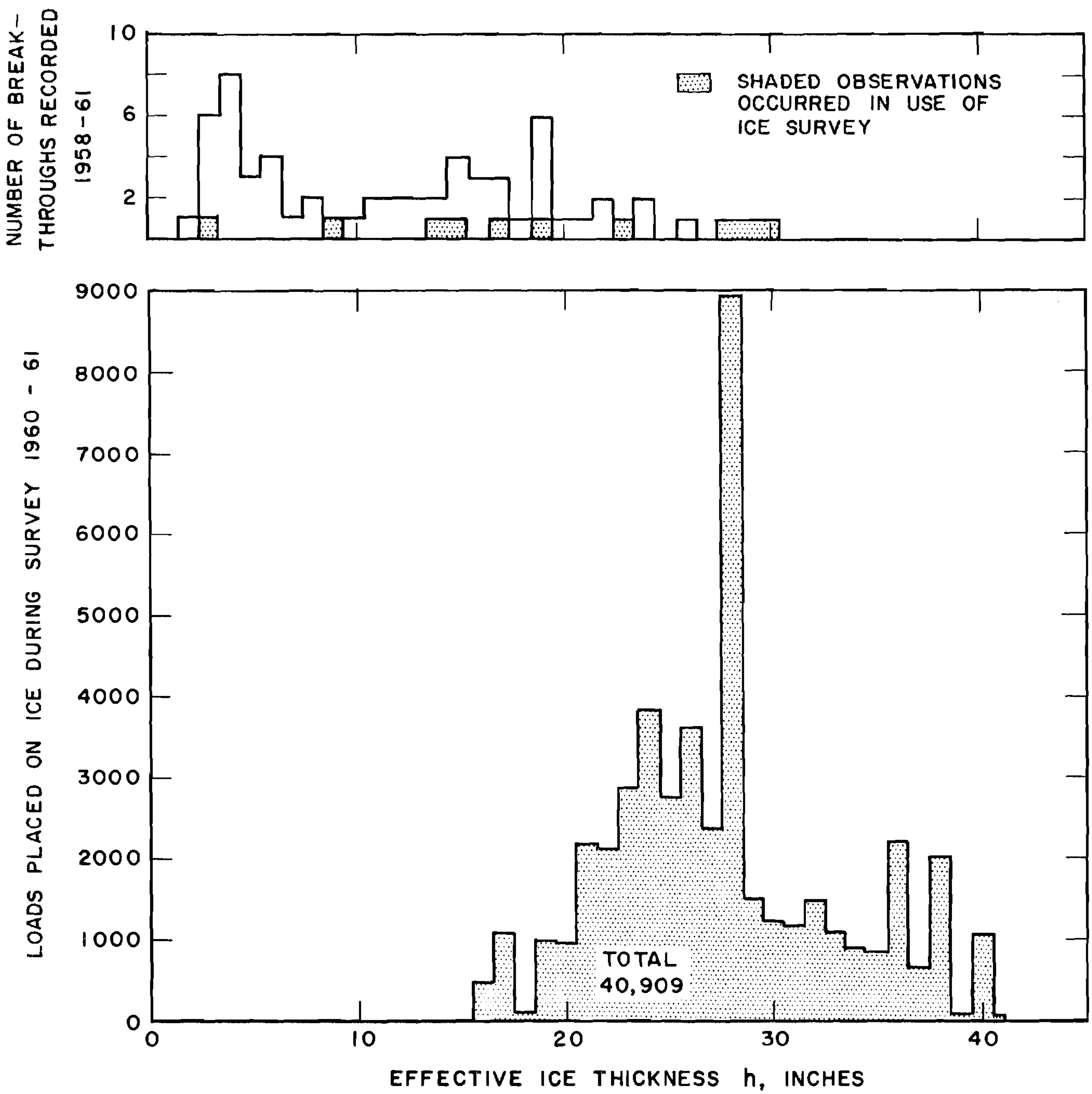

FIGURE 4

NUMBER OF LOADS PLACED ON ICE AND NUMBER OF BREAKTHROUGHS FOR EFFECTIVE ICE THICKNESSES IN STEPS OF ONE INCH

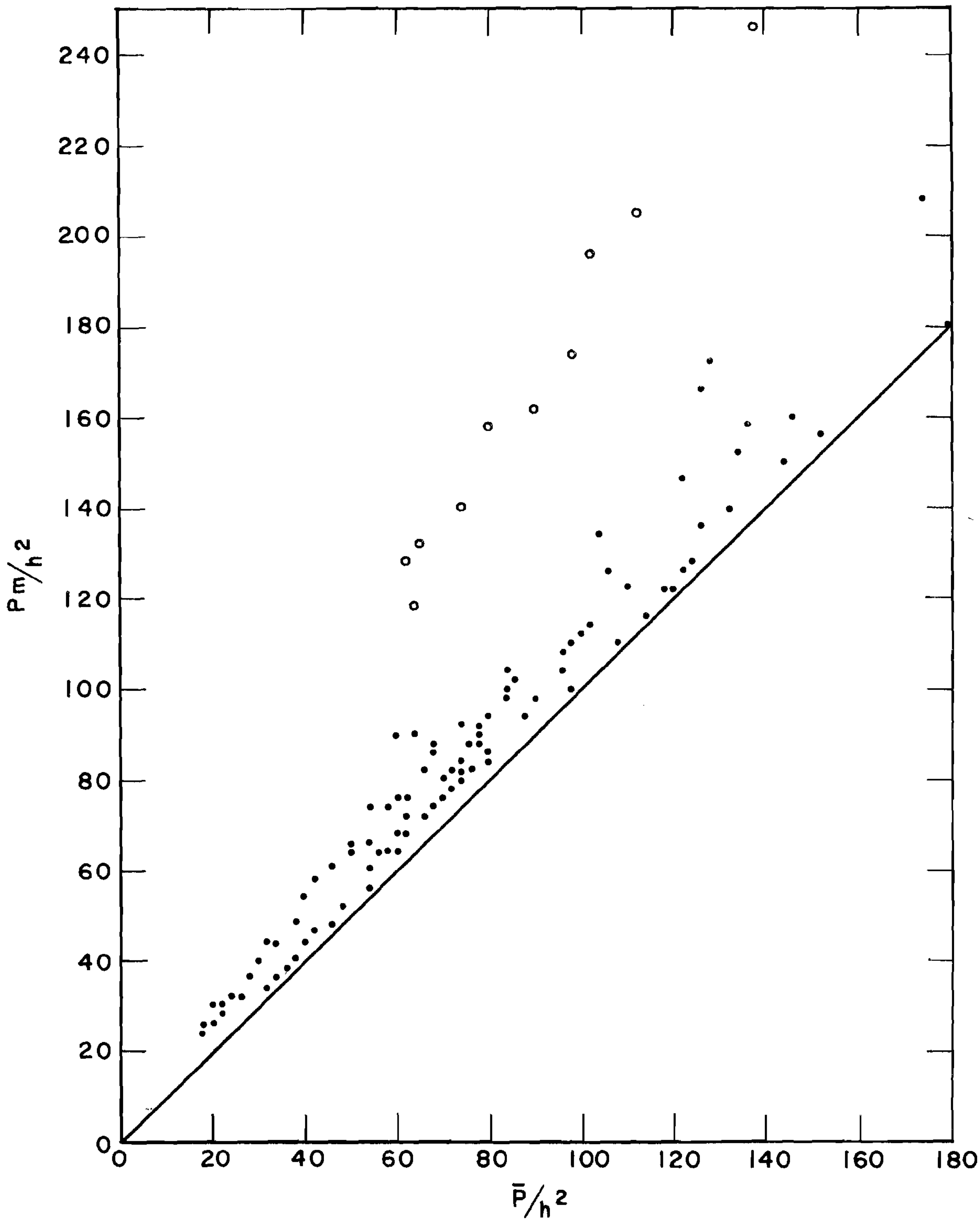

FIGURE 5

MAXIMUM LOADING OF ICE COVERS FOR EACH AVERAGE LOADING, P AND Pm IN LB, h IN INCHES

DR 2448-3