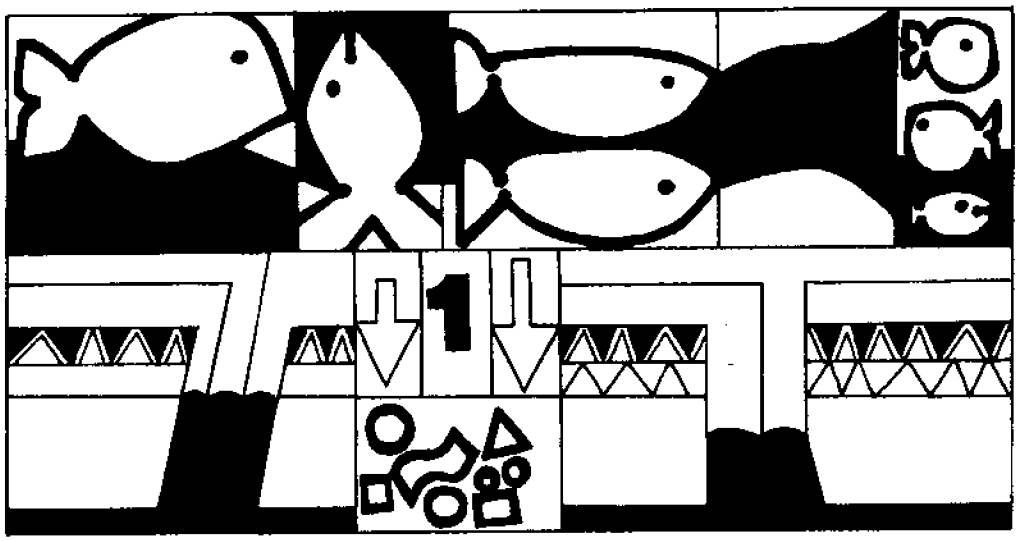
ICE ENGINEERING IN SMALL CRAFT MARINAS

An Annotated Bibliography



John P. Zarling

Sea Grant Advisory Report No. 8
University of Wisconsin

The University of Wisconsin Sea Grant College Program is sponsored by the National Oceanic and Atmospheric Administration's Office of Sea Grant, U.S. Department of Commerce, and by the state of Wisconsin.

SEA GRANT COMMUNICATIONS OFFICE
1800 University Avenue
Madison, WI 53706

WIS-SG-74-408

ICE ENGINEERING IN SMALL CRAFT MARINAS

An Annotated Bibliography

John P. Zarling
Engineering Science Division
University of Wisconsin-Parkside
Kenosha, Wisconsin

THE UNIVERSITY OF WISCONSIN SEA GRANT COLLEGE PROGRAM

ADVISORY REPORT #8

November 1974

ACKNOWLEDGEMENT

Professor John Klus and Professor Allen Wortley of the University of Wisconsin-Engineering Extension, and Professor Lon Ruedisili of the University of Wisconsin-Parkside are also participants in the Marina Ice Study project and their assistance is acknowledged. The author also expresses his thanks to Robin Rhodes and Dave Jacyna, Parkside students, and Mrs. Barbara Johnson, Parkside Engineering Science Division Secretary, for their efforts in the preparation of this bibliography.

This project was funded by the National Oceanic and Atmospheric Administration's Office of Sea Grant, U.S. Department of Commerce, through a grant to the University of Wisconsin.

ICE ENGINEERING IN SMALL CRAFT MARINAS

An Annotated Bibliography

by

John P. Zarling

INTRODUCTION

During the past fifteen years, there has been a rapid growth in the recreational boating industry. Paralleling this growth within the industry, the number of marinas and services offered by these marinas have also increased.

In the upper Great Lakes region, ice damage to marina facilities is an annual problem. Every year tens of thousands of dollars must be spent to repair marina facilities after experiencing ice damage. As a result, it was evident a need existed to conduct a study at this time which would aid all facets of marina operation confronted with ice problems.

The first stage of this study was the appointment of an Advisory Committee made up of representatives from educational instututions, govermental agencies, and the marina industry. During a one day seminar held in Madison, Wisconsin, the Advisory Committee identified three specific problem areas in which applied research was needed. These areas were: a) vertical ice forces on piles, b) horizontal ice forces on piles, and c) ice prevention/suppression techniques. As a second step in this study, a literature survey was conducted to assemble the information available related to ice engineering in small craft marinas. This annotated bibliography is the result of that survey and is to serve as a vehicle for those parties interested in the state of the art of ice engineering. The third step in this study will be to develop design aids and solutions to the problems identified based on current engineering practice and knowledge.

The bibliogrpahy contains over 400 references with annotations given for the majority of the entries. These entries were selected from a literature search conducted between September 1973 and August 1974. The literature survey covered the holdings of the University of Wisconsin libraries at Madison, Milwaukee and Parkside.

Also, bibliographic surveys published by the Cold Regions Research and Environmental Laboratory (U.S.A. CRREL) and the International Association of Hydraulic Research (I.A.H.R.) were reviewed. Finally, a number of reference materials were purchased in order to review and abstract these publications.

The annotations are abstracts, condensations, or direct quotes from the individual papers or from previous bibliographic publications. The entries are listed alphabetically by author. Near the end of this bibliography there is a subject index which will aid the user in finding previously published literature related to his research or design interests.

In the United States, the Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire, has had a contractual agreement for the past 20 years with the Library of Congress to perform a bibliographic service. This service consists of gathering bibliographic citations to monographs, research reports, journal articles, and other materials relevant to cold regions science and engineering. These citations are published as CRREL bound reports in order to disseminate this information to the scientific and engineering community. The CRREL organization also has a very extensive library holding relevant to cold regions science and engineering at their offices in Hanover, New Hampshire.

In Canada, the National Research Council in Ottawa serves a similar function as CRREL in the United States. There is also considerable ice research performed in the Soviet Union. English translations of some of the Russian literature exist and are noted in the bibliography.

1. Abraham, G., and Burgh, P.V.D. "Pneumatic Reduction of Salt Intrusion through Locks." Journal of the Hydraulic Division, Vol. 90, No. HY1, January 1964, p. 83-119.

   The investigation dealt with herein shows that a considerable reduction of intrusion of salt water through navigation locks can be obtained by releasing bubbles of air from perforated pipes placed on the bottom of the lock chamber. The bubbles of air create an upward flow of water that reduces the intrusion of salt water, provided that sufficient air is applied. A theory to determine the influence of the upward flow of water is developed. Theory and measurements made in difficult locks with depths of 5 m, 7-1/2m, and 10 m agree favorably. The presented data can be used to determine the required quantity of air under variable operation conditions.

2. Anderson, Per Fruensgaard. "Ice Free Harbours " Engineering Journal, July/August, 1972.

   Means of ice removal are discussed in this paper which would tend to solve harbour ice problems. Wave machines would be installed at the back of the harbour to produce waves which would:
   - prevent solid ice cover from forming in the harbour
   - move the formed slush ice out of the harbour into deeper water where incomplete ice cover and currents would remove it.

   The present paper will describe and model small scale tests required before proceeding with the study prototype harbour installations.

3. Alumbaugh, R. L., "Protective Coatings For Steel Piling, Results of 30-Month Tests," U.S. Naval Project Y-R007-08-401. June 1962. AD 278356.

   Eight coating systems selected from a previous study were evaluated by the laboratory as protective coating systems for steel piles. The systems were applied to both sheet and the piles. The coated piles were driven in the surf of the outer harbor at Port Hueneme and exposed for periods of 12 to 30 months. At the conclusion of the 30 month exposure period, all eight systems showed some coating deterioration resulting either from the driving operation or the exposure condition. The most severe damage was attributed to the action of the sea-water-sand slurry which caused moderate to heavy abrasion damage, just above the mudline, to all the systems.

4. Anderson, Per Fruensgaard, "Ice Free Harbours " Engineering Journal, Montreal, 55(7-8): July-Aug. 1972, 23-31.

   Presented at: Engineering Inst. of Canada, Annual Meeting. (Held in Aue., Can., Sept. 1971).

   Means of maintaining ice-free harbors are investigated. The installation of wave machines at the back of the harbor is proposed to prevent solid ice cover from forming in the harbor

and to move the slush ice out of the harbor into deeper water where incomplete ice cover and currents would remove it. Results of experiements with bubble machines are included. The wave action concept of ice prevention and removal is feasible, particularly for salt water ports. The use of wave machines to keep harbors free of ice could significantly extend the shipping season.

5. Anderson, "Preliminary Results and Review of Sea Ice Elasticity and Related Studies," Trans. Eng. Inst., Canada, Vol. 2, No. 3, September 1958.

   There are many methods of determining elasticity that can be used on ice. These can be divided into laboratory and field studies, and further divided into static and dynamic determinations. Two field methods are deflection and seismic. Preliminary results from a mass of data include that the elasticity of sea ice is less than that of fresh ice. Preliminary analysis indicates that elasticity can be related to a parameter which includes temperatures, liquid- and air-content.

6. Andrews, J. T., "Estimating the Strength of Lake Ice." New Scientist, Vol. 17, March 28, 1963, p. 702-705.

   Outlines factors affecting lake ice growth and regional variations in ice quality. Reference not in Engineering Societies Library and not verified.

7. Anonymous, De-icing overhead lines, Water Power, 18, 1966 No. 1, Jan., pp. 41-42.

   A description is given of a promising device for de-icing lines recently developed. The device consists of an aluminum-jacketed low curie temperature alloy core which is fitted round the line conductor in the form of a sleeve.

8. Anonymous, Manual of Ice-Formation Forecasting for Rivers and Inland Lakes, Leningrad, State Publ. House of Hydrology and Meteorology, 1963, 290 pp.

   Contents: Forecasting of floating-ice formation on rivers;
   forecasting of ice-cover formation on rivers;
   forecasting of ice-cover formation on lakes and reservoirs;
   forecasting of ice-cover thickness;
   forecasting of ice-cover break-up on rivers;
   forecasting of ice-free periods on lakes and reservoirs;
   forecasting of ice jamming and water levels during ice jamming
   (in Russian)

9. Are, F. E. and Balobaev, V. T., "Protection of Ground Against Winter Freezing by an Air-Ice Cover." 1965 (Zaschita grunta ot zimnego promerzaniia pri pomoschchi vozdushno-ledianogo

pokrytiia.) Akademiia Nauk USSR, Sibirskoe Otdelenie, Institut Merzlotovedeniia. Moscow: Ixd-vo Nauk, p. 82-93.

Different types of air-ice covers, consisting of ice layers separated by air, are discussed and their thermal conductivities evaluated mathematically. It is recommended that layer thickness be held to a minimum, thus increasing the heat protection effect of the covers, the depth of the water layer on the ground being the same. The surface ice layer must be thick enough to withstand the weight of a man with an instrument and the weight of snow cover; the underlying layers must be much thinner. The thickness of air layers is determined by the possibilities of maintaining water level to the least required depth while that of the underlying ice layers is determined by the capability of withstanding their own weight. From SIP 25697.

10. Are, F. E., "Thermal Conductivity of Air-Ice Covers," 1965 (Teploprovodnost vozdushno-ledianykh pokrytii.) Akademiia Nauk USSR, Sibirskoe Otdelenie, Institut Merzlotovedeniia. Moscow: Izd-vo Nauka, p. 73-81.

The term "air-ice" cover is used for a layer of ice, supported above ground by short wooden or concrete pillars, which protects the ground against winter freezing. Such a cover is obtained by flooding the ground with a layer of water of certain thickness and letting it freeze down to 20-30 cm with subsequent evacuation of the remaining water. The air-ice cover is widely used in practice, the dimensions usually being estimated intuitively. The author presents a method of calculating thermal conductivity coefficients of ice and air interlayers, and a detailed discussion of the optimal dimensions of the cover and their calculation. From SIP 25696.

11. Ashton, George D. and Kennedy, John F., "Ripples on Underside of River Ice Covers." Journal of the Hydraulics Division, ASCE, Vol. 98, No. HY9, Proc. Paper 9191, September 1972, p. 1603-1624.

A mathematical model is developed to predict the occurrence and describe the properties and behavior or ice ripples that form on the underside of river-ice-covers. The local rate of freezing or melting at the ice-flow interface is realted to the difference between the local heat transfer rates by conduction through the ice and by turbulent transfer from the flow to the ice. The local heat flux to the interface from the flow is expressed as a small perturbation expansion in terms of the steepness of the monochromatic interfacial wave, and is assumed to be shifted relative to the interface wave. The analysis yields a stability criterion and expressions for the amplication rate and celerity of the ripples. Laboratory data are used to obtain values for the constants introduced into the theory and to corroborate the analytical results. Field data are examined in the light to the laboratory results.

12. Ashton, G. D., and Kennedy, John F., "Temperature and Flow Conditions During the Formation of River Ice." IAHR Ice Symposium, Reykjavik, Iceland, 1970.

    An investigation of the temperature and velocity characteristics of flow in rivers during the onset and occurrence of ice covers is described. Vertical and lateral temperature and velocity distributions, and ice thickness and configuration were measured in an Iowa river at frequent intervals during the period of ice cover. Variations in the lateral and vertical temperature distributions are reported. The undersurface of the ice was observed to remain plane as the ice thickened and to become wavy as the ice melted. The shear velocity associated with the wave forms are determined. Just prior to breakup the ice was observed to become very porous in the lower portions of the ice cover. Preliminary observations of the diurnal temperature variation prior to the formation of an ice cover are described.

13. Ashton, George D. and Uzuner, M. Secil and Kennedy, John F., "Two Investigations of River Ice" sponsored by Rock Island District US Army Corps of Engineers Contract No. DACW 25-69-C-0098, IAHR Report No. 129, Iowa Institute of Hydraulic Research, The University of Iowa, Iowa City, Iowa, Oct. 1970.

    An investigation of the temperature and velocity characteristics of flow in rivers during the onset and occurrence of ice covers is described. Vertical and lateral temperature and velocity distributions, and ice thickness and configuration were measured in an Iowa river at frequent intervals during the period of ice cover. Variations in the lateral and vertical temperature distributions are reported. The undersurface of the ice was observed to remain plane as the ice thickened and to become wavy as the ice melted. The shear velocity associated with the wave forms was determined. Just prior to break up the ice was observed to become very porous in the lower portions of the ice cover. Preliminary observations of the diurnal temperature variation prior to the formation of an ice cover are described. This paper was presented, with minor modifications, at the IAHR Ice Symposium, Reykjavik, September 1970. The laboratory investigations included studies to determine the critical velocity at which a broken ice cover becomes unstable, an investigation of the reformation of ice after passage of an ice breaker, and the characteristics of ice during formation. Several stages in the instability behavior of a broken ice cover were noted and the associated critical velocities were compared with a criterion proposed previously. The effect of a channel on the rate of thickening of the ice cover was determined. Ice experiments were conducted using the Iowa low temperature facility. Supplemental experiments using simulated ice were also conducted in a glass-walled tilting flume.

14. Ashton, George D., and Kennedy, John F., "River-Ice Problems: A State-of-the-Art Survey and Assessment of Research Needs," Journal of the Hydraulics Division, ASCE, Vol. 100, No. HY1, Proc. Paper 10281, January, 1974, pp. 1-15.

The problems associated with river ice are examined, the current state-of-the-art is reviewed, and recommendations for future research are made. The highest research priorities are assigned to the topics of formation processes or river ice, ice jams, ice forces, and heat exchange processes and the effects of thermal enrichment. A number of other problems that merit attention are delineated and include ice formation on submerged surfaces, properties of ice, friction factors, sediment transport in rivers with ice, design of water intakes for ice conditions, formation of icings and river glaciations, glacial outbursts, and ice formation at navigation locks.

15. Assur, A., "Breakup of Pack-Ice-Floes," Ice and snow; properties, processes, and applications. Ed. by W. D. Kingery Cambridge, Mass., M.I.T. Press, 1963, p. 335-347, Microform No. SIP 22059. GB2405.K55 26-3532. Misc. Publication 40.

Long-wave cracks are mathematically analyzed on the basis of plate mechanics, and other forms of cracks are discussed. Long-wave cracks form with complete disregard of thickness and shape of the floes. They form instantaneously, the crack propagation is fast; there is no way to predict the location of a crack to be formed; and the ice floe, once split, drifts apart in a matter of minutes. Parallel-edge cracks running closely alongside existing edges are by far the most common. They form 12 to 15 m from the edge under combined bending and buckling originating from the pressure exerted from a neighboring floe. Perpendicular-edge cracks which form at fairly uniform distances of 50 to 100 m apart, are more dangerous for the existence of an intact ice floe. They may propagate beyond the parallel crack into the ice floe and give reason for concern and action on behalf of the occupants of an ice floe.

16. Assur, A., "Bearing Capacity of Floating Ice Sheets," American Society of Civil Engineers. Engineering Mechanics Division Journal, June 1961 87(EM 3) p. 63-66 3 refs. Microform No. SIP 19298. 26-3533. Miscellaneous Publications 41.

Meyerhof's calculation of the collapse of ice sheets (See SIP 18826) is criticized on the basis of field and laboratory work conducted by USA CRREL. That the idealized stress distribution leading to the full plastic bending movement does not correspond to the actual stress in an ice sheet may hold for fresh ice and quick loading, but may be proper for prolonged loading and especially for sea ice. The assumption that the hydrostatic reaction is confined within the hinge circle is unfounded, since experiments indicate considerable deflection at the circumferential hinge until collapse occurs. The assumption that the hinge radius is equal to the radius of the deflection dish is also incorrect. The circumferential crack occurs well within the deflection radius and at the place where the elastic theory predicts max. radial stress. The conditions for this location are calculated and also considered on the basis of A. Johansen's concept of yield line.

17. Assur, A., "Flexural and Other Properties of Sea Ice Sheets," International Conference on Low Temperature Science, Sapporo, Aug. 14-19, 1966, Proceedings, Vol. 1, Part I, Sapporo, Institute of Low Temperature Science, Hokkaido University, 1967, 557-567.

Physics of sea ice has now advanced to the point that one can predict composite properties of sea ice sheets on a rational basis. This leads to a synthesis on the basis of past analysis. For practical purposes nomograms of computer techniques can be developed, with easily measured quantities as input. The foundation for such methods is laid in this paper. The composite properties discussed are: zero strength and deformation layer, neutral layer, average crushing strength and Young's modulus, flexural strength, plate rigidity, action radius as well as failure mechanism. The principal assumption underlying the future construction of nomograms from equations is a linear temperature profile and constant salinity. For computer techniques a more flexible polynomial approach is suggested. The basical physical parameter invariably is the brine volume which can be calculated from temperature and salinity. Only surface temperature could be used under simplifying assumption, but profile data at least for four points are suggested for computer techniques. Comparison with test data is now proceeding.

18. Assur, Andrew Dr., "Structures in Ice Infested Waters." IAHR Symposium, Ice and Its Action on Hydraulic Structures, Leningrad, USSR, 1972.

A method is presented to calculate the effective ice load on vertical structures depending upon width of structure related to ice thickness and fundamental ice properties (anisotropic semi-restrained crushing strength, Young's modulus, Poisson's ratio, internal friction). The basic equation satisfies the theoretical indentation solution for a narrow pile and approaches exponentially the crushing value for a straight wall. Both extremes appear as simple intercepts on a plot which furthermore can be linearized. The concept is compared with largely Russian test material and equations which show good agreement. Internal friction must be considered in the analysis since it increases possible ice forces. Due to this local indentation forces by ice can be higher as previously assumed for the design of ships. Buckling instability introduces complication in model tests. For structures in the field the random configuration of ice collars must be considered. For this a complete solution is still not available.

19. Assur, A., "Maximum Lateral Pressure Exerted by Ice Sheets," IAHR 8th Congress Montreal 1959, Sem. I, pp. 22-SI-1-5.

An ice sample, being warmed, exerts pressure against confined ends, which can be measured in the laboratory. This knowledge can be applied to ice sheets in nature if the penetration of a temperature wave from the surface into the ice is known. The maximum force, however, exerted by the ice sheet against

confining structures might be limited by failure in buckling. A few steps towards final solution are proposed in this paper.

20. Aune, C. A., Beaudin, L. A. and Borrowman, J. K.,"Effects of Ice on Inland Navigation," 19th Assembly of the PIANC, London 1957, SI, C3, pp. 71-94.

    The two great "fresh water" systems of N. America, the Great Lakes and the Mississippi River and principal tributaries more sensitive to low temperatures than the saline tidal waterways, are described. Climatic conditions. Types of ice encountered. Seasons of navigation. Types of navigation. Ice effects on movements and safety of vessels. Measures to cope with ice. Ice forecasting.

21. Bader, H., "Density of Ice as a Function of Temperature and Stress." U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) Special Report 64 (AD 448069), 1964.

    The equations of calculating the density of ice of moderate porosity (density more than .8) as a function of temperature and stress conditions are developed, and the values of parameters are calculated from best available experimental data.

22. Baines, D. W., "On the Transfer of Heat from a River to an Ice Sheet." Presented at 1961 Hydraulics Conference, American Soc. of Mech. Eng. and the Eng. Inst. of Canada. Montreal, 8-11 May 1961.

23. Baines, W. Douglas, "The Principles of Operation of Bubbling Systems." Proceeding of the Symposium on Air Bubbling, TM70 N.R.C., Ottawa, May 11, 1961.

    The function of the air bubbler is to increase the transport of heat from a body of water to the ice cover or open upper surface. Ideally, the air bubbler should be designed for the minimum rate of heat transport so that the heat in the lake or river will be available for the maximum length of time. This is not feasible because of many gaps in the theory but enough is known of the heat flow so that the general principles of operation can be delineated making it possible to avoid serious mistakes in the design of air bubblers. The source of heat for the air bubbler lies in the excess temperature in the lower layers of the water. The bubbler induces a vertical current of water which carries this heat to the upper levels and against the under side of the ice sheet. Thus it is the flow pattern of the water current which is of primary interest to the engineer. From an experimental study of this flow pattern and some field observations, the author has obtained a detailed picture of the general characteristics.

24. Balanin, V. V., and Ivanov, L. V., "Calculation of a Flow Forming Unit for Protection of Docks from Floating Ice-Blocks," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

    When placing ships into floating docks in winter, many difficulties connected with the penetration of drifting ice

(together with the ship) into the dock are likely to arise. To prevent the case, stream forming devices may be efficiently used. In this work are obtained the dependences allowing to establish rational disposition of flow forming units along the floating dock and their main parameters for protection of slipdeck from floating ice-blocks when towing the ship and lifting the dock up.

25. Balanin, V. V., Borodkin, B. S., Melkonian, B. I., "Utilization of Deep Water Heat in Reservoirs for the Maintenance of Unfrozen Water Areas," 1970 275p. AD-716 306 Translation of Ispol'zovanie tepla glubinnykh vod vodoemov dlia podderzhaniia nezamerzaiushchikh akvatorii. Moscow, Izd-vo Transport, 1964. 121 refs. 25-2430. CRREL Draft Translation 12.

Laboratory and filed data are presented on measures for maintaining water areas in reservoirs in an unfrozen state by using the heat of deep waters. The thermal regime of reservoirs and the physical principles of the methods of utilizing water heat are reviewed. Descriptions and diagrams are provided of various installations in use at dam gates, navigable locks and canals, port and ship-building facilities, etc. Laboratory investigations include kinematics of lifting bottom waters by air bubbles, the phenomenon of air outlet freezing, and air movement in a perforated pipe used to keep a water area ice-free by compressed air. Theories and computations are provided for the operation of pneumatic installations and flow generators and maintaining a pool of unfrozen water during transfer of warm deep water from one reservoir to another.

26. Balderston, C., "Ice Inside Cast Iron Column Raises Floor." Eng. News Record, v. 84, 1920, p. 1166.

Relates a case of ice formation inside a cast iron column which resulted in lifting the column several inches off its base and pushing a heavy granite sidewalk a like distance.

27. Barnes, D. F., "Preliminary Measurements of the Strength of Melting Lake Ice,"Transactions of the E.I.C., Vol. 2, No. 3, September 1971.

The strength of the ice sheet covering permanently frozen Angiussaq Lake in Greenland was studied during the summer of 1957. The ice temperature remained at the melting point for more than two months during which the thickness decreased from 12 to 6 feet. In-place, cantilever beams cut in the ice gave breaking strengths of 20-30 psi. or 1.5-2.0 kg/cm^2, but vertical slits cut in these beams showed that approximately the upper 20 inches of the ice sheet had essentially no strength. Accordingly the lower part had a strength fairly close to that of cold ice, but the development of bubbles in this lower ice reduces the effective beam cross section by about a quarter. The ability of the sheet to support loads of as much as 100,000 lb. is confirmed by the presence of rock piles which have rested on the ice for at least five years.

28. Barnes, H. T., "Crushing Strength of Ice," Royal Soc. of Canada, Trans. Ser. 3, v. 8, 1914, Section 3, pp. 19-22.

C. A. Mees concluded that the crushing strength of ice might reach as high as 800 pounds in a short column. He says, however, "Wherever the effects of ice expansion have been carefully observed, it has been noted that bending takes place, and this may be expected because we have a long column effect." On this account assuming one has the crushing strength may be developed before bending, the maximum thrust may equal about 400 pounds per square inch. The author states: Probably the best experiments have been made by George G. Ball; if we neglect his highest result, which appears to be too high, we find values more consistent ranging from 358 to 783 pounds. Details of author's experiments are given.

29. Barnes, H. T., Ice Engineering, Montreal: Renouf Publishing Co., 1928, 364 p.

This book discusses the molecular bonding of ice, the physical properties of ice (density, specific heat, elastic constants, etc.), the formation of sheet ice including the heat transfer conditions and the mathematical analysis of the rate of formation of the ice sheet. The author also considers the force created by the thermal expansion of the ice sheet and gives data on the magnitude of these forces.

30. Barnes, H. T., Hayward, J. W. and McLeod, N. M., "Expansive Force of Ice," Royal Soc. of Canada, Proc. Ser. 3, v. 8, 1914, Section 3, pp. 29-49.

Table of coefficient of expansion of ice; observations made by the authors on the ice in the Montreal filtration chambers, 1914; conclusions as result of preliminary study of ice expansion, it is found that: (1) the crushing strength of ice is most probably 400 lbs. per sq. inch; (2) an ice block will yield under pressure at approximately 200 pounds per sq. inch, which is probably due to the slipping of the crystals; (3) an ice sheet will form cracks on the upper and under surface due to unequal strain; (4) that a permanent expansion may result if the cracks become filled and frozen; (5) according to the most trustworthy results of other observers, the ice frozen to concrete develops its full crushing strength, and the tensile strength of ice is under 200 lbs. per sq. inch.

31. Bayley, F. J., and Lock, G. S. H., "Heat Transfer Characteristics of the Closed Thermosyphon," Journal of Heat Transfer, Transactions of the American Society of Mechanical Engineers, February, 1965, pp. 30-40.

This paper describes a series of closely controlled experiments made to investigate the performance of the closed thermosyphon. All the regimes previously observed in the open system were identified, and suggestions are made concerning the nature of the process by which the heated and cooled regions of the thermosyphon are hydrodynamically coupled together. A theoretical analysis of the laminar boundary layer regime is given and comparisons made with the experimental results.

32. Beccat, R. and Michel, B., "Thrust Exerted on a Retaining Structure by Unconsolidated Ice Covers," IAHR 8th Congress Montreal 1959, Sem. I, pp. 11-SI-1-3.

The force, per unit width, acting on an unconsolidated ice cover expressed by: p = pd + ps + pv + pg (where p = total force at a normal section of flow; pd = hydro-dynamic thrust on the frontal edge of the cover; ps = force exerted by water friction; pv = thrust exerted by wind friction on the cover, and pg = weight component of the cover) are investigated.

33. Beebe, K. E., "A Preliminary Study of Force in Ship Moorings Due to Wave Action," Series 91 and 92, Issue 1, University of California, Berkeley, AD 74611, July 1955. From NOy-73260.

A series of experiments was performed to determine the forces induced in weightless cables mooring a rectangular block which was subjected to wave action, for a particular set of mooring cable conditions. The purposes of this study were to extend the experimental work of a previous study to a wider range of wave conditions, and to attempt to predict changes in mooring cable forces qualitatively for a large range of wave dimensions. The results are summarized in graphical form, with the forces exerted on the mooring system presented as a function of wave length and height.

34. Begemann, H. K. S. Ph., "The Maximum Pulling Force on a Single Tension Pile Calculated on the Basis of Results of the Adhesion Jacket Cone," Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering, Volume II, 1965, pp. 229-233.

With the adhesion jacket cone both the cone resistance and the local friction of the various layers can be measured. By means of the ratio between these two, the type of soil can be identified. On the basis of results of various pulling tests a calculation method has been developed making it possible, on the strength of the cone resistance and local friction measurements, to compute the maximum pulling force both for a continuous load and for fluctuating loads. Furthermore, the shape of the pile point and the pile system prove to have an influence which can likewise be allowed for in this method.

35. Bellmond, E. de, "On the Increase of Friction Loss Due to Surface Ice," IAHR 8th Congress Montreal 1959, Sem. I, pp. 26-SI-1-3.

Additional loss of head due to ice formations in streaming water can be caused by additional friction on the ice covered surface or by anchor ice on the bottom of the stream. Frazil ice, if any, can further restrict the free passage of water. Considerable backwater will arise of course when obstacles are formed in the controlling sections of flow. This paper

deals only with the frictional loss of head caused by recently formed smooth surface ice. This loss was measured between two gauges 1600 m (one mile) apart in the open earth canal with uniform cross-sections.

36. Beukema, Christian F. (Remakrs) "Seminar on Extension of Shipping Season." Seaway Review, Vol. 1, No. 4, 1970.

This is a report on the extension of the shipping season until February 2nd by seven ships of the U. S. Steel Corporation. The project also required the assistance of the U. S. Coast Guard and the U. S. Corps of Engineers. Though there was some trouble with ice at times, the ships were able to transport their cargo at a cost less than the cost of using less efficient vessels to carry this cargo during the regular shipping season. Furthermore, there was no appreciable ice damage to the ships during the extended season. When U. S. Steel had attempted to send ships out in early April, during the normal shipping season, there had been extensive damage to their vessels.

37. Bidde, Devidas D., "Laboratory Study of Lift Forces on Circular Piles," Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol. 97, No. WW4, Proc. Paper 8495, November 1971, pp. 595-614.

Ocean waves exert lift (i.e., transverse) forces on piles under some circumstances in addition to the longitudinal forces. The lift forces are related to the formation and shedding of eddies. The lift forces were found to be as great as 60% of the longitudinal forces. The Keulegan-Carpenter number is found to be a reasonable parameter to determine the regime in which eddies form and to be related to the ratio of the lift to longitudinal forces. Eddies form in the lee of a vertical cylindrical pile subject to water waves when the Keulegan-Carpenter number has a value of about 3. For higher Keulegan-Carpenter numbers two eddies are developed and shed and the lift force is more or less regular with a frequency twice the frequency of the waves. For further increase in the Keulegan-Carpenter number turbulence develops and the lift forces show a random pattern. The ratio of the lift to the longitudinal forces appears to be at a maximum for a Keulegan-Carpenter number of about 15.

38. Bilello, M. A., "Formation, Growth, And Decay of Sea Ice in the Canadian Artic Archipelago," July 1960, 18 p. plus 16 p. appends. U.S. CRREL, AD-653 137 16 refs. 24-3223 Research Report 65.

Equations relating the accretion and decay of sea ice to standard meteorological data are derived empirically from observations at 5 stations (Alert, Eureka, Isachsen, Mould Bay, and Resolute) with varying periods of record from 1947-1957. The equations differ from existing formulas in that they are differential in nature, to permit calculation of ice growth by

increments, and contain a separate term allowing for variations in snow-cover depths. The use of the formulas requires only a knowledge of air temperatures and snow depths. A good correlation is found between the decrease in ice thickness and accumulated degree days above -1.8C. The location of each station, the names of the surrounding water bodies, and the approximate water depths where ice thickness measurements were made are listed in Appendix A; the techniques used in the measurements are described in Appendix B.

39. Bilello, M. A., "Method for Predicting River and Lake Ice Formation," Journal of Applied Meteorology, Feb. 1964 3(1), p. 38-44, 5 refs. Microform No. SIP 22923. U.S. CRREL Miscellaneous Publication 64.

    Two sets of curves are developed which can be used to forecast the dates of: 1) first appearance of ice in the fall; and 2) ice formation from shore to shore on the Mackenzie River at Fort Good Hope, Canada. Similar curves, based on the same method, can be derived for sheltered harbor, lake and river locations. The numerical constants necessary to develop these curves were obtained from a relationship between mean daily air temperatures and previously observed dates of ice formation. To apply the curves, an adjusted temperature record, based on a numerical constant (N) and daily air temperatures, is maintained starting in early summer. Subsequently, this daily-adjusted temperature is applied to the family of curves to provide a day-to-day forecast of the date of the ice formation.

40. Bilello, Michael A., "Water Temperatures in a Shallow Lake During Ice Formation, Growth and Decay," Research Report 213, U.S. Army Material Command, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Dec. 1967 20 p. AD-696 408 35 refs.

    Continuous water temperature measurements were made in a shallow lake in upper Michigan prior to and during ice formation, and during ice growth and decay. Several full circulations or "overturns" at 4.C were observed during autumn and the temperature throughout the lake just prior to complete freeze-over reduced to a minimum of 0.2C. After a permanent ice cover had formed, the water beneath the ice began to warm up. Within a 25-day period during December the water temperature near the bottom of the lake increased from 0.3C to 3.0C. Quantitative analysis of this heat gain showed that it came principally from the energy stored during the summer in the underlying soils. During the ice thaw period in April a unique reduction in temperature was recorded throughout the main mass of water.

41. Bilello, M. A., "Ice Prediction Curves for Lake and River Locations in Canada," Cold Regions Research and Engineering Laboratory, Research Report 129, Hanover, N. H., July 1964.

A series of curves were developed which can be used to forecast the date of ice formation at 1 bay, 10 lake and 17 river locations in Canada. The numerical constants necessary to develop these curves were obtained from a relationship between mean daily air temperatures and previously observed dates of ice formation. Two ice formation periods are considered (1) first appearance of ice in the fall; and (2) the date of complete ice coverage. For 19 stations, however, numerical constants and forecast curves are derived for only one of the periods because of insufficient data. To apply the curves, an adjusted temperature record, based on a numerical constant (N) and daily air temperatures, is maintained starting in early summer. Subsequently, this daily-adjusted temperature is applied to the family of curves to provide a day-to-day forecast of the date of ice formation. The procedure is discussed in detail, using Fort Good Hope as an example.

42. Bligh, W. G., "Dams and Weirs," Am. Tech. Soc. Chicago, 1915, pp. 206.

Discussion concerning the necessity of considering ice pressure in designing dams, bridges and reservoirs.

43. Bock, H., "Ice-breaking on Navigable Rivers with and without Power Plant Ponds." 19th Assembly of the P.I.A.N.C. London 1957, SI, C 3, pp. 37-50.

Recently, the use of waters of navigable rivers has also been claimed by the power industry, thus altering the winter regime of such rivers by operating the plants necessary for this purpose. In this paper the nature of these alterations and their extension are discussed on the basis of practical experience gained on the Danube.

44. Boger, D. V., and Westwater, J. W. "Effect of Buoyance on the Melting and Freezing Process." Journal of Heat Transfer, Transactions of the American Society of Mechanical Engineers, February, 1967, p. 81-89.

Measurements were made of interfacial velocities and transient and steady-state temperature profiles during the freezing and melting of water in a 0.5 x 0.5 x 2-in high test chamber. Heat flow was one-dimensional, up and down. Tests both included and excluded the density-inversion temperature of 4 deg C. Freezing at the top and at the bottom, melting at the top, and at the bottom, all were achieved by selection of cold-end temperatures between -50 and -5 deg C and hot-end temperatures between 3 and 97 deg C. Runs included conditions with buoyancy forces in the liquid, with buoyancy forces existing but insufficient to cause convection, and with natural convection occurring at all times.

45. Bogordskii, V. V., "Elastic Properties of Ice," Akusticheskii Zhurnal, Vol. 4, Jan-Feb 1958, p. 19-23.

Describes measuring apparatus, and tabulates data obtained for river, lake and sea ice. The effects of temperature, density, and age of the ice on its elastic properites and variations of the Posson ratio in particular are discussed. (The magazine is translated cover to cover, under the title "Soviet Physics - Acoustics," and may be obtained from the American Institute of Physics, 335 East 45th Street, New York, N. Y. 10017).

46. Bonisteel, W. D. and Bergs, A., "Investigation of a Compressed Air Bubbler System Used for Ice Melting," Proceedings of the Symposium on Air Bubbling, TM70, N.R.C., Ottawa, May 11, 1961.

The building of a highway between Atikokan and Ft. Frances, Ontario necessitated the building of a bridge over Rainy Lake. After the first two sections of the bridge were completed, a bubbler system was installed to limit the effect of ice pressure on the steel piles supporting the structure. It was found that the system used would not melt an ice cover if the thickness was 6 in. or greater but it would prevent it from building up and damaging the bridge. The author suggested that a system be designed that would flush out water from the pipes in a more reasonable amount of time.

47. Bouthilier, Patrick H., "Oxygen Depletion in Ice Covered River," Journal of the Sanitary Engineering Division, ASCE, Vol. 98, No. SA2, Proc. Paper 8841, April, 1972, pp. 341-351.

Oxygen use in the Red Deer River is compared to stream loading. The drop in dissolved oxygen levels below the City of Red Deer is related to the change in biochemical oxygen demand (BOD) and to the change in total organic carbon (TOC) in a 50 mile (80 km) stretch of river. The oxygen used in the river approximates 2.7 times the drop in BOD -5-20 and is approximately equal to the drop in TOC. A rate constant for dissolved oxygen use in the river is computed as 1.0 per day (natural log). Some 95% of oxygen depletion occurs in 40 mile (65 km) of river.

48. Bowen, I.S., "The Ratio of Heat Losses by Conduction and by Evaporation from any Water Surface." Physical Review, Vol. 27, June 1926, p. 779-787.

It is shown that the process of evaporation and diffusion of water vapor from any water surface into the body of air above it is exactly similar to that of the conduction of "diffusion" of specific heat energy from the water surface into the same body of air. Because of this similarity it is possible to represent the ratio R of the heat loss by condution to that by evaporation by the formula

$$R = .46 \left(\frac{T_w - T_a}{P_w - P_a}\right)\frac{P}{760}$$

where T_a and P_a are the original temperature and vapor pressure of the air passing over the lake, and T_w and P_w are the corresponding quantities for the layer of air in contact with the water surface. The substitution of R times the evaporation loss for the value of the conduction heat loss in the Cummings equation for evaporation makes it an exact equation for the determination of evaporation from any water surface in terms of the net radiant energy absorbed by the water and the heat stored in the water.

49. Brill, Rudolf, "Structure of Ice," U.S.A. Snow, Ice and Permafrost Research Establishment, Corps of Engineers, SIPRE Report 33, 1957, 67 p. AD-149 029 24-3024.

The procedures for growing samples of ice used in the experiments are described. Experiments using the method of bending bars of ice to determine their viscoelastic behavior were made. Tests were conducted on single crystals with various orientations, polycrystalline samples, and mixed crystals of ice-NH4F. These tests showed that the hexagonal base plane is the gliding plane at plastic deformation and that Becker's equation can be used for description of the viscoelastic creep of ice. Studies show that amounts up to 10 percent of NH4F may be absorbed in the ice lattice. Dielectric studies indicate that the relaxation time decreases markedly with increasing concentration of NH4F, down to a minimum value corresponding to some concentration between 0.1 and 1 percent NH4F, and then increases again with further increasing concentration.

50. Brill, Rudolph and Camp, Paul R., "Properties of Ice,"USA SIPRE, Research Report 68, 1961, 75 p.

This report summarizes the results of a number of studies on ice performed by researchers at the Polytechnic Institute of Brooklyn during the period 1955-59. Section of the report are entitled as follows: growth of large crystals of ice and ammoniumfluoride; degree of perfection of glacial ice crystals; thermal motion in ice and heavy ice; viscoelastic properties of ice; dielectric relaxation; effect of pressure on dielectric relaxation.

51. "Bubble Bubble No Trouble" by Staynew Filter Facts. Compressed Air Magazine, March 1960, p. 23.

Maine winters are mighty cold. To combat subzero temperatures and keep water flowing over its dam at the Weston Station at Skowhegan, the Central Maine Power Company has installed an air-operated deicing system. Twin dams supply the hydraulic power for the 12,000-kw Skowhegan facility. The north dam has a bubble system that agitates water along the dam face, the washboards and gates. This air agitation raises water from the bottom preventing freezing. Air for the bubbles comes

an Ingersoll-Rand 450x8 Axi-compressor located in a building on the north shore. This is a 1-stage positive displacement unit driven by a 20-hp electric motor. It provides 190 cfm of air at 15-psig pressure. A Dollinger Staynew D5-250-B5 filter prevents entrance of dirt or contaminants that would harm the compressor or clog the bubble holes in the system's piping. Sixteen square feet of active filtering area are contained in the filter. The air travels to the strategically located perforated pipes and the north dam is kept ice-free and functioning even when temperatures dip to minus 30°F.

52. Bulson, P. S., "Currents Produced by an Air Curtain in Deep Water – Report on Recent Experiments at Southhampton." The Dock and Harbour Authority, May 1961, p. 15-22.

Large scale tests were undertaken in August 1960 in the Trafalgar Graving Dock, Southhampton, to investigate the speed, power and thickness of horizontal currents produced by an air curtain in water up to 34 ft deep. The maximum quantity of free air delivered to the manifolds by an air-bleed jet engine was 1.65 cusecs per foot. Measurements included horizontal and vertical currents, lateral and longitudinal distribution of surface current, amplitude and width of turbulence at the surface. It was concluded that orifice size and spacing, and manifold arrangements are not influential factors, and that current thickness apparently varies logarithmically with a function of manifold depth. This is also suggested in a theoretical comparison of current and air power. The discovery of these facts has enabled a number of controversies to be set aside, and the way cleared for large scale tests under controlled conditions with waves.

53. Burke, C. Thomas, "Coming Soon: Year-round Port Operation," The Seaway Review, Vol. 1, No. 4, 1970, p. 10-13.

The Seaway Port of Duluth, in the winter of 1970, initiated a pilot project geared to keeping a major shipping channel ice-free in Duluth-Superior Harbor. This is one step in a rapidly unfolding series of events that many lake shipping seers foresee as the forerunners to 12-month cargo movements over Great Lakes shipping lanes. A compressed-air bubbler was used to bring the warmer water from the bottom up to the surface. The Duluth, Missabe and Iron Range Railways conducted an air bubbling experiment roughly 60 by 120 ft. and found it could remove 24 in. thick ice in 5 days. After a week, an area approximately 75 by 180 ft. was ice-free. The Port of Duluth views this experiment as a possible prototype of what most lake ports may employ in the near future.

54. Butkovich, T. R., "Crushing Strength of Lake Ice," August 1955, 5p. AD-075 249 24-3176, SPIRE Research Reports 15.

Tests were made to determine the effects of size of prismatic specimens, cross section, ratio of overall length to length of side of square section, types of ice, both natural clear

ice and snow ice, orientation of c-axis, and size of candle. Rough-cut specimens were crushed in a 120,000 lb capacity press. The results of the tests show that: 1) large-grained clear ice is stronger in compression, 2) ice is stronger parallel to the ice sheet than normal to it, 3) specimens of smaller cross-section have higher crushing strength, 4) prisms with lower ratios of length to width are stronger. No effect of c-axis orientation was detected.

55. Butkovich, T. R., "Recommended Standards for Small-Scale Ice Strength Tests." Trans. Eng. Inst., Canada 2, 1958.

The effects of specimen size and shape on the strength values obtained with small scale unconfined compressive tests are shown. Results are given that show that a loading rate of 0.5 kg/cm^2-sec. is required for all small scale strength tests to minimize plastic effects which accompany slow loading of ice. The ring test, which is a useful new type of test to measure the tensile strength of ice, is described. Standards for specimen size, shape, and configuration along with loading rates and equipment are discussed and recommended.

56. Butkovich, T. R., "On the Mechanical Properties of Sea Ice, Thule, Greenland, 1957," August 1959, 11p. plus 9. appends. AD-235 872, 6 refs. 24-3212, U.S. CRREL, Research Report 54.

The investigations on sea ice, conducted at Thule, Greenland, during February and March 1957 included: strength, and flexural strength tests on simple beams for both horizontal and vertical test specimens. Additional tests were made to determine the modulus of elasticity with the simple beams in flexure. Tests were also made for creep in uniaxial compression. Although there is a high scatter of results, a dependence of strength and creep on temperature and brine volume is evident. Higher compressive, tensile, and flexure strengths, along with higher values of the elastic modulus were obtained at lower temperatures or brine volumes. The minimum creep rate decreases with decreasing temperature and brine volume.

57. Butkovich, T. R., "Thermal Expansion of Ice," Journal of Applied Physics, Vol. 30, No. 3, 1957, p. 350-353.

Linear thermal expansion coefficients of natural and artificial single ice crystals, commercial ice, and snow ice were determined in the temperature range near 0 to -30°C. There was no measurable difference in the coefficients of linear thermal expansion parallel and normal to the c axis of single crystals or polycrystalline ice. However, a steady decrease of expansion coefficients with each succeeding measurement on the same ice specimen was observed. The total decrease was of the order of 2×10^{-6}, while an estimated error calculation yielded a value of about 4×10^{-7}. An entirely satisfactory explanation of this phenomenon cannot be given at this time, and further investigation on this point would be desirable. Values of C_v, the specific heat at constant volume, were calculated from thermodynamic relationships. Average

C_p/C_v values were 1.030. Gruneisen's constant was found to average 0.78, and essentially independent of temperature between o°C and -30°C.

58. Butkovich, T. R. and Landauer, J. K., "Creep of Ice at Low Stresses," 1960, SIPRE Res. Report 72, 1-6. 60 AD-653 135 16 refs. 24-3230.

Uniaxial compression tests were made on 2x2x6 cm samples of large-grained commercial ice and small-grained glacier ice at temperatures from -1.3 to -18.9C and stresses down to about 10,000 dynes/sq.cm., using a special apparatus to permit simultaneous measurement of 3 samples at different stresses. The uniaxial stresses and strain rates were reduced to shear stresses and strain rates by dividing and multiplying, respectively, the former by sq. root of 3. The log shear strain rate vs log shear stress curves was essentially linear for the low-stress creep measurements. Assuming a linear flow law for low-stress creep, activation energies for creep of about 14,300 cal/mole were determined. The smaller-grained ice had a higher viscosity coefficient than the larger-grained ice. The observed activation energy for creep of ice is probably that for self-diffusion.

59. Butkovich, T. R., "Ultimate Strength of Ice," U.S. Army Snow Ice and Permafrost Research Establishment (USA SIPRE) 1954, Research Report 11.

The crushing and torsional shear strengths of clear lake ice, natural snow ice and commerical artificial ice as well as the tensile strength of commercial ice were measured in the laboratory. Data are tabulated and graphed, and earlier results obtained by different investigators are reviewed. Specimen shape influenced crushing-strength values with machined cylindrical specimens yielding the highest values. Crushing strength parallel to the ice sheet for clear lake ice, but differences between the 2 orientations were insignificant for natural snow ice. Values obtained for commercial ice were slightly lower than those for clear lake ice. Torsional shear strength for clear lake ice showed a strong temperature dependence as well as anisotropism between shear and orientation, while for snow ice temperature dependence was weak and anisotropism absent.

60. Butkovich, T. R., "Strength Studies of Sea Ice," USA Snow Ice and Permafrost Research Establishment, Corps of Engineers, Research Report 20, 1956.

Investigations on sea ice at Hopedale, Labrador, March 1956 included: small beam tests and in-place cantilever beam tests for flexural strength; ring tensile-strength tests; unconfined compression tests, with stress-strain studies to determine "Young's modulus"; and double shear tests. The results exhibit a great deal of scatter, primarily due to the inhomogeneity of sea ice. Ring tensile strength values range between 3.3 kg/sq cm and 22.3 kg/sq cm between-2.5C and -19.1C. The small beam

tests give flexural strength values from 0.5 to 17.3 kg/sq cm in a similar temperature range. The in-place pull-up cantilever beam tests give flexural strength values of 2.2 to 4.0 kg/sq cm, with much less scatter. Crushing strength values range from 26.3 to more than 107 kg/sq cm in the range -4.9C to -18.3C.

61. Butkovich, T. R., and Landauer, J. K., "The Flow Law for Ice," SIPRE Misc. Publication 56, 1959, p. 1-7.

The results of laboratory creep tests in a shear apparatus at -5c on 2x2x3/8 in. samples of commercial ice, artificial single crystals, and 6 types of ice from the Greenland Ice Cap, at shear stresses of about 0.5 - 3 kg/sq cm are reported. Some uniaxial tests were made at stresses from 6-28 kg/sq cm to supplement the shear tests. Creep data could usually be represented approximately by one of more linear sections on a log-deformation vs log-time plot. The linear sections of the double logarithmic curve imply a creep curve of the form "e equals ct exp·(m)" where e is the strain. For all samples tested, except single crystals sheared in easy glide, m averaged 0.5 for shear deformations up to about 1 percent, and approached unity for more deformation. For single ice crystals oriented for easy glide, m averaged 1.7, implying a strain softening. Single crystals oriented for hard glide behaved similarly to polycrystals, indicating a rate-controlling process such as dislocation climb.

62. Butkovich, T. R., "Linear Thermal Expansion of Ice." U.S. Army Snow Ice and Permafrost Research Establishment, Research Report 40, Wilmette, Illinois, December 1957.

Linear thermal expansion coefficients of natural and artificial single ice crystals, commercial ice, and snow-ice were determined. In the temperature range near 0°C to -30°C, there is no appreciable difference in the coefficients of linear thermal expansion parallel and normal to the c-axis of single crystals or in polycrystalline ice. There was a steady decrease of the expansion coefficients with each succeeding measurement on the same ice specimen. Since the total decrease was of the order of 2×10^{-6}, and an error estimation yielded a value of about 4×10^{-7}, it is presumed that this change is due to slow annealing. Values of C_v, the specific heat at constant volume, were calculated from thermodynamic relationships. Average C_p/C_v values were 1.030. Gruneisen's constant (γ) was found to average 0.78, and was independent of temperature between 0°C and -30°C.

63. Callaway, Elliot B., "An Analysis of Environmental Factors Affecting Ice Growth," U.S. Navy Hydrographic Office, H.O. TR-7, September 1954, 31p. 19 graphs.

Discusses experimental evidence of effect of environmental factors on growth of fresh- and salt-water ice. An equation relating these factors developed by Kolesnikov is evaluated and the results applied to forecasts in specific areas in USSR and Baffin Bay.

64. Camp, Paul, R., "Properties of Ice, Part II," Cold Regions Research and Engineering Laboratory, Research Report 114, Hanover, N.H., November, 1963.

Modifications are reported of a previously described apparatus for the preparation of single crystals of pure and doped ice. Some results of using this apparatus to grow crystals of several crystallographic orientations are discussed. An effect of an electric field on the nucleation of ice at a metal-water interface is described. Various x-ray techniques for investigating the quality of ice crystals are discussed and experimental results of applying them to Alaskan Glacier crystals are given. Among the techniques used are the measurement of the half width of the reflection curve, the integrated reflecting power of a Laue reflection, studies with polarized x-rays and a transmission technique due to Lang. The thermal motion of ice molecules in a direction perpendicular to the c-axis and the temperature dependence of the lattice parameters of ice have been measured by x-ray techniques. Dielectric relaxation and electrical conductivity of ice are discussed. Experiments have been performed to determine the effect of length of the sample and to study the effect of small amounts of NH_4F as a substitutional impurity. Special attention is given to long period dielectric processes. At least two such processes seem to be present, one which dominates the first 3 to 30 seconds of discharge and the other which determines the long time behavior. The possibility of altering the conductivity and dielectric relaxation of ice by optical generation of Bjerrum defects is explored and experiments to test this possibility are reported.

65. Camp, P. R., Barter, C.F., "Rate of Growth of Ice at an Aluminum-Water Interface," Nature, May 1, 1965 206(4983) p. 495-496, 1 ref. Microform No. SIP 23414 25-2074. US CRREL Misc. Publication 94.

The dependence of the velocity of interfacial growth of ice on supercooling was measured for substrates of gold, copper, steel, and lead in the temperature range 0 to -5C. Two growth modes were found for each surface. The results for copper and gold were similar to those for aluminum, the high-angle growth dominating over most of the temperature range. For lead and steel, the low-angle mode dominated over most of the range. An expression was derived which summarizes these measurements within the limits of experimental error. The thermal property of the substrate, which is rate controlling, cannot yet be assigned with certainty. For good conductors of heat at supercoolings of the order of 1C or more, the thermal properties of the substrate appear to play a major role in determining how the growth rate of a given mode varies with substrate temperature.

66. Carey, Kevin L., "Performance of the Demonstration Bubbler System," USACRREL, Duluth Harbor, Minnesota, April 1971.

During the testing of a bubbler system in Duluth Harbor, Minnesota, the U. S. Army Cold Regions Research and Engineering Laboratory monitored the temperature of water. By calculating the heat required to melt the ice and making an estimate for the heat lost to the atmosphere, they concluded that a temperature reduction of 0.65°F should have occurred. Since this did not happen, it is believed that the heat extracted to melt the ice is replaced by heat advected and/or conducted into the area from elsewhere in the harbor. This gives rise to the hope that the operation could be conducted for a considerably longer period of time than the three weeks that the test ran.

67. Carey, Kevin L., "Icing Occurrence, Control and Prevention: An Annotated Bibliography," Cold Regions Research and Engineering Laboratory, Special Report 151, Hanover, N.H., July 1970.

An icing is a mass of surface ice formed during the winter by successive freezing of sheets of water that seep from the ground, from a river, or from a spring. Icings cause severe problems when they occur near highways, railroads, airfields, or structures. Annotations given for 93 papers, articles, or books from North America and the Soviet Union describe the ways in which icings form and develop, as well as a wide variety of techniques for controlling and preventing icings and their harmful effects on transportation. The entries span the period from 1919 to 1966. The annotated bibliography can serve many purposes in the transportation field, such as (a) providing an understanding of the mechanics of icing processes, (b) expanding acquaintance with the various methods for combating icings, and (c) giving an assessment of the degree of success of familiar methods as experienced in the Soviet Union.

68. Carpenter, J. S., "Ice Protection for Hydroelectric Plant," Power Plant Engng., v. 24, 1920, p. 1125-6.

Explains methods for deflecting ice jams. Ice forms around speed rings of turbine causing water passages to become clogged.

59. Carr, McGraw and Shapiro, "Investigation of Ship Mooring Forces," Quarterly Reports I and II, July 1952. U.S. Navy Report 3, October 1952. Final Report, April 1953. AD 80461.

A feasible approach to the rational design of a mooring structure is a program of experimental measurements of a sufficiently large range of conditions to permit eventual generalizations. The experimental measurements of the mooring forces should be correlated wherever possible with the coexisting environmental factors - wind, wave and current conditions, type of vessel, and mooring configurations. The process of obtaining a body of statistically reliable information will be expedited in direct ratio to the degree of

correlation obtained between forces and environment. It must be appreciated, however, that a certain minimum number of observations are necessary to establish correlation. This report covers the contract period of one year and describes the development of equipment to measure and record mooring forces together with the subsequent force measuring program.

70. Carstens, T., "Hydraulics of River Ice," LaHouille Blanche, Vol. 8, 1968, p. 271-284.

This paper describes the transport of a solid phase which is lighter than water, using terms from the more familiar transport of sediments. The findings apply to most organic debris and to logs, but ice has been our main concern. A model investigation of the Burfell intake on the river Thjorsa in Iceland, carried out at the River and Harbour Laboratory at the Technical University of Norway, illustrates most of the problems that are discussed.

71. Carstens, Torkild, "Structure and Physico-Mechanical Properties of Ice," IAHR Symposium, Ice and its Action on Hydraulic Structures, Leningrad, USSR, 1972.

Because of its low melting point and large crystals, ice has provided scientists with a convenient material for the study of crystal structure. On the other hand, the anisotrophy of this structure and the rheological effects of the low melting point have proved to be serious obstacles to the experimental determination of ice strength. Our knowledge of the structure of broken-up fields in nature is largely descriptive and therefore insufficient for prediction of ice action. The need for stress observations to supplement laboratory strength data is recognized and a first generation of field instruments is now being developed.

72. Cartier, L. and Beccat, R., "Mechanism of Ice Cover Formation on Rivers," Experimental studies with natural ice. IAHR 8th Congress Montreal 1959, Sem I, pp. 12-SI-1-2.

Subject of the experiments was the analysis of: conditions of buoyancy and submersion of superficial floes coming to rest, maximum flow velocities against which ice covers build up or recede and factors governing the process of their formation and progress. The theory developed in the laboratory relates this mechanism to accumulation to a definite thickness of drifting floes when carried underneath the cover as it builds up, following the laws of transportation of coarse material on stream beds.

73. Chaney, Charles A., Marinas: Recommendations for Design, Construction and Maintenance, Published by National Association of Engine and Boat Manufacturers, Inc., 1961.

This volume offers designers and builders a manual of construction methods and materials that may be incorporated into the modern marina. It is the result of ideas first published under

this title by the NAEBM in 1939 and supplemented in 1947. Since then, a more advanced marine technology necessitates this completely new edition that takes advantage of modern methods and materials, and at the same time draws upon the best elements of earlier work and experience.

74. Chekotillo, A. M., "Icings and Countermeasures," 1940, 47p. AD-659 641. For original Russian text see SIP U658. 20 refs. 26-5211. CRREL Translations 7.

This basic textbook is intended for use in planning and building railroads and highways in permafrost regions. Nearly half of the text is devoted to description and classification of icing processes and phenomena, theory of icing formation, magnitude of subsurface water pressure, and influence of snow cover on icing. One chapter deals with desription of icing effects on railroad dams and excavations, tunnels, railroad stations, living quarters, and shipping. The following anti-icing measures are discussed: (1) transfer of structures, (2) clearing away of icing, (3) widening excavations, (4) removal of water causing icing, (5) protective dams and fences, (6) drainage, (7) permafrost barriers, and (8) deepening, straightening and warming of river and creek beds.

75. Chellis, R. D., Pile Foundations, 2nd Edition, 1961.

Reference No. 113 is to B. Lofquist. Lifting force and bearing capacity of an ice sheet. Technical translation TT-164, National Research Council of Canada, Ottawa, 1951.

76. Clark, D. B., "Strain Gage Technique For Dynamic Measurements of Ice," Project Y-F015-11-022, February 1960, AD 235057, PR 146971, U.S. Navy.

Strain gages were applied to various samples of fresh water and sea water ice. These were compression-loaded dynamically to failure while the strain was recorded with an oscillograph and bridge amplifier. Sufficient strain data was recorded to indicate the validity of the new technique. Under rapid compression loading to a point near failure of the ice, a strain gaged ice sample can be cycled without permanent deformation or flow of the ice, and without slippage of the gage. Gages properly coated are shown to hold their high electric impedance against sea water ice for a period of time exceeding three weeks. Resistance wire strain gages, with proper preparation and application, can be used advantageously to measure the dynamic strains in fresh water ice or sea ice, and thus determine their structural characteristics. From R-060.

77. Clinch, R. L., Millman, R. N. and Erickson, O. M., "Ice Problems at McCormick Dam, Tests on a Pilot Bubbler System," IAHR 8th Congress Montreal 1959, Sem. I, pp. 13-SI-1-5.

An experimental bubbler system was installed at McCormick Dam on the Maniconagan river in Quebec, to investigate the

practicability of preventing ice thrust on approximately 3,500 feet of mass concrete gravity dam and 500 feet of spillway.

78. Coffin, R. C., "Technical Data from Deep Freeze I, II and III Reports," (1955 to 1958), U.S. Navy Project Y-F015-11-002, April 1961, OUO, AD 256459.

This report is a compilation of technical data obtained principally from the fourteen volumes of reports prepared by mobile construction battalion (special) for Operations Deep Freeze I, II, III. Supplemental information was obtained from correspondence and situation reports originated by Deep Freeze Forces, and reports of military and professional civilian observers, which are listed in the references and bibliography. The information is grouped into fifteen general technical subject areas, which are subdivided into specific problem areas. Within the problem areas the data are presented by individual U.S. Antarctic Stations whenever different environmental, topographical, or operational conditions contributed diverse solutions for the same or similar problems. From R-155.

79. "Concrete Road Uninjured by Weight of Ice Jam" Engng. News, V. 85, 1920, p. 29-31.

Gives example of Clark's Perry at Junction of Juanita River with Susquehanna, where a concrete pavement remained undamaged after a heavy ice jam.

80. Cornick, Henry F., M.C., FICE, Dock and Harbour Engineering Charles Griffin & Company Limited, London.

Volume 1 - The Design of Docks; Volume 2 - The Design of Harbours; Volume 3 - Buildings and Equipment; Volume 4 - Dock and Harbour Construction.

81. Crawford, C. B., and Legget, R. F., "Ground Temperature Investigations in Canada," Engineering Journal, March 1957, p. 263-269.

This paper describes the program of work undertaken by the Division of Building Research, of N.R.C., to determine ground temperature variations in Canada. Some of the practical results and theoretical problems are discussed.

82. Creager, W. P. Engineering for Masonry Dams, 1917, J. Wiley Sons, N.Y. 229 pp.

Ice pressure is discussed, pp. 37-9, including the subject of ice thrust and allowances which must be made when designing a structure. A table given ice pressures adopted for various dams, the design of reservoirs, pp. 76-104 examples showing the necessary allowances to be made in building to account for ice pressure.

83. Danys, J. V., "Lightpiers on Friction Piles in Deep Soft Marine Clay," Canadian Geotechnical Journal, 8, 1971, No. 3, pp. 434-445.

The deposit of marine clays in Lake St. Peter, Quebec, is as much as 300 ft (91 m) deep. As the navigation season is being extended into winter, the need for lightpiers becomes greater. Apart from the sensitive and very compressible clays, the heavy ice forces made a design very difficult. Introducing novel design features and applying the present knowledge of soil mechanics two piers were designed and built in 1966 on 157 friction piles each, and two more in 1969. Extensive boring and laboratory testing programme preceded construction, and the shear strength data of the clay was used for the pile foundation design. Field pile testing confirmed the design assumptions.

84. Davis, A., "Protection of Kookik Dam Gates from Ice Pressure by Use of Air," Stone & Webster Jnl., v. 22, 1918, p. 199-206.

An example is given of ice exerting a force of 92 tons, knocking out a thirteen ton steel gate and carrying it 800 feet below the dam. The new air system which deals satisfactorily with ice pressure is explained. Air is discharged under water at the middle of each spillway, and the water circulated by it keeps it open. A motor driven air compressor furnishes air for the system.

85. Dearstyne, S. Charles, and others. Report on Small Craft Harbors. American Society of Civil Engineers, New York: 1969.

This manual is made up of five parts. Planning includes a procedure of master planning and provides certain criteria on which this planning may be based. Entrance protection deals with the protection that may be necessary to provide safe and useful moorage of small craft within a harbour area. Harbour structures describes in detail the development of facilities within the harbour and their construction. Economics and finance, covers financing possibilities particularly where public agencies are involved, and some sources of Federal and other financial aid that may be available.

86. Deslauriers, C. E., "Ice Break-Up in Rivers," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

Technical literature related to ice break-up in rivers is mostly of recent date. How much of it is useful? What are the needs for further observations and investigations? This paper is a summary of the science and an outline of the needs for further observations and investigations.

87. Devik, O.,"Present Experience on Ice Problems Connected with the Utilization of Water Power in Norway," Journ. of Hydr. Res., IAHR, 2, 1964, nr. 1, pp. 25-40.

Description of the problem in general, formation of ice on rivers, and natural ice dams. Relation between ice formation, water temperature and flow velocity. Measures against the formation of ice in front of intakes of water power stations.

88. Dick, T. M., "Description of Air Bubbling Systems at Cambridge Bay and Tuktoyaktuk N.W.T." Proceedings of the Symposium on Air Bubbling, TM-70, N.R.C., Ottawa, May 11, 1961.

Because of their remote locations, wharves in Artic water are costly to repair when damaged by ice. A compressed-air bubbler was installed at Tuktoyaktuk, at the mouth of the Mackenzie River, and a burper was installed at Cambridge Bay on the southern shore of Victoria Island. The units were intended to keep thick ice from freezing to the piles and lifting them when the tide rose. They need not prevent ice formation but only keep the ice thin enough so that the ice will fall before the pile is lifted. The Tuktoyaktuk bubbler was quite effective but the Cambridge Bay burper was unable to cope with the ice possibility because of the lower temperature and higher salinity of the Cambridge Bay ice. Bubblers are found to have certain advantages over burpers. They are easier to install and maintain, they don't have to be removed every spring to prevent damage done by ships, and the burpers can only melt ice in a circular shape.

89. "Diffraction of Waves," taken from Shore Protection, Planning and Design, Technical Report No. 4, Third Edition, 1966, U.S. Army Coastal Engineering Research Center.

Diffraction in water waves is that phenomenon whereby energy is transferred laterally along a wave crest. It is most noticeable where an otherwise regular train of waves in interrupted by a barrier such as a breakwater.

90. Dillon, Howard B., and Andersland, "Deformation Rates of Polycrystalline Ice," Proceedings of International Conference on Low Temperature Science, Sapporo, Japan, Vol. 1, 1966.

The results of a series of creep tests at constant stress and several constant strain rate tests performed on cylindrical polycrystalline ice samples are reported. Experimental creep data and creep data available in the literature are analyzed in terms of the rate process theory assuming that one mechanism of deformation predominates. Best fit curves are adapted to the data at three temperatures using octahedral shear stresses and octahedral shear strain rates. High and low stress regions are approximately defined by strain rates greater or less than 10^{-5} per minute, respectively. For low stresses, the analysis gives a value of 11.44 kcal/mole for the heat of activation. This agrees with the self diffusion energy of 11 kcal/mole obtained approximately from the melting

temperature by Dorn (1959). The experimental value for the entropy of activation equals -36.1 cal/mole/°K. A combination of the experimental values for heat and entropy of activation gives a free energy of activation equal to about 21 kcal/mole for the low stresses and the temperature range under consideration. At higher stresses larger values for the free energy of activation are obtained, indicating a possible stress dependence. Flow volumes ranging from 2.5×10^7 to 5.3×10^7 cubic angstroms indicate that boundaries of ice grains of slip along basal planes of single ice crystals are probably involved in the creep process. Experimental creep data exhibit a discontinuity in the vicinity of -10 to -14°C in that faster creep rates are observed for the same stress at a colder temperature.

91. Dingman, S. Lawrence, and Assur, Andrew, "The Effects of Thermal Pollution on River Ice Conditions, Pt. II: A Simplified Method of Calculation." Cold Regions Research and Engineering Laboratory, Hanover, N.H., Res. Rept. 206, Aug. 1969

In a previous report, Dingman et al. (1967) developed a method for calculating the temperature profile of a cooling river below a source of thermal pollution and the length of ice-free reach which could be maintained by such a source. Computer programs were used to calculate heat-loss rates based on mean daily values of meteorological parameters and to numerically integrate a complicated heat-loss expression. The present paper describes a simplified approach to the same problem, in which heat loss is calculated as a linear function of the difference between water temperature and air temperature, so that the integration can be performed analytically. A simplified but fairly general procedure for calculating water-air heat-loss rates on the basis of air temperature, windspeed, solar radiation, and general atmospheric conditions is also presented.

92. Dinkla, E., and Sluymer, T. J., "Ice Pressures Against Isolated Structures," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The paper describes the approach taken in determining the ice loadings on some offshore structures located in areas subject to heavy ice movements.

93. Djunkovski, N. N., and Kasparson, A. A., Paper of the 20th Int. Nav. Congr., 1961, Baltimore, S II-1, p. 329-343.

In the fifth chapter the various forces acting on jetties along unsheltered sea coasts are determined; in formulas given are treated: wave forces, ice forces, and vessel impacts.

94. Donaruma, L. G., "Ice Adhesion (Preparation of Ice Releasing Coatings) (Sev 27)" 1972, 7p. U. S. Navy Contract DACA89-71-C-0027-26-5184. Unpublished Internal Report 184.

The work in this subtask was directed toward the development of ice releasing coating compounds for metals. A one year effort was devoted to this end. Insofar as possible, the preparation of coating compounds was guided by principles of surface chemistry and by the test results.

95. Donn, W. L. and Shaw, D. M., "The Heat Budgets of an Ice-Free and an Ice-Covered Arctic Ocean" Journ. of Geoph. Res., 71, 1966, nr. 4, Feb., p. 1087-1093.

Tentative estimates of heat budgets of the Arctic Ocean are based on incomplete observational data and certain subjective assumptions, but they appear to be justifiable in the light of present knowledge. The thermal regime of the present North Polar Sea is controlled to a large extent by the essentially permanent ice cover (mean albedo about 61 percent). Additional factors influencing present surface temperature are ocean current heat flux, long-wave radiation and evaporation and sensible heat.

96. Donnelly, P., "An Outline of the Design and Operation of the Montreal Ice Control Structure," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC no. 9851, Ottawa.

Land reclamation in Montreal Harbour to develop a site for the Canadian Universal and International Exposition (EXPO '67) involved narrowing of the St. Lawrence River channels. This narrowing of the river channels increased the dangers of ice jams, and consequently, the flood hazard not only to the EXPO '67 site itself but also the City of Montreal and adjacent municipalities. To minimize the danger of winter floods caused by ice jams, a special ice control structure was built across the river at the lower end of LaPrairie Basin about three miles upstream from the EXPO '67 site. This structure, which is almost 7,000 feet long, consists of 72 reinforced concrete piers, between fitted removable, floating steel stop-logs. The stop-logs permit the formation of an ice cover on LaPrairie Basin at a somewhat more premature stage compared to natural conditions; that is to say, an ice cover can be formed on LaPrairie Basin without the necessity of waiting until ice jams and partial jams further downstream have backed up the water in the basin.

97. Dotson, William A., "Operational Details of Project Polynya," Proceedings of the Symposium on Air Bubbling, TM-70, N.R.C., Ottawa, May 11, 1961.

In 1958 a study was made of the effect of an air bubbling on ice formation in Thule, Greenland at Delong Pier. This report

gives the results of experimenting with a more effective and permanent ice prevention system in 1959 and in 1960 after further modifications were made. Under stable conditions with initial formation of fast ice outside the bubble area not breaking up and drifting into the bubble area and with no power outages, it is believed that the system presented could maintain open at the pier at Thule but the present design does not have reserve power built into it to overcome freezing from electrical failure. T. A. Harwood has suggested that the system may have been successful because warmer and more saline water occasionally flushed into Thule Harbor from outside.

98. Drouin, Marc, "State of Research of Ice Thermal Thrust," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The thrust exerted by the thermal expansion of ice covers on hydraulic structures are still unknown. Up to now, researches are not conclusive and the suggested values cannot be scientifically accepted because they should take into account the crystallographic structures and the optical orientations of the different types of ice formed in nature. This paper presents the state of art of this question followed by a description of the actual research underway at Laval University.

99. Drouin, M., "Static Ice Force on Extended Structures," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

Consideration is given to the formula developed by Royen for calculating the deformation of ice under compressive loads, and the modified Royen formula used by the Russians for calculating design ice pressures. It is shown that the original Royen formula is not in agreement with observations on the dependence of the deformation of ice on the stress. The experimental results of Brown and Clarke, and of Monfore, as well as the theoretical calculations of Rose, are reviewed, discussed and evaluated. Suggestions are presented concerning the research work necessary for obtaining the information required for predicting the forces that ice can exert on structures.

100. Duff, C. H., "Ice Landings," Canadian International Paper Company.

This paper outlines in general terms the thinking of logging operators on the strengthening of ice sheets. Equipment and practices are described. Loads allowed on different ice thicknesses are mentioned.

101. Dumble, J. H., "Ice Phenomena, from Observations on Rice Lake," Canadian Journal of Industry, Science and Art, New Series, Vol. 3, Sept. 1858, 414-422.

Ice damage to piers and bridges on this Canadian lake is described, and its causes are discussed. A sudden increase in air temperature caused immediate expansion of ice toward the shore, the force of expansion depending on the degree of temperature change. Most violent expansion occurred with an increase in temperature of 20°F, prior to a rain storm. Greatest observed expansion in a horizontal direction was 6 ft. Max. contraction did not exceed 3 in. when temperature dropped from +30° to -20°F. A snow cover in excess of 6 in. effectively prevented ice movements by protecting the ice from outside influences. Since only the upper ice layers were influenced by air temperatures, the lower layers remained at a constant temperature a few degrees below that of water. A temperature decrease resulted in a separation and fracturing of the ice mass at its weakest point. A temperature increase produced shoving and overlapping. The unequal distribution of ice pressure in various directions is attributed to inequalities in thickness, density, glare, and reaction to heat. When ice has uniform density, thickness, and glare and is heated uniformly, it expands from the center toward the periphery.

102. Dumble, John H., "Some Observations on the Expansion and Contraction of Ice on Canadian Waters," Trans. Can. Soc. Civil Engrs., v. 5, 1891, p. 270-308.

Experience of the effect of ice movement upon bridge piers. Abstract. Movement of bridge piers by expanding and contracting ice.

103. Dunham, James W., "Design Considerations for California Marinas," American Society of Civil Engineers, Paper No. 3309, Vol. 127, 1962, Part IV.

Considerations and criteria for the functional layout and structural design of marinas for small craft, as proposed by the California State Division of Small Craft Harbors, are presented. Examples of successful design practice are given, and recommendations are made for use of various types of material and design under different conditions of exposure.

104. Dunham, H. F., "Ice Formation on Lakes," Engineering News-Record, Vol. 92, Jan. 31, 1924, 209-210.

Discusses effects of ice pressure resulting from temperature changes in the ice covers of small lakes. Cracks form in the middle of the lake because the tensile strength is not sufficient to draw the ice from the shore area during contraction of the cover with falling temperature. Water from beneath fills the cracks and freezes. The ice cover expands as the

temperature increases, and since the resistance of ice to compression is 5-6 times its tensil strength, marginal ice is pushed shoreward forming ridges along the shore line.

105. Eckhard, G. F., "Large Highway Bridge Wrecked by Pressure of Cake Ice," Engng. News, v. 84, 1920, p. 902-4.

Gives example of the Brattleboro (Vt.) Steel Span of 330 ft. pushed off its supports by floating ice. Weight of steel in bridge was 270 tons. Distortion of floor system increased until horizontal deflection of the lower lateral system became at least 2 ft.

106. Ely, Allen L., and Nichol, John M., "Congestion in Marina Entrance Channels Due to Sailboats," Journal of the Water ways, Harbors and Coastal Engineering Division, ASCE, Vol. 99, No. WW4, Proc. Paper 10137. November 1973, p. 415-424.

Overcrowding of marinas has caused traffic congestion in many entrance channels, primarily because of the diagonal tacking patterns of sailboats in the presence of axially moving power boats. This problem is analyzed on the basis of probability of interference of imaginary "blockading areas" surrounding the boats as they traverse the channel. The relationships of the various parameters that enter into this analysis are evaluated mathematically, and a "congestion index" is derived in terms of probable interferences per acre of navigable channel during peak-hour traffic. It is suggested that values for this index be computed for an extensive sampling of marinas in different parts of the country to assess its general validity.

107. Engineering News 120: 161, 168-9, F. 3, 1938, "Record Ice Jam at Niagara Falls Wrecks Famous Arch Bridge."

108. Frankenstein, G. E., "Strength of Ice Sheets," Ice Pressures Against Structures, Proceedings of a conference held at Laval University, Quebec, 10-11 November 1966, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851. Technical Memorandum No. 92, Ottawa.

This paper describes the results of a number of large load tests performed on an Arctic Lake. The purpose of the load tests was to gain further knowledge in determining the bearing capacity of floating ice sheets. The tests were of two types: (1) distributed loads and (2) relatively concentrated loads. In the distributed load tests a 15 ft. diameter aluminum tank, with a height adjustable to 20 ft. was placed directly on the ice surface. Lake water was pumped into the tank at a more or less constant rate to load the ice. The concentrated load tests were conducted in the same manner as the distributed tests except that the tank was placed on a platform balanced on a 24 in. diameter wooden block. The deflection of the ice sheet was measured at the load and at distances away from the load. A deflection profile for each test in included in the report.

109. Frankenstein, Guenther E., and Garner, Robert. "Dynamic Young's Modulus and Flexual Strength of Sea Ice." Cold Regions Research and Engineering Laboratory, Technical Report 222, Hanover, N. H., May 1970.

This report describes the results of tests made to determine the dynamic Young's modulus E of young sea ice. The ice samples were mainly parallelepipeds but a few were 7.62-cm-diam cores. The longitudinal wave velocity was determined by measuring the time required for a sound wave to travel the length of the sample. The velocity c_o of a longitudinal wave of infinite wavelength traveling through a long bar is

$$c_o = \left(\frac{E}{\rho}\right)^{1/2}$$

where ρ is the density of the bar. The measured wave velocities were corrected, by Love's frequency equation, to apply for infinite wavelengths. The flexural strength of the ice was determined by conducting a number of simple beam tests. the average value for the flexural strength was 11.3 kg/cm^2.

110. Frankenstein, G. E., "Ring Tensile Strength Studies of Ice," February 1969, 36p. AD-686 284 8 refs. 24-3126. CRREL Technical Report 172.

This paper gives the results of ring tensile strength tests of lake and sea ice. The sea ice tested was normal, low-salinity, and high-salinity sea ice. The strength results plotted against the square root of the brine volume gave a least squares equation. A series of tests was conducted to test the theory that the concentration factor, 1, for a solid cylinder is equal to 6. The average of the new K values computed from the test results is 5.2.

111. Frankenstein, G. E., "Strength of Ice Sheets," National Research Council, Canada, Associate Committee on Geotechnical Research. Technical Memorandum March 1968, No. 92. Ice pressures against structures, proceedings of a conference held at Laval University, Quebec, 10-11 November 1966, p.79-87, 11 refs. 23-4225. CRREL, Misc. Publication 122.

This paper describes the results of a number of large load tests performed on an Arctic Lake to gain further knowledge in determining the bearing capacity of floating ice sheets. The tests were two types: (1) distributed loads and (2) relatively concentrated loads. In the distributed load tests a 15-ft diameter aluminum tank, with a height adjustable to 20 ft, was placed directly on the surface. Lake water was pumped into the tank to load the ice. The concentrated load tests were conducted in the same manner as the distributed tests except that the tank was placed on a platform balanced on a 24 in. diameter wooden block. The deflection of the ice sheet was measured at the load and at various distances away from the load. A deflection profile for each test is included.

112. Frankenstein, G. E., "Strength Data on Lake Ice," U.S. Snow, Ice and Permafrost Research Establishment. Technical Report No. 59, Dec. 1959, 20p.

Gives results of in-place cantilever beam tests and small-beam tests with center loading, conducted in 1956 and 1957 on lake ice in Minnesota, Wisconsin, and Michigan.

113. Frankenstein, G. E., "Strength Data on Lake Ice," U.S. Snow, Ice and Permafrost Research Establishment. Technical Report No. 80, Jan. 1961, 12p.

Continuation of tests. The results of in-place supported beam tests and in-place cantilever beam tests conducted in 1957-58 on lake ice in Michigan are reported, and the data tabulated and graphed. The tests were made on clear ice and a combination of clear ice and snow-ice. The supported beams had a higher computed flexural strength than similar cantilever beams. The flexural strength of the supported beams with the surface layer in tension was always higher than the supported beams with the bottom layer in tension. As reported in Technical Report 59, the flexural strength of cantilever beam tests was highest when the bottom layer was in tension. On a clear day with a bright sun and near positive temperatures, the flexural strength decreases from morning to mid-afternoon.

114. Frederking, R. and Gold, L. W., "Ice Forces on an Isolated Circular Pile." Reserved Paper No. 546, National Research Council of Canada, Ottawa, 1972.

This paper presents a mathematical model for calculating the forces that a moving ice cover will exert against an isolated pile. The model requires knowledge of the relationship between strain rate in the ice and the rate at which the ice cover is moving relative to the pile. An experimental and a theoretical approach to the derivation of this relationship are advanced. It is assumed that compressive failure of the ice in the zone adjacent to the pile controls the thrust on the pile. It is further assumed that the mode of failure in this zone is comparable to that for uniaxial compression tests in the laboratory. The model takes into account the influence of ice type, strain rate, pile geometry and temperature on the thrust on the pile.

115. Frederking, R. and Gold, L. W., "Ice Forces on an Isolated Circular Pile," Research Paper No. 546 of the Division of Building Research, Ottawa,November 1972.

This paper presents a mathematical model for calculating the forces that a moving ice cover will exert against an isolated pile. The model requires knowledge of the relationship between strain rate in the ice and the rate at which the ice cover is moving relative to the pile. An experimental and a theoretical approach to the derivation of this relationship

are advanced. It is assumed that compressive failure of the ice in the zone adjacent to the pile controls the thrust on the pile. If it is further assumed that the mode of failure in this zone is comparable to that for uniaxial compression tests in the laboratory. The model takes into account the influence of ice type, strain rate, pile geometry and temperature on the thrust on the pile.

116. Freiberger, A., and Lacks, H., "Ice-Phobic Coatings for Deicing Naval Vessels," Proceedings of the Fifth Navy Sciences Symposium, 1961, p. 234-237.

117. Freysteinsson, S., "Calculation of Frazil Ice Production," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The most serious ice problems at some potential power plant sites in the Thjorsa River System, Southern Iceland, and some other Icelandic rivers as well, are because of enormous quantities of frazil ice produced in reaches which remain open throughout the winter. These problems will be most pronounced at run-of-the-river power plants where accumulations of frazil ice might block the intakes for longer or shorter periods. The Burfell Power Plant, the first and, as yet, the only power plant on the Thjorsa River System is an excellent example of this type. A part of the river discharge is here used to flush the frazil ice over a specially constructed diversion dam.

118. Garbaccio, D. H., San Marino, California, "Creep of Floating Ice Sheets Computer Calculations," Science Engineering Associates, December 1968. U.S. Navy Contract N62399-68-C-0023.

Using a digital computer calculations were made of the deformations and bending moments in a floating ice sheet. The ice behavior was described by a linear viscoelastic model consisting of a Maxwell and a Voigt element in series. Loading with circular symmetry uniformly distributed was applied to a plate of finite thickness described by Reissner theory. The effect of superposed loads describing aircraft landing gear was considered. Calculations were also made for a linearized approximation to the problem of a thin sheet described by a power creep law. The method was only partially successful because the time span of applicability was short.

119. Garbaccio, D. H., Zwior, G., Wilson, B. W., "Engineering Study on the Economics of Boat Floats," (Los Angeles and San Diego Areas), San Marino, California, Science Engineering Associates February 1966, U.S. Navy Contract NBY 62190, AD 631464.

A variety of types of boat floats, used as floating platforms for embarking or disembarking personnel from launches and other small landing craft, have come into use over the years at port and marinas for both military and civilian purposes. These floats utilized materials such as timber, steel, concrete, plywood, ceramic and plastic. In their environments these floats have shown different responses in regard to life, initial costs and maintenance expense. The problem posed in

this report is that of determining which type or types of floats are economically most suitable for the areas of Los Angeles and Long Beach Harbors and for the Port of San Diego. From CR-66.003.

120. Garbaccio, D. H., "Creep of Floating Ice Sheet" San Marino, California, Science Engineering Associates, April 1967. U. S. Navy Contract N62399-66-C-0032, AD 654742.

Theory was developed for a finite length line load on an elastic plate on elastic foundation. When the solution for a finite thickness plate failed to give convergent expressions for the bending moments under load, the solution was reduced to the case of a thin plate for which a convergent solution was obtained. The correspondence principle was applied to obtain the linear viscoelastic problem. An approximate method of Laplace transform inversion was used to obtain the time dependent behavior of the creeping plate. Numerical results are presented. Theory was developed using the Hankel and Laplace transforms for a plate of finite thickness with circular symmetrical loading which was later reduced to a uniform load over a circular area. The solution is presented in a form where numerical calculations can easily be made with a digital computer. From CR-67.025.

121. Garg, S. C., "Investigation of Heat Pipe Technology for Naval Applications," U. S. Navy Project ZFXX-512-001-018, Feb. 1972.

A survey of heat pipe theory, applications and developments has been carried out with particular reference to long heat pipes. Applications in Naval operations where the heat pipe technology could be profitably employed are pointed out. Recommendations are made to design and test a long heat pipe in the laboratory with a view to applying the technology in improving equipment operation and reliability, reducing maintenance of component replacement, reducing cost of operation, or permitting designs which otherwise might not be feasible. From N-1207.

122. Gisiger, Paul E., "Safeguarding Hydro-Plants Against the Ice Menace," ASCE. Civil Engineering, Vol. 17, No. 1., Jan. 1947, Pages 24-27.

123. Globe, Samuel, and Dropkin, David, "Natural-Convection Heat Transfer in Liquids Confined by Two Horizontal Plates and Heated from Below." Journal of Heat Transfer, Transactions of the American Society of Mechanical Engineers, February 1959, 24-28.

This paper presents results of an experimental investigation of convective heat transfer in liquids placed between two horizontal plates and heated from below. The liquids used were water, silicone oils of 1.5, 50, and 1000 centistoke kinematic viscosities, and mercury.

124. Gold L. W., "The Cracking Activity in Ice During Creep" Canadian Journal of Physics, Vol. 38, No. 9, Sept. 1960.

Observations were made at one temperature on the cracks that form in ice during creep under constant compressive load. The ice had a hexagonal symmetry with respect to the grain boundaries. The load was applied perpendicular to the long axis of the grains. A piezoelectric crystal was used to detect the cracking activity in the ice. Two stages of cracking were observed. The first occurred during the transient period of the creep, and the plane of these cracks tends to be parallel to the grain boundaries and to the direction of the stress. The rate at which these cracks formed decreased very markedly as the creep rate approached a constant value. Above a certain stress, the creep rate continuously increased with time. Under this condition the second stage of cracking was observed. These cracks tend to be more irregular in direction and to occur in planes that are at 45° to the applied stress.

125. Gold, L. W., "Elastic and Strength Properties of Fresh Water Ice," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

Information on the elastic and strength properties of ice is reviewed. Representative values for the ultimate strength of ice in shear, tension and compression are presented. The failure behaviour of ice during creep and constant load rate tests, and the internal cracking activity that occurs during such tests, are discussed. It is suggested that the failure behaviour of ice in uniaxial tests can be explained on the basis of the behaviour of imperfections associated with plastic deformation. It is pointed out that caution should be used when applying the results of uniaxial tests to biaxial and triaxial conditions encountered under field conditions, because of the role that the shear stress plays in the deformation and failure behaviour of ice.

126. Gold, L. W., "Crack Formation in Ice During Creep," Scripta Metall., 3, 1969, p. 367-370.

The gradual breakdown of a material during creep due to the formation of cracks is a subject receiving widespread attention. Although considerable information has been obtained as to how individual cracks are nucleated, grow, and ultimately join together to cause failure, not much attention has been given to the possible interrelation between crack formation and stress and time dependence of the deformation. Williams (1) has recently presented information on crack density and creep behaviour for an aluminum-zinc alloy. The author has considered similar information for ice. In addition to demonstrating a correlation between cracking activity and deformation, these observations show an interesting similarity in

behaviour, although the mode of crack formation is different for the two materials. It is the purpose of this letter to present information on the creep dependence of crack formation in ice to complement that presented by Williams for the aluminum-zinc alloy, and to draw attention to the similarity in cracking activity and deformation behaviour of the two materials.

127. Gold, L. W., "Dependence of Crack Formation on Crystallographic Orientation for Ice." Can. Jour. Phys., 44, 1966, 2757-2764.

Observations are reported of crack propagation in columnar-grain, polycrystalline ice subjected to constant compressive load applied perpendicular to the long axis of the columns. About three-quarters of the cracks observed were transcrystalline and the remainder occurred at grain boundaries. The plane of the crack lines tended to propagate either parallel or perpendicular to the basal plane. At least two-thirds of the grain boundary cracks were associated with boundaries for which the slip plane of one or both of the adjacent grains were close to parallel or perpendicular to the boundary. It is shown that the observations are consistent with the hypothesis that a minimum number of independent slip systems are required for a grain to conform to an arbitrary deformation under constraints imposed by neighboring grains.

128. Gold, L. W., "The Initial Creep of Columnar-Grained Ice," Can. Journ. Phys., 43, 1965, p. 1414-1422.

Previously undeformed columnar-grained ice exhibits a period of increasing or constant creep rate during the transient creep stage when loaded in simple compression perpendicular to the long axis of the columns. It is shown that this behavior is associated with the formation of small-angle boundaries and internal cracks. Creep strain beyond 0.25% for first load tends to a power-law dependence on time. On reload, specimens exhibit a normal transient creep behavior and have, initially, a lower resistance to deformation than for first load. With deformation, this resistance increases so that the reload creep curves cross the first load curves about 0.2% creep. For reload, creep strain less than about 0.025% and greater than about 0.2% appears to have a power-law dependence on time with exponent about equal to that for first load.

129. Gold, L. W., "The Initial Creep of Columnar-Grained Ice," Canada Journal Physics, 43, 1965, p. 1423.

Observations on the initial creep behavior of columnar-grained ice are analyzed by assuming that the creep strain at a given time has a power-law dependence on the applied constant compressive stress. The exponent for the stress was time-dependent during transient creep. For first load it started at a low value, increased to a minimum of about 2.23 approximately 75 minutes after the application of the load. Creep rates at

a given time, calculated from the observed power-law dependence of the creep strain on stress, also has a power-law dependence on stress for time greater than about 25 minutes after the application of the load. The observations are shown to be in agreement with observations by Krausz (1963) on the deflection rate of ice beams and by Steinemann (1954) and Glen (1958) on the stress-dependence of the minimum creep rate during secondary creep. The observations indicate that the creep rate during secondary creep varies approximately as $t^{-0.5}$.

130. Gold, L. W., "Time to Formation of First Cracks in Ice," Proceedings of International Conference on Low Temperature Science, Sappora, Japan, Vol. 1., 1966.

Observations have been made at two temperatures on the time to formation of the first internal cracks in columnar-grain ice subjected to a constant compressive load applied perpendicular to the long direction of the grains. Crack formation was observed to be a thermally activated process, with the time to formation of the first large crack (2 or more mm wide and 20 or more mm long) following the general law

$$t = t_0 \exp \frac{(U_0 - \alpha\rho)}{kT} .$$

The value of U_0, the activation energy for zero applied stress ρ, was found to be about 25 kcal/mole, t_0 about 4.6×10^{-17} sec and α about 1.4×10^{-20} cm^3/molecule. The amount of strain associated with the formation of the first crack was observed to increase with decreasing stress, but to be independent of temperature to within the accuracy of the experiments. The results were found to be consistent with the models for crack nucleation by pile-up of dislocations discussed by Stroh (1954) and Bullough (1964). It was observed that dislocation cracks could initiate Griffith cracks if the stress exceeded about 7 kg/cm^2, and no cracks were observed when the applied stress was less than about 5 kg/cm^2.

131. Gold, L. W., "The Failure of Ice," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

Information is presented on the cracking activity that occurs in columnar-grained ice during creep and constant rate of strain tests, when the load is applied perpendicular to the long direction of the grains. This cracking activity is responsible for the occurrence of tertiary creep or failure in uniaxial compression tests when the stress exceeds about 12 bars. The behaviour of ice around structures is discussed with reference to the results of the laboratory studies.

132. Gold, L. W., and Krausz, A. S., "Investigation of the Mechanical Properties of St. Lawrence River Ice," Canadian Geotechnical Journal, Vol. 8, No. 2, May 1971, p. 163-169.

Observations are reported on the stress-strain behavior at -9.5± 0.5°C of four types of ice obtained from the St. Lawrence River. The ice was subject to nominal rates of strain covering the range 2.1×10^{-5} min^{-1} to 5.8×10^{-2} min^{-1}. A ductile-to-brittle transition was observed for strain rate of about 10^{-2} min^{-1}. In the ductile range the four types had an upper yield stress that increased with strain rate according to a power law.

133. Gold, L. W., "Observations on the Movement of Ice at a Bridge Pier," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851.

Photogrammetric observations on the movement of an ice cover about a bridge pier are presented. Most of the movement was across river rather than up or downstream, and appeared to be related to the crack pattern that developed about the pier due to changes in water level. It is suggested that when cracks form on the under side of the cover they fill with water which subsequently freezes. Because of the resulting increase in area, a thrust is developed in the cover when the water returns to its original level. Flooding of the cover about the pier had a major influence on the characteristics of the ice adjacent to the pier. Observations on the vertical deflection of the cover and the location of cracks gave for $E/(1-\sigma^2)$ a value of about 3.5×10^5 psi where E and σ are the effective Young's modulus and Poisson's ratio. It is suggested that observations on the deflection of ice covers adjacent to long straight walls can give useful information on the vertical forces that ice can exert on structures.

134. Gold, L. W., "Process of Failure in Ice," Canadian Geotechnical Journal, Vol. VII, No. 4, November 1970, 405-413.

Information is presented on the failure behavior of columnar-grained ice during compressive creep and constant strain rate tests. The role in crack formation in establishing the failure condition is briefly described. Breakdown of structure is responsible for a marked change in the creep behavior of ice in the stress range of 10 to 12 kg/cm^2. A ductile-to-brittle transition is observed at a strain rate of about 5×10^{-3} min^{-1}. The upper yield stress in constant strain rate tests is shown to increase with increase in the strain rate up to the ductile-to-brittle transition.

135. Gold, L. W., "Some Observations on the Dependence of Strain on Stress for Ice," Canadian Journal of Physics, Vol. 36, No. 9, September 1958.

Observations were made on the longitudinal and transverse strain of rectangular ice samples stressed at the rate of 2 kg/cm^2/sec to a maximum stress of 10 kg/cm^2. The duration of the stress was kept less than 10 seconds. Under these conditions the ice behaved elastically. The observations indicated that two deformation processes contributed to the measured strain. It is concluded that the two sources of strain are deformation of the grains and slip at the grain boundaries.

136. Goodman, T. R., "The Heat-Balance Integral and Its Application to Problems Involving a Change of Phase," Transactions of the American Society of Mechanical Engineers, February 1958, p. 335-341.

An approximate mathematical technique utilizing the "heat-balance integral" is presented for solving for the location of the melt line in heat-conduction problems involving a change of phase. Analytical expressions are derived when (a) boundary temperature is fixed; (b) heat flux at boundary is given; (c) heat flux is generated aerodynamically or by radiation; (d) heat flux at boundary is given and melt is completely removed; (d) heat flux at boundary is given, and at time t melt beings to vaporize. Comparisons with known solutions have been made when available, and ultimately all the solutions are presented in graphical form.

137. Goodman, T. R., and Shea, John J., "The Melting of Finite Slabs," Journal of Applied Mechanics, Transactions of the Society of Mechanical Engineers, March, 1960, 16-18.

An approximate method, known as the heat-balance integral, is used to determine the melting rate of a finite slab which is initially at a uniform temperature below the melting point. The slab is acted upon by a constant heat input at one face and has its other face either insulated or kept at its initial temperature. The first three terms of series solutions in an intrinsically small parameter are obtained for the time histories of melting and the temperature distribution in the slab.

138. Gotlib, Ia, L., "Discharge of Ice Through the Openings in the Dam of the Hydro-Electric Plant Bratsk," (2.2.4) Gidrotekh. Stroit 31, 1961, no. 6, pp. 27-31.

The river discharges 20-1000 m^3/sec of ice in sheets of 100-200 m^2 and up to 2 m in thickness through the cross-section of the dam. While building the dam for the power station Bratsk from 1959-1960, changes of waterlevels, velocities, the way of melting and of discharging ice and the amount of ice carried off were observed. (in Russian).

139. Green, T., "Wave Action in the Coastal Zone," ASCE, Sept. 1960, Third Edition.

Gives an overview of water wave properties in the coastal zone. Leaving the reader with an appreciation of the subject so that he can either interface intelligently with a specialist, or pursue the topic further on his own. Gives the reader a feel for the accuracy of various commonly used formulas.

140. Groat, H. F., "Ice Diversion for St. Lawrence River Power Co.," Canad. Engr., v. 39, 1920, p. 545-52.

Discusses construction of submerged weir and ice diversion works in South Sault Channel of St. Lawrence River. Ice jams cause high backwater thus reducing the head on the turbines during such periods, sometimes by as much as ten feet.

141. Gullidge, Ellsworth J., and Urabeck, Frank J., "Planning for Pleasure Boating on Regional Basis," Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol. 96, No. WW3, Proc. Paper 7453, August, 1970, p. 583-600.

A regional study of Puget Sound and adjacent waters, in Washington State, provided comprehensive information for use in planning of small boat harbors and other facilities required by pleasure boaters. This study included: an inventory of existing facilities and shoreline; measurement of marine facility demand by a questionnaire survey; comparison of demand with existing facilities to determine needs for additional facilities and projections of needs to 1980, 2000 or 2020. The paper displays a systematic approach towards the measurement of boater demand, both of quality and quantity, thus providing techniques for use by planners seeking to plan and develop facilities for pleasure boating.

142. Graves, Ernest, "Economics of Season Extension," The Seaway Review, Vol. 2, No. 2, 1971, 17-19.

The Army Corps of Engineers estimates that for 1980, a shipping season that lasts until Dec. 15 on the Great Lakes can yield economic benefits from 2.5 million dollars up to 35.8 million dollars for a year round operation. Cost estimates for bringing about this extension range from 5 to 27 million dollars per year. Section 107 of the 1970 River and Harbor Act authorized a major study into the feasibility of extending the season and directed the Secretary of the Army to undertake a program to demonstrate the practically of extending the season. The law requires that a report describing the results of this program be submitted to Congress no later than July 30, 1974.

143. Hagström, B., "Protection of Dam Gates"(gates with bottom seal below downstream water level), IAHR 8th Congress Montreal 1959, Sem. I, pp. 19-SI-1-2.

Description of protecting means of heating on dam gates in gate chambers.

144. Hagström, B., "Protection of Dam Gates," (gates with bottom seal above downstream water level), IAHR 8th Congress Montreal 1959, Sem. I, p. 18-SI-1-2.

A description is given of the heating system at present normally suggested by Vattenbyggnadsbyran (VBB), to be used for Tainter gates in Sweden or where climatic conditions are similar to those in Sweden.

145. Hansen, R. W., Sherwood, G. E., "Pioneer Polar Structures - Erection of Portable Maintenance Shelter," U. A. Navy Project Y-5015-11-01-143, May 1964, 57p. AD 601373.

The U. S. Naval Civil Engineering Laboratory, Port Hueneme, California, has developed a shelter for the maintenance and repair of construction and other equipment in pioneer polar camps. The shelter, which is 20 by 24 feet, will accommodate equipment as large as a standard size 4 tractor. It consists of a skid-mounted aluminum frame of knock-down construction and a canvas cover. Accessories include a gantry-mounted, 2-ton traveling hoist, an electrical harness, and a personnel side entry. An 8- RY 20- foot skid-mounted wanigan outfitted with tools and shop equipment has been developed as a companion item for the shelter. It is called an equipment-repair wanigan, this technical note provides a guide for erecting and outfitting the shelter and the wanigan. A detail description of the portable maintenance shelter is given in NCFL Technical Report R-317, and a detail description of the NCEL family of wanigans is given in NCEL Tech. Report R-309.

146. Harich, Henry W., "Reducing Ice Formation at Navigation Dams" Journal of the Waterways, Harbors and Coastal Engineering Division. ASCE, Vol. 98, No. WW3. Proc. Paper 9114, August 1972, pp. 343-355.

Increasing the turbulence at the movable gates of the Mississippi River Navigation Dams in the St. Paul District by discharging over bulkheads during the winter rather than under the gates has prevented severe icing at the dam. This study has shown that movement of the gates has been facilitated substantially, but maintenance costs on the bulkheads have increased. Providing aeration facilities, culverts through the earth dams and slots through emergency spillways have increased dissolved oxygen in downstream slackwaters and have benefited fish life by reducing stagnation. Additional aeration is possible by improving facilitations.

147. Harrison, C. D., "Provision for Uplift and Ice Pressure in Designing Masonry Dams," Am. Soc. Civil Eng. Proc., V. 37, Pt. 2, 1911, p. 1195-98.

The question of uplife discussed with reference to type of construction for bridges and dams. Ice pressure on reservoirs and the necessity of considering this factor in connection with bridge or dam design.

148. Hausser, T. and Galiana, G., "Transportation and Deposit of Frazil Ice Under Ice Covers," IAHR 8th Congress Montreal 1959, Sem. I, pp. 6-SI-1-6.

After an ice-cover is formed, its thickness usually increases mainly because of frazil ice deposits. Frazil ice being transported in suspension, turbulence phenomena play an essential part and make similitude impossible. We have tried to solve this problem by calculation and have checked the results obtained by field measurements.

149. Hausser, R. and Michel, B., "Variations of Temperature of Water Under Ice Covers in Rivers," IAHR 8th Congress Montreal 1959, Sem. I, pp. 5-SI-1-3.

Studies show that the temperature of water increases as water progresses under ice covers. An application to the Beauharnois Canal has been memorized.

150. Hausser, R., and Beauchemin, R., "Rate of Ice Production on an Open Water Surface," IAHR 8th Congress Montreal 1959, Sem. I, pp. 8-SI-1-3.

A summary of results is given on the added graph. It can be seen from these results that the MacLachlan's formula is sufficient to calculate the mean ice production in the Montreal area.

151. Hawkes, I., "Development and Evaluation of an Apparatus for the Direct Tensile Testing of Ice," October 1969 27p. AD-698 022, 21 refs. 25-998, CRREL Special Report 131.

This report discusses the theory of the uniaxial tensile test of a brittle material and describes in detail the development and calibration of an apparatus designed to subject fine-grained polycrystalline ice specimens to uniaxial tensile and compressive loads up to failure, and to give a continuous stress-strain curve during the loading cycle. A technique for preparing fine-grained ice specimens is also given together with a preliminary tensile strength value (19.3 kg/sq cm) and stress-strain relationships (initial tangent modulus 5.6x 100,000 kg/sq cm) at a temperature of 15F and a strain rate of 3.6×10^{-6} strain/sec.

152. Hawkes, I. and Mellor M., "Deformation and Fracture of Ice Under Uniaxial Stress," Journal of Glaciology, Vol. II, No. 61, 1972.

Techniques for making precise uniaxial tests for strength and deformability of ice are described. Results are given for tests made in uniaxial tension and uniaxial compression at constant displacement rate, using bubbly polycrystalline ice. These results include stress/strain curves, elastic moduli, rupture or yield strength, and failure strains, all for a range of strain-rates. A few results for ice doped with hydrogen fluoride are also given. The fracture mechanism for ice is discussed, and the test results are compared with data reported by previous investigations.

153. Haynes, F. D., "Tensile Strength of Ice Under Triaxial Stress," Research Report 312, CRREL, Hanover, N. H., December 1973.

An investigation was conducted to determine the effect of a compressive stress on the tensile strength of bubbly polycrystalline ice. One hundred forty-five tests were made in an apparatus of novel design. A cylindrical dumbbell specimen was stressed in axial tension and radial and tangential compression by a hydraulic system which minimized bending stresses. Compression-tension ratios ranging from 0.21 to 10.14 were used for the tests. Tensile strength was found to decrease with an increase in the ratio. At the ratio of 3.155 the tensile strength is about one third the uniaxial value. The test results support the evidence that the Brazil test underestimates the tensile strength for ice. They also indicate that the Brazil test value for ice and be no greater than one third the uniaxial tensile strength. A comparison of the experimental results with a few prominent biaxial failure theories indicates a lower tensile strength than predicted by any theory. However, the best approximation to the results is the Coulomb-Mohr criterion.

154. Hearst, P. J., "Coating Material for Prevention of Ice and Snow Accumulations," Further Investigations, U. S. Navy Project Y-R007-08-4-410, April 1964, 5 p., AD 600425.

The possibility of obtaining or developing a coating material to prevent ice and snow accumulation was further investigated. Qualitative ice adhesion and frost retention experiments indicated that all available materials would accumulate ice under the proper conditions. Although it might be possible to develop suitable coatings with low adhesion to ice, rather than no adhesion, the potential usefulness of such coatings to the Bureau of Yards and Docks does not appear to be sufficient to warrant further research at the present time. From N-541 Add.

155. Helmer, Frederick L., "Great Lakes and St. Lawrence Seaway," Report on Demonstration Bubbler System, Planning Branch, USACREL, August 6, 1971.

In March of 1971 a bubbler system was installed in Duluth Harbor, Minnesota. Mechanical trenchers were used to cut the ice enabling workers to place the pipes below the ice. Bubbling was initiated on March 8th but due to difficulties only one of the lines was started then. The other was put into operation on March 10th. The ice melted until it lost contact with the surface. Eventually the ice sagged and re-established contact with the surface. For the line that started operation on the 8th, bubbling was terminated on March 29th, and for the other one, bubbling was halted on March 24th. On March 25, the Coast Guard Cutter Woodrush proceeded from the Coast Guard dock to the area of the system. On the trip the Woodrush was required to use alternate forward and reversing movements and was limited to about 200 ft. on each forward movement. Upon entering the test area, the Woodrush split the entire 1,600 ft. length of the test area and was able to proceed nonstop with no difficulty.

156. Hendrickson, J. A., San Marino, California, "Interaction Theory for a Floating Elastic Sheet of Finite Length with Gravity Waves in Water of Finite Depth," (including a comparison with experimental data), Science Engineering Associates, April 1966. Contract NBY 62185. AD 635581.

In the present study a theory is developed for the dynamic interaction of a floating elastic plate with incident gravity waves. The theory is two-dimensional and assumes finite dimensions for the plate and a finite depth for the water. The depth of submersion of the plate, however, is neglected. This investigation extends the work of previous investigations by considering the two-dimensional, finite depth aspect of the fluid flow. The theory is adapted to a numerical means of analysis and a computer program is developed to calculate the response parameters of the elastic sheet for given input parameters. Numerical results are obtained for a particular plate and water depth for four different input waves. These conditions were chosen to be the same as those for which model tests were performed under a different study. From CR-66.005.

157. Hess, H., "On the Elastic Constants of Ice," 1950 12p. AD-719 313 Translation from Zeitschrift fur Gletscherkunde, V. 27: 1-19, 1940-41. 15 refs. 25-4069. SIPRE Translations 4.

Data from earlier experiments were used to establish the dependency of Young's modulus on temperature and pressure with in the range of 0-9 C. Functional relationships involving Poisson's ration, the factor of incompressibility, the modulus of torsion, and Young's modulus were obtained. In measuring glacial depths with seismic waves, it was shown that in order to use appropriate velocity formulas, which are dependent on

the above mentioned factors, a correction factor (between 1.5 and 3) must be applied to Young's modulus. Application of these formulas in connection with the seismic method yielded smaller depths for Greenland ice than had previously been found.

158. Hess, P. M., "Air Bubbler System Maintains Open Channel in Ice Sheet," Electrical World, March 9, 1953.

The initial installation for this experiment consisted of a 1,000 ft. length of 1.5 in. and 1 in. galvanized steel pipe laid on the bottom of the pond (approximately 50 ft deep at the dam). Graded orifices, varying in drill size from No. 35 to 38, were placed every 20 ft. on the pipe. Approximately 200 cfm of free air was required to supply the demand.

159. Higashi, A., "Plastic Deformation of Hollow Ice Cylinders Under Hydrostatic Pressure," SIPRE Res. Rept. 51, 1959, 1-10.

The study was made in order to simulate the deformation of a tunnel in glacier ice and compare the results with the theoretical value derived from compression or tension tests. The plastic deformation of commercial polycrystalline ice and manufactured snow-ice was determined by measuring the discharge of oil from the cavity of closed hollow ice cylinders subjected to high external pressure in an oil-filled pressure chamber. The deformation vs. time curves were similar to those obtained in compression or tension tests. The relationships between minimum strain rate and applied pressure, or between minimum strain rate and the circumferential stress at the surface of the inner cavity, were found. Analysis of time-deformation curves indicates that viscoelastic models proposed by former investigators do not apply to the mechanism of the plastic deformation of ice.

160. Hills, B. L., "Extension of the Shipping Season: A Significant Conference Emerges Out of a Season of Exploration and Study," The Seaway Review, Vol. 2, No. 1, 1971, 15-19.

A top-level seminar to study the progress and assess the problems of extending the shipping season in the Great Lakes - St. Lawrence Seaway System was held in Cleveland. This is a list of the speakers who were featured at the conference.

161. Hitch, P. D., "Flexural Strength of Clear Lake Ice," U. S. Snow, Ice and Permafrost Research Establishment, Technical Report No. 65, July 1968, 8p.

Values for the modulus of elasticity and strength of freshwater lake ice in flexure were determined by laboratory experiments on 63 beams tested under various rates of loading at -5°C and -20°C. Ice was harvested from Lake Superior off Keneenaw Bay.

162. Holden, O., "Ice Conditions in the Niagara River," IAHR 8th Congress Montreal 1959, Sem. I, pp. 29-SI-1-11.

Description and photo's.

163. Horvath, S. and Laszloffy, W., "Ice Conditions on the Danube Between the Mouth of Morava River and the Black Sea," 19th Assembly of the PIANC, London 1957, SI, C 3, p. 219-226.

This paper contains an extensive study on ice conditions from data recorded over about 100 years. As the result of this study, periods for protection of navigation from damage caused by ice can be given. Reduction of the ice period can be effected (1) by breaking up the ice with explosives or with the aid of ice breakers (2) by river regulation.

164. Hromadik, J. J. "Relative Column Strength of Long Piles," U. S. Navy Project Y-F015-10-305, February 1960, OUO, AD 250614.

Sufficient data are lacking on which to base accurate design criteria for long piles used to support waterfront structures. In order to determine the selection of the best type of commercially available pile, full-scale tests on the relative column strengths of six different types, 80 feet long, were conducted at the U.S. Naval Civil Engineering Laboratory. Nine of the eighteen specimens scheduled for the test program were tested under conditions of piles at refusal, utilizing a field test tower capable of producing loads up to 400 tons, in which specimens with an unsupported length of 60 feet or more were loaded to buckling failure. Tests on four types were conducted to failure, test on two types were terminated at the capacity of the loading system. This report is an interim on the results of tests to date. Data are sufficient to determine ultimate load capacities with reasonable accuracy. From R-066.

165. Hughes, R. R., and Gilliland, E. R., "The Mechanics of Drops," Chemical Engineering Progress, Vol. 48, No. 10, October, 1952, 497-504.

As a preliminary to a general study of mass transfer in fluid particle systems, a review and analysis were made of the mechanics of drops. The general review presented includes both the gross motion of drops and the detailed motion in and around individual drops. The emphasis of the review is on new concepts and correlations in connection with the effect of acceleration on drag, the equilibrium distortion, and the internal circulation caused by in friction.

166. Hume, J. D. and Schalk, M., (1964), "The Effects of Ice Push on Arctic Beaches," American Journal of Science, Vol. 262, No. 2, p. 267-273.

167. Hunt, I. A., "Ice Problems in the Design of the St. Lawrence River Power Project," IAHR 8th Congress Montreal 1959, Sem I, pp. 20-SI-1-2.

It has been shown that ice thickness depends on the average ambient air temperature and the surface velocity and surface temperature of the water.

168. Hunter, A. H., and Davidson, M. T., "Measurements of Pile Load Transfer," Performance of Deep Foundations, ASTM STP444 1969, pp. 106-117.

Load transfer data are presented for six piles embedded in sand. The data were adjusted to account for residual loads caused by driving in order to arrive at the true variation of skin friction with depth. Residual loads of 25 to 48 tons were observed for conventionally driven piles, whereas the load for a pile driven with vibratory hammer did not exceed the weight of the driver. Friction during compression was found to exceed that during tension by 30 percent. An average lateral earth pressure coefficient of 1.1 was observed, with a value of 0.75 being observed for a jetted pile. The data indicate that conventional hammers may compact the soil below the pile tip and improve point bearing capacity. Skin friction adjacent to the pile tip was found to be significantly lower than for other parts of the pile.

169. "Ice Pressure Against Dams; A Symposium," American Society of Civil Engineers Transactions, Vol. 119, 1954, 1-42.

Contains the following papers:
ASCE Joint Division Committee on Masonry Dams: "Foreward," 2-5.
B. Lofquist: "Studies of the Effect of Temperature Variations," 6-16; Discussion, 17-21.
A. D. Hogg: "Some Investigations in Canada," 22-25.
G. E. Monfore: "Experimental Investigations by the Bureau of Interior," 26-38; Discussion, 39-42.
Contains a number of bibliographic references.

170. "Ice Thrust Against Dams," Engineering News-Record, Vol. 99, Nov. 10, 1927, 742-743.

Discusses two causes for ice thrust, expansion of ice in process of formation within a confined area, and the thrust of a thick sheet of ice as it expands due to temperature increase within a range below the freezing point. An ice sheet 1 mile long will increase in length approximately 1.5 ft. for each 10° rise in temperature.

171. Ince, Simon, "A Guide to the Design of Air Bubblers for Melting Ice," Hydraulics Section, National Research Council, Ottawa, Canada.

The use of air bubblers for maintaining ice-free areas in lakes and in the sea has been reported abundantly in the technical literature. This author reported his observations on two air bubbler installations in the Canadian Arctic to the Eighth International Conference on Coastal Engineering. The results of these investigations were, at that time, still inconclusive. Today, some of the mystery is resolved and it is the author's opinion that the existence of a heat reserve is the answer to the problem. Based on this premise, an attempt is made here to develop some guide lines for the proper utilization of this thermal reserve.

172. Ince, S., "Recent Experimental Observations on the Use of Air Bubbling Systems," Proceeding of the Symposium on Air Bubbling, TM-70, NRC,Ottawa, May 11, 1961.

An experiment was conducted to test the efficiencies of four different air bubbler systems. There were a great many variables which effected the outcome of the experiment but it is believed that certain facts and questions were brought out. A unit that released 15 cu. in. bubbler was found to be the most efficient when tested against one that discharged air through a 1/16 in. oriface, and two units identical to the two aforementioned except for the fact that they are surmounted by 4 in. diameter pipe. It is believed that the superior efficiency of this unit is due to the more efficient circulation pattern set up. It was also shown that the stackpipe does not contribute, at least in shallow depths, to the effectiveness of the 15 cu. in. unit. Temperature measurements indicated that the idea of the stackpipe unit drawing the warm water from the bottom and delivering it to the surface without mixing with the intervening levels of colder water is false. The original temperature stratification is quickly broken up by the circulation and temperature gradient.

173. Ince, S., "Winter Regime of a Tidal Inlet in the Arctic and the Use of Air Bubbles for the Protection of Wharf Structures," International Conference on Coastal Engineering, Mexico, 8th, 1962, 499-504.

Shipping in the Canadian Arctic is limited to about 2-1/2 months in summer. During this short period all communities have to be supplied with sufficient provisions and fuel to last the long winters. The Department of Public Works of Canada has built wharves and docking facilities in various Arctic centers to speed up the unloading operations. Many of the conventional pile structures have been destroyed by the 6 ft. thick ice layer, which grips the piles and moves them up and down in response to the tide. To prevent this, an air bubbler system was installed three years ago at Tuktoyaktuk, N.W.T. to inhibit the formation of ice around the wharf. This unit has been operating successfully since that time and no further damage has been reported. This first success inspired the installation of a second unit at Cambridge Bay, N.W.T. where similar difficulties were being encountered. The air bubbler system at Cambridge Bay did not fulfill its

promise and the wharf was damaged. This had been predicted, but the success at Tuktoyaktuk - despite the suspected influence of the Mackenzie River - was a mystery. In April 1961 the author investigated the bubbler system and its oceanographic environment at Cambridge Bay, and in April 1962 those in Tuktoyaktuk. The results of these surveys are reported in the following paragraphs.

174. "International Association of Scientific Hydrology," General Assembly of Helsinki 25.7 - 6.8, 1960. International Association of Scientific Hydrology, Publ. No. 54, 584 pp.

Subjects: 1. Sea and lake ice-snow. 2. Snow accumulation and ablation. 3. General glacier studies: Glacio-meteorology. 4. Response of glaciers to climate. 5. Glacier surveying and thickness measurement. 6. Glacier flow.

175. Ivanov, K. E. and Lavrov, V. V., "Peculiarity of the Mechanism of the Plastic Deformation of Ice," 1951, 3p. AD-718 766 Translation from Zhurnal tekhnicheskoi fiziki, 20(2): 230-231, 1950. 25-4073, SIPRE Translation 10.

It is well known that crystalline bodies differ from amorphous bodies, not only because they are anisotropic, but also because of their special behavior in plastic deformation. The latter in crystals occurs in leaps and bounds and, as a result, the deformation curves clearly show this step-like characteristic. Up till now, this phenomena had been discovered in the crystals of NaCl, brass, zinc and cadmium, and also in metals in the polycrystalline state (as brass and aluminum). It is shown that this peculiarity is also present in ice.

176. James, D. W., "The Thermal Diffusivity of Ice and Water Between -40° and +60°C," J. Material Sci., 3: 540, 1968.

The thermal diffusivity α_S of triply-distilled deionised water, and α_L of single-crystal ice along the c-axis, have been measured by Angström's method. The temperature range covered was -40 to +60°C. The results for water compare well with published data for the thermal conductivity, but for ice there are unexplained discrepancies. The linear relationships $\alpha_S = (8.43-0.101T)\ 10^{-3}$ cm^2/sec and $\alpha_L = (1.35+0.002T)\ 10^{-3}$ cm^2/sec where T°C is the temperature, fit the data obtained.

177. James, J. W., "On the Driving of Piles to Resist the Force of Ice Tending to Draw Them From the Ground," Institution of Civil Engineers Minutes of Proceedings, Vol. 41, 1874-75, Pt. III, 191-201.

Gives results of experiments carried out by the author.

178. Jellinek, H. H. G., "Adhesive Properties of Ice," U. S. Army Snow Ice and Permafrost Research Establishment, Research Report 38, Wilmette, Illinois, September 1957.

An apparatus has been constructed for the investigation of the adhesive strength of ice by shear experiments. For the system sno-ice/stainless steel, shear experiments yielded pure adhesive breaks down to a temperature of about -13C, where a sharp transition to cohesive breaks took place. The adhesive strength for this system is a linear function of the temperature, and is independent of the cross-sectional area and height of specimens in the ranges investigated. The system ice/polystyrene yielded a linear relationship between adhesive strength and temperature in a rnage from -2 to -25.5C. Cross-sectional area and rate of stress application had no effect on the adhesive strength in the ranges investigated. The system ice/polymethylmethacrylate showed a larger adhesive strength than the system ice/polystyrene. The experimental results are explained by the assumption of a liquidlike layer between ice and the solid interface. The thickness and consistency of this liquidlike layer are a function of temperature and the nature of the solid interface. The surface tension forces and frictional forces operative in the liquidlike layer are discussed.

179. Jellinek, H. H. G., "Adhesive Properties of Ice, Part II," July 1960, 10p. AD-638 344 11 refs. 24-3220, US-CRREL Research Report 62.

The results of shear tests on the system ice/stainess steel and ice-optically flat fused quartz as a function of the rate of sheat and roughness of the steel surface are reported. The adhesive strength decreased with decreasing roughness of steel surface, and the force-vs-time curves for smooth steel plates resembled those of 2 solids sliding over each other with a liquid layer between. This behavior was especially evident in the case of quartz. The adhesive strength as a function of rate of shear was linear for both ice/stainless steel and ice/quartz, but there were indications of yield values. The results agree with the assumption of a liquid-like layer on ice. Ratios of viscosity coefficient to layer thickness were evaluated for both systems, and viscosity coefficients are estimated. The importance of interfacial free-energy considerations is pointed out.

180. Jellinek, H. H. G., "Ice Adhesion," Canadian Journal of Physics, October 1962 40 (10) p.1294-1309 27 refs. Microform No. SIP 20744, 25-2016. U.S. CRREL, Misc. Publication 198.

Results of shear tests for the system ice-stainless steel and ice-optically flat fused quartz as a function of the rate of shear and roughness of the steel surfaces are presented. The adhesive strength decreased with decreasing roughness of

the steel surfaces, and the force vs. time curves for smooth steel plates resembled those of two solids sliding over each other with a liquid layer between them. This behavior was especially evident in the case of the optically flat quartz. The adhesive strength as a function of rate of shear was linear for both ice-stainless steel and ice-quartz, but these were indications of yield values. The results agree with the assumption of a liquidlike layer on ice. Ratios of viscosity coefficient to layer thickness were evaluated for both systmes, and viscosity coefficients estimated. Shear experiments on thin water films between glass plates support the assumption of a liquidlike layer on ice. The importance of interfacial free energy considerations is pointed out.

181. Jellinek, H. H. G., and Brill, R., "Viscoelastic Properties of Ice," Journal of Applied Physics, Volume 27, No. 10.

An apparatus has been constructed for the study of deformation under tension of single and polycrystalline ice. Deformations of single and polycrystals was investigated as a function of time, stress, and temperature. Deformations down to 10^{-5} cm could be measured. Whereas the strain rate for polycrystalline ice decreased with time, that for single glacier ice increases linearly with time. The deformation for fine-grained polycrystalline ice consists of an instantaneous elastic deformation, a transient creep and a steady state creep. Deformation curves can be represented by empirical equations. The recovery curves on removal of the loads have also been investigated and the plastic flow has been deduced from the residual deformation after complete recovery. This plastic flow was found to be Newtonian within the range of stresses investigated poises, where 16 100 calories is the energy of activation for the plastic flow. The total deformation can be represented satisfactorily by a large number of Voigt units representing a distribution of retardation times, in series with a Maxwell unit.

182. Jellinek, H. H. G., "Bonding of Flat Ice Surfaces," U. S. Army Snow Ice and Permafrost Research Establishment, Research Report 61, Wilmette, Illinois, July 1960.

Experiments have been performed on the bonding of polished and microtomed ice surfaces at -5C. These surfaces showed an appreciable curvature and uneveness. The force of separation after bonding for 60 min. under different weights increased with weight. The surfaces placed together immediately after preparation showed an appreciably higher force of separation than those placed together after a time interval. The force of separation for surfaces placed together at zero humidity showed a higher force of separation than those placed together in an atmosphere of 100% relative humidity. A preliminary simplified theory of bonding of irregular surfaces has been developed.

183. Jellinek, H. H. G., "Tensile Strength Properties of Ice Adhering to Stainless Steel," U. S. Army Snow Ice and Permafrost Research Establishment, Research Report 23, Wilmette, Illinois, January 1957.

Tensile strength measurements on ice cylinders adhering to stainless steel have been made as a function of rate of loading, thickness and cross-sectional area of specimens, and temperature. A rapid increase of tensile strength occurs as the volume is decreased and the data for a temperature of -4.5C can be represented over a thousandfold range of volumes by an equation as follows:

$$S = 2.74AV^{-0.84} + 9.4 \text{ kg/cm}^2$$

Where S is the tensile strength, A the cross-sectional area in cm^2 and V the volume in cm^3. The experimental results are interpreted by means of a statistical treatment involving imperfections in the specimens. The statistics for a model consisting of a large number of parallel elements is elaborated. The final equation derived on statistical grounds approximates the equation found empirically, and reads as follows:

$$\bar{S}_{r,n} = kA^{1/\beta_V - 1/\beta} + C$$

where $\bar{S}_{r,n}$ is the number average of the tensile strength, k, β, and C are constants and r is the number of imperfections in each of n parallel elements. The conclusion reached is that the tensile strength is a statistical function of the volume and cross-sectional area of the specimens due to imperfections. Superimposed on to the statistical effect is a stress distribution effect, which becomes predominant for large volumes.

184. Johannesson, I. J., and Bjerrum, L., "Measurement of the Compression of a Steel Pile to Rock Due to Settlement of the Surrounding Clays," Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering, Vol. 2, Montreal 1965, p. 261-264.

The paper describes the measurements of the compression of a steel pile driven to rock. The compression is caused by the negative skin friction from the surrounding clay only. The clay is a soft to medium soft marine clay and under the weight of 10 m of fill it has settled about 1.2 m. From the shortening of the pile, it can be concluded that the stresses in the steel due to the negative skin friction are high and exceed the allowable design load near the point of the pile. An interpretation of the observed compression of the pile indicates that the developed adhesion between pile and clay is approximately distributed as the effective vertical stresses. A reasonably good agreement was obtained between observed

and computed compression of the pile, when the negative skin friction was assumed equal to $\sigma'_v K \tan \phi'_a$, where σ'_v is the effective vertical stress. It was found that the ultimate value of $K \tan \phi'_a$ is of the order of magnitude 0.20.

185. Johansson, N., "Ice Problems Relating to Dam Gates," IAHR 8th Congress Montreal 1959, Sem. I, p. 27-SI-1-4.

A measure against ice on a sector gate is described.

186. Johnson, Philip R., "The Potential of Thermal Piles in Arctic Marine Structures," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The heat transfer characteristics of three types of thermal piles, the Long Pile, the Balch Pile and thermal convection loops, have been investigated. Empirical performance relationships have been developed for several piles and the effect of change of size has also been investigated. The results suggest that thermal piles could be used to build large steel-reinforced ice structures for use in the Arctic Ocean. The thermal piles would build the ice in place during the winter and would also act as the tensile reinforcement.

187. Jones, John R., and Gardos, Michael N., "Adhesive Shear Strength of Ice to Bonded Soild Lubricants," Lubrication Engineering, December, 1972, Vol. 28, 12, 464-471. Presented at the 27th ASCE Annual Meeting in Houston, Texas, May 1-4, 1972.

Low-temperature adhesive shear tests were conducted on an electronic compression and tensile tester to determine the force required to break ice away from steel surfaces coated with various bonded solid lubricants. A coating based on a polyimide resin and REP (fluorinated ethylene propylene) gave lowest shear value and was found, in LFW-1 tests, to have low friction and satisfactory wear life.

188. Kaplar, C. W., "Evaluation of a 20-Inch Guarded Hot-Plate Thermal Conductivity Apparatus Range -50F to 250F," June 1971, 39p. AD-727 668 13 refs. 26-2353, US-CRREL Special Report 137.

A new custom-made guarded hot-plate thermal conductivity test apparatus capable of accommodating two 20x20 in. specimens up to 3 in. thick is described. The apparatus was designed for testing materials ranging from thin, rigid, foamed thermal insulations to 3 in. thick pavement sections of asphaltic or portland cement concrete, with a 1 ft. sq. metered area. The effective temperature range of the apparatus is from +250F to -50F. Some performance test data on a calibrated gum rubber specimen and results of evaluation tests on a frozen wet sand are presented. The k-values

obtained for the frozen sand compare well with those obtained by other techniques.

189. Kaplar, C. W., "Laboratory Determination of the Dynamic Moduli of Frozen Soils and Ice," National Research Council. Publication 1966, 1287 International Conference on Permafrost, Nov. 11-15, 1963, Lafayette, Ind. Proceedings p. 293-301, 22 refs. Microform No. SIP 24864. 25-2124, U.S. CRREL, Misc. Publications 211.

Vibratory nondestructive techniques can be applied successfully in the laboratory to the study of dynamic elastic properties of frozen soils and ice. The dynamic moduli and wave transmission velocities of frozen soils increased with a decrease in temperature. Below 20F, the dynamic properties of fine-grained soils were more temperature dependent than those of coarse-grained soils. Elastic moduli for coarser-grained soils were more than 4 times those for fine-grained soils and ice. The dynamic elastic properties of ice, including wave velocities, were consistent with findings of other investigators.

190. Kaplar, C. W.,and Wieselquist, K., "Summary Report of Laboratory Studies Performed Under Project SP-15 and SP-48 Materials in Cold Climates," Sept. 1967, 224p. 72 refs. 26-5046. U.S. CRREL, Unpublished Internal Reports 46.

The report presents a compilation of data obtained over a period of several years during a laboratory investigation of the moisture absorbing characteristics of foamed board type insulations. Results of soaking tests in water and long-term (3 years) imbedment in moist soil are presented, showing internal distribution of absorbed water. Initial trials and evaluation of several available techniques for the determination of thermal conductivity of soils and insulations are presented and discussed. Selected data from experimental laboratory tests with thermal (line heat source) probes are presented for a silt soil. Initial exploratory tests in site with special field probes are presented.

191. Kendall, G. R., "Meteorological Information Relevant to Ice Pressures," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Tech. Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

Details are given concerning the source of information on ice thickness, freeze-up and break-up of lakes and rivers accumulated by the Canadian Meteorological Service. Information is also presented on the maximum temperature change for a six-hour period in January for 22 Canadian cities and return periods of 5, 15 and 25 years.

192. Kingery, W. D., Ice and Snow - Properties, Processes and Applications, The M.I.T. Press, Cambridge, MA, 1963.

Table of Contents includes:
Glen, J. W. "The Rheology of Ice"
Gold, L. W. "Deformation Mechanisms in Ice"
Weertman, J. "The Eshelby-Schoeck Viscous Dislocation Damping Mechanism Applied to the Steady-State Creep of Ice"
Kuroiwa, Daisuke and Hamilton, Wayne L., "Studies of Ice Etching and Dislocation Etch Pits"
Eckerbom, Eric and Palosuo, Erkki, "A Study of Ice Crystals at Storglaciaren, Kebnekajse"
Anderson, Don L., "Use of Long-Period Surface Waves for Determination of Elastic and Petrological Properties of Ice Masses"
Langleben, M. P. and Pounder, E. R., "Elastic Parameters of Sea Ice"
Brown, James H., "Elasticity and Strength of Sea Ice"
Kozlovskii, A. M., "The Formation and Structure of Fast Ice at Mirny Anchorage and in Alasheev Bright"
Chikovskii, S. S., "The Supercooling of Sea Water Under Natural and Laboratory Conditions"
Yakovlev, G. N., "The Use of High-Speed Gas Jet to Break Ice"
Shvaishtein, A. I., "The Use of Steady High-Pressure Jets to Cut Ice"
Nikolaev, S. E., "The Use of a Directional Explosion to Break Sea Ice"
Cherepanov, N. V. and Kamyshinkova, A. V., "Sizes and Shapes of Congealed-Ice Crystals"
Gollandtseva, A. N. and Glukhova, N. V., "A Study of the Structure of Sea Ice"
Vitko, N. A., "A Trial Calculation of Icebreaker Passibility Through Sea Ice"
Smirnov, V. N. and Lin'Kov, E. M., "Tiltmeter Observations of Sea Ice-Oscillations"
Yekovlev, G. N., "Studies in Ice Physics and Ice Engineering"
Peschanskii, I. S., "Static Pressure of Sea Ice"
Yakovlev, G. N., "Method for Predicting Strength Characteristic of Ice Cover"
Shavishtein, Z. I., "Experimental Studies in an Ice-Research Laboratory"
Lavrov, V. V., "Scale Effect as Indication of Ice-Breaking Mechanism"
Petrov, I. G., "Division of the Artic Marine Ice Cover into Regions According to Ice Structure"
Smirnov, V. N., "Determination of Elastic Characteristics of an Undististurbed Ice Cover Using Static and Dynamic Methods"
Afanas'ev, V. P., Dolgopolov, Yu. V. and Shvaishtein, Z. I., "Ice Pressure on Individual Marine Structures"
Kheisin, D. E., "Some Unsteady-State Problems in Ice-Cover Dynamics"
Nazintsev, Yu. L., "Melting of Ice in Hummocks"-"Isostatic Phenomena on Pack-Ice Floes"
Fedotov, V. I., "Radiation Break-up of Antarctic Fast Ice"
Peyton, H. R., "Some Mechanical Properties of Sea Ice"

Graystone, Peter and Langleben, M. P., "Ring Tensile Strength of Sea Ice"
Kingery, W. D. and French, D. N., "Stress-Rupture Behavior of Sea Ice"
Coble, R. L. and Kingery, W. D., "Ice Reinforcement"
Nye, J. K., "Theory of Glacier Variations"
Haefeli, R., "Observations in Ice Tunnels and the Flow Law of Ice"
Roethlisberger, Hans, "Ultrasonic Measurements of Deformation Around a Rectangular Ice Tunnel"

193. Kivisild, H. R., "River and Lake Ice Terminology," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

River and lake ice terms have been evolved gradually in the last 40 years as the processes of ice formation and breakup have become better understood. The IAHR has considered it appropriate to contribute to a systematic river and lake ice nomenclature. The preparation of a terminology was given to a subcommittee headed by the author and a set of terms is presented herewith for discussion and approval. The set is presented in English only, since a multilingual glossary should be based on an agreed set of terms. The terminology has been developed to be in harmony with the work by UNESCO on sea ice, since a submission from us to UN on lake and river ice terms has been requested.

194. Kivisild, H. R., "Hanging Ice Dams," IAHR 8th Congress Montreal 1959, Sem. I, p. 1-SI-1-2.

Theoretical considerations indicate that the Froude number at the upstream end is a likely criterion to determine whether ice running down the river will be attached to the upstream end or otherwise carried: Fr<0,08, ice is accumulating at the upstream end; Fr=0,08, the pack tends to become more massive; Fr>0,08, ice is carried under the ice cover.

195. Kizzor, A. J., "Built-In Bubbles Bar Ice," Compressed Air Magazine, February 1963, p. 8-9.

Compressed air systems to be installed at the Bureau of Reclamation's Blue Mesa Dam Project in western Colorado will prevent formation of ice at the intake structure for the outlet works and at the gate structure for the spillway. Because of the altitude (7,528 feet above sea level) and the severity of the winters (temperatures during winter months average about -15°F), protection against ice formation at intake and gate structures is essential for 12-month operation. Outlet works include the intake structure and a 16 ft. diameter, 973 ft. long tunnel through the right abutment. A 16 ft. wide by 18 ft. wide free wheel gate is to be installed in the intake structure for emergency closure. Flood waters of the Gunnison River are to be passed through a tunnelage spillway also extending through the right abutment. The tunnel will vary in size from 24 ft. 8 in. near the gate structure to 21 ft. at the downstream pour.

196. Kobeko, P. P., and Marei, F. I., "Wetting and Strength of Adhesion," U. S. Army Snow Ice and Permafrost Research Establishment, Translation 59, Wilmette, Ill., July 1958.

It has been demonstrated that the strength of adhesion of water and other liquids to hard surfaces does not depend on whether a substance is moistened by the liquid or not. The strength of adhesion of ice to plastic materials and lacquers is approximately ten times weaker than to glass and metals. However, this strength (about 2 kg/cm^2) is considerable, and coating with these substances could not prevent icing of a surface. Non-polar substances such as polystyrene, Escapone, and other polymers do not present any advantages in comparison with lacquered coatings in use at the present time. Since the adhesive strength of frozen liquids to solids is not dependent upon polarity and wetting, and also, from available comparative data, not dependent upon adhesive strength to various lacquered surfaces and plastics, we must recognize the futility of searching for a suitable lacquer coating to prevent icing. This situation has been verified by numerous unsuccessful attempts of many foreign scientists seaching for a similar solution. One should not forget also that surfaces are not as clean in practice as those carefully prepared in the laboratory. Under natural conditions, any surface will soon pick up dirt, and a very thin layer of sediment is sufficient to alter surface forces.

197. Koike, Tatsui, and Koike, Eiichi, "An Experimental Study on Prevention of Ice-Cover Formation in Reservoirs by Means of Air-Blow Method," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

In the instance of ice-covered reservoirs in wintertime, it is necessary to keep the upstream side of the spillway gates in an ice-free state so as to keep them functional in case of a flood emergency, and a useful measure to this end is to blow air into the water so as to prevent the surface from forming an ice-cover. This paper describes the results of the experiments conducted at a few reservoirs of medium or small scale concerning the relation among air temperature, blow air volume and ice-free area width; it forms the first of a series of experiments to be conducted in the future to establish a general rule in this respect.

198. Kolesnikov, A. G., Pantaleev, N. A. and Ivanov, V. N., "Experimental Studies of the Turbulent Layer under Drift Ice," Izvestiya, Atmospheric and Oceanogr. Physics., 1, 1965, No. 12, Dec., p. 769-773, 8 fig., 4 ref.

Results of an experimental study of turbulent velocity fields in the surface water layer under an ice field drifting in the ocean are presented. A turbulence meter was used to measure the mean and fluctuating velocity components of the drift current under the ice. The instrument allowed continuous

recording of vertical and horizontal velocity fluctuations components. After statistical treatment the results were used to determine the main characteristics of turbulence in the near ice layer and their depth distribution.

199. Koros, R. M., Deckers, J. M., Andres, R. P. and Boudart, M., "The Sticking Probability of Water on Ice," Chem. Engr. Sci., 21, 1966, nr. 10, Oct., p. 941-950.

A direct method to determine the sticking probability or condensation coefficient α_c of water molecules on ice has been developed. A high-flux molecular beam of water vapor is impinged on an ice target supported by a cooled copper sheet suspended from a quartz spring. The sticking probability is obtained from the increase in weight of the target. The value found for α_c is 0.83 $\pm$ 0.15 for the temperature range of -115°C to -140°C.

200. Korzhavin, K. N., "Ice Affecting Engineering Structures on the Siberian Rivers During Ice-Run," IAHR 8th Congress Montreal 1959, Sem. I, p. 16-SI-1-5.

The interaction between ice forced against piers, and these piers, is analyzed. Design values of ice ultimate strength, design form coefficients of piers, and formulas for computing the ice forces on piers are dealt with.

201. Korzhavin, K. N., Action of Ice on Engineering Structures, Cold Regions Research and Engineering Laboratory, Draft Translation 260, Hanover, N. H., September 1971.

Conditions of ice-breakup in rivers of the European part of the Soviet Union are described and compared with those of the Siberian rivers. Methods of computing the strength of ice under compression, cutting, bending and fracturing during ice flow are offered and conversely methods are recommended for determining the strength of structural supports, load, size of ice packs, contact pressures, velocity of flow, and air temperatures. The effect of the edge slope of ice breakers is discussed. A proposed method for the determination of the minimum permissible span of bridges or apertures in hydraulic structures insures a free flow of ice.

202. Korzhavin, K. N., "Dynamic Ice Pressures and Deformation of Structures," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

Considered is a calculation scheme for estimating the forces of interaction occuring under dynamic ice loads. Design formulae are presented for determining the magnitude of dynamic ice pressure on vertical piers with due regard to the coefficient of elastic response.

203. Korzhavin, K. N., "Regarding the Effect of Pier Deformation of Structures Due to Dynamic Ice Pressure," Transactions of the Novosibirsk Institute of Railroad Transportation Engineers, Issue 94, Novosibirsk, 1969, USSR.

204. Korzhavin, K. N., Ptukhin, F. I., "Evaluation of the Compressive Strength of Ice Under the Short-Term Rapidly Increasing Load," August 21, 1969, FSTC-HT-23-188-68, 14 p. AD-693 277. For original Russian article and abstract see SIP 25971. 9 refs. 25-1178. CRREL Draft Translation 81.

205. Kramek, Robert E., "Coast Guard Programs and their Challenge to the Naval Engineer," Naval Engineers Journal, Washington, D.C., June 1972, 84(3), 49-66.

U. S. Coast Guard (USCG) activities in the next decade, especially in the fields of polar and domestic ice breaking, aids to navigation, marine environmental protection, and commercial vessel safety, will present a challenge to the coast guard naval engineer. Through the combined efforts of research and development, merchant marine safety, and naval engineering, the coast guard naval engineer will provide the engineering technology and management systems for these activities. The major objectives of the USCG marine environmental protection program is to prevent damage to the marine environment; the objective in ice breaking is to provide water-born access to ice-bound locations; and the objective of the boat safety program is to minimize lives lost, property damage, and personal injury.

206. Kranich, L., "Betriebliche Vorkommnisse und Erfahrungen beim Eisgang vom Winter 1962/63 auf Aare und Rhein," Wasser- und Energiewirtschaft, 56, 1964, No. 1, Jan. p. 1-12.

Description of the ice problems in the upper Rhine river area and that of its tributary the Aare river. The problems are related to barrages and power stations. A description is given of some methods of attack to the special problems encountered (in German).

207. Krausz, A. S., "Plastic Deformation of Fresh-Water Ice," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1977, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No.9851, Ottawa.

In this review the results of laboratory experiments on the plastic deformation of ice are presented from the engineering point of view. A discussion is also presented on the creep behavior of columnar-grained and snow ice in tension, compression, bending and shear emphasizing the effect of the crystal structure. The relationship between strain rate $\dot{\varepsilon}$, creep time, stress σ and temperature are represented by the

simple expression $\dot{\varepsilon} = A\sigma^n$ where the factors A and n are functions of the creep time and temperature. To illustrate the significance of the deformation history on the creep properties of ice, information obtained in repeated loading tests is presented. The effect of variable stress as well as non-uniform and complex stress fields on the plastic deformation process is briefly reviewed.

208. Krecker, F. H., "Periodic Oscillation in Lake Erie," The Franz Theodore Stone Laboratory. Contribution No. 1, Ohio State University Press, Columbia, Ohio, 1928, 22p.

Deals with seiches. Reference not in Engineering Societies Library and not verified. On file in U. S. Geological Survey Library, Washington, D. C.

209. Kristinsson, Bjorn, "Ice Monitoring Equipment," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

Description of monitoring methods for ice phenomena in rivers. In some Icelandic rivers ice problems exist in connection with operation of Hydroelectric Power Plants and three types of monitoring equipment were developed, i.e., one for frazil ice discharge, another for ice thickness and a third one for stepbursts. The monitor for frazil ice is described in some detail and a short mention is made of the other two types. The frazil ice detector and the ice thickness detectors are based on measurements of electrical conductivity changes. The step bursts detector is a pressure sensitive detector.

210. Krushchov, M. M., Berkovich, E. S., "Study of the Hardness of Ice," 1970, 48p. AD716 457 Translation of Izuchenie tverdosti l'da. Moscow, Izdvo AN USSR, 1960. 25 refs. 25-2551 CRREL Draft Translation 74.

The present monograph is intended as a systematic representation of data collected on the hardness of ice by the present authors and other investigators using various methods. It is believed that the monograph will be of general interest to scientists and engineering-technical workers concerned in any way with ice, frozen soil, or snow at low temperatures.

211. Kuroiwa, Daisuke, "Icing and Snow Accretion on Electric Wires," Cold Regions Research and Engineering Laboratory, Research Report 123, Hanover, N. H., January 1965.

Icing and snow accretion are similar in appearance, but there are great differences in the meteorological conditions durwhich the phenomena take place. Icing is a result of the repeated impingement and freezing of fog paticles carried one after another to an object by wind. Therefore, liquid-water droplets, supercooled below 0°C in the atmosphere, and strong winds are necessary. Snow accretion is a result of the

accumulation of wet snow neat the air temperature 0°C. The existence of snowflakes and weak wind is required for its occurrence.

212. Land, H. L., "Ice Problems in the St. Lawrence River," IAHR 8th Congress Montreal, 1959, Sem. I, p. 21-SI-1-2.

The ice problems discussed in this paper belong to the group of problems on flood control.

213. LaPlaca, S. and Post, B., "Thermal Expansion of Ice," Acta Crystallographica, Vol. 13, No. 6, 1960, p. 503-505.

214. Larsen, Peter, "Hydraulic Roughness of Ice Covers," Journal of the Hydraulics Division, ASCE, Vol. 99, No. HYI, Proc. Paper 9498, January 1973, p. 111-119.

Cold region rivers and canals covered with ice have been found to develop ripple-like reliefs on the ice underside causing head losses considerably in excess of those of smooth boundaries. Observations showed that ice thickness near the banks was several times that of the conveying part of the waterway. It is postulated that these features are caused by heat transferred from the bottom of the waterway. Note that observed ratios of wave height to wave length of the ripples do not exceed approximately 0.12. This is the free flow over sinusoidal waviness. Some measured values of ice roughness coefficient (Mannings n) are given. A graph presenting a dimensionless solution for composite roughness coefficient as a function of ice underside and channel bed coefficients is included.

215. Larsen, P. A., "Head Losses by an Ice Cover on Open Channels," Journal of Boston Society of Civil Engineers, Vol. 56, No. 1, January 1969.

The underside of ice on a channel has been found to have irregularities that are formed by the flowing water. The effect of these irregularities corresponds to a certain roughness expressible in terms of a certain roughness height. The mechanics of the formation are not known, and therefore it is not possible at the present time to predict the roughness of the ice cover on a channel of given hydraulic characteristics and given climatic conditions. The formula derived for composite roughness in this paper is based on the assumption of two paralleled boundaries which limits the applicability.

216. Laurie, A. H., "Battling with a Bubble Gun," Compressed Air Magazine, January 1961, p. 26-29.

Personnel of Marine Developments Ltd., Nassau, Bahamas, have made (ironically, in view of their headquarters location) a close study of ice formation and how to delay it. They have observed that to keep channels open in the winter, five things are needed. (1) Convection must be re-established after the body of water has cooled to 39°F. (2) The warm water must be raised intact from the bottom to the surface, that is, with

out being cooled or diluted by mixing with layers of colder water near the surface. (3) The bottom water must be discharged at the surface in quantity, and at a velocity sufficient to insure that it is properly mixed with the surface water. Otherwise it will naturally fall to the bottom again. (4) When lifted, the bottom water, with its stored heat, must be deployed over the maximum area of channel to be kept free of ice. (5) The apparatus for this system, must be durable, efficient, and commercially feasible.

217. Lavoie, N. Y., "Ice Effects on Structures in the Northumberland Strait Crossing," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NCR No. 9851.

A description is presented of the analysis carried out to determine the maximum load that the ice cover could be expected to exert on piers for the proposed Northumberland Strait Crossing. The results of the analysis are presented in graph form.

218. Lavrov., V. V., "Temperature Dependence of Ice Viscosity," 1950, 7p. AD-718 887, Translation from Zhurnal tekhnicheskoi fiziki, 17(9): 1027-1034, 1947. 6 refs. 25-4070 SIPRE Translation 5.

The role and significance of crystalline structure in the study of the plastic properties of ice has been demonstrated. An anomalous change in the rate of plastic deformation of specimens of sufficiently regular crystalline structure occurs when they are subjected to sharp change in temperature constituting a phenomenon of interest to the theory of plasticity. It has been demonstrated that the phenomenon of rest, well known in the literature on crystallography, holds for ice as well. A sufficiently well-gounded evaluation of the relation between the viscosity of ice, and temperature is offered for the first time, within a temperature range of -3 degrees and -23 degrees C.

219. Lavrov, V. V., "Influence of Ice Structures Upon Its Strength," January 1972, 12p. AD-737 823, Translation of Problemy arktiki i antarktiki 20:61-27, 1965, 3 refs. 26-3372, CRREL Draft Translation 306.

220. Lazier, Samuel S., and Metge, Michel. "Temperature Gradients in a Lake Ice Cover," IAHR Ice Symposium, Reykjavik, Iceland 1970.

In order to acquire a better knowledge of static ice forces, the authors developed a finite difference method for calculating temperature gradients in an ice cover. This method was checked against Taylor's (1945) analytical solution and

it proved to be precise and simple. Measurements of ice temperatures were carried out during the winter 1969 in Kingston harbor. These experiments showed that the gradients predicted with given ice surface temperatures were fairly close to those measured, and also that there is a fundamental difference between the changes in temperature gradients due to solar radiation and those due to changes in air temperature only.

221. Lee, Kiin-Jen, and Raichlen, Fredric, "Oscillations in Harbors With Connected Basins," Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol. 98, No. WW3, Proc. Paper 9094, August, 1972 pp. 311-332.

A theory is presented to analyze the response to periodic incident waves of an arbitrary-shape harbor containing several inter-connected basins. The domain of interest is divided into an open-sea region and several inner basins depending on the harbor geometry. The solution in each region is formulated in terms of the unknown normal velocity at the entrance, or at the common boundary between basins, or both; the velocity is then determined by matching theoretical results agree well with experiments both for an irregular shape harbor and a harbor composed of two connected circular basins. Various aspects of the response of harbors composed of connected circular basins as well as circular harbors with rectangular entrance channels and side channel resonators are discussed. To a first approximation it appears that the response curve of a harbor composed of coupled basins can be synthesized from the response curves of the individual basins.

222. Legget, R. F., "Conference on the Bearing Strength of Ice," M.E.I.C., Director, Division of Building Research, National Research Council, Ottawa, 16 and 17 April, 1958, Transactions of the E.I.C., Vol. 2, No. 3, Sept. 1958.

The National Research Council, in keeping with its research service to the people of Canada, included experimental work in snow and ice in its early program. It was, however, the demands of the last war that emphasized the need for more research on the properties of snow and ice. One particular investigation arose from the need to know something of the properties of snow in order to facilitate the development of better designs of skis for the winter operation of aircraft. Mr. George J. Klein, Of the N.R.C. Division of Mechanical Engineering, was responsible for this work and his contributions to the study of snow as a material have become well known.

223. Lehmann, R. W. Paul, "Thrusts, Breaks and Melting Phenomena of Ice Covers on Inland Water," Cold Regions Research and Engineering Laboratory, Draft Translation 308, Hanover, N. H., January 1972.

Translation of Stauungs-, Zerreissungs- und Schmelzungserscheinungen auf dem Eise von Binnengewassern. Petermanns Geographische Mitt., Vol. 38, p. 188, by Arctic Institute of North America. 26-3568.

224. Leonard, R. W., "Masonry Pier Moved by Ice and Replaced," Trans. Can. Soc. Civil Engrs., V. 12, 1898, p. 131-4.

The thrust of the ice was about 11 tons per square foot, considering the ice three feet thick and striking the pier obliquely on a width of five feet.

225. Likens, G. E. and Ragotzkie, R. A., "Vertical Water Motions in a Small Ice-Covered Lake," Journ. Geophys. Res., 70, 1965, No. 10, May 15, p. 2333-2344.

The use of radioactive tracers in previous studies has demonstrated that appreciable water movement can occur in ice-covered lakes. Mathematical evaluation of these results show that the vertical component of this motion can be calculated and is between one and three orders of magnitude less than the horizontal component.

226. Lindgren, Sune, "Thermal Ice Pressure,: IAHR Ice Symposium Reykjavik, Iceland, 1970.

Single-axis tests with 7x7x20cm ice prisms have been carried out. The relationship between pressure, deformation and time is used to determine the elasticity and viscosity of the ice. Double axis tests, at temperature increase and with restricted expansion on an ice sample 80 cm in diameter and 7 cm thick have been carried out. The relationship between the pressure and speed of deformation is used to determine the viscosity of the ice. The dependence of the moduli of deformation on temperature, pressure, period of load and size of crystals is studied and approximate formulas are given for calculation. An example is given to show methods of calculating ice pressure at a given air temperature from the moduli of deformation obtained.

227. Lindgren, S., "Effect of Temperature Increases on Ice Pressures," The Institute for Hydraulic Engineering, Royal Institute of Technology, Stockholm. 73 pages and figures, 1968.

228. Lliboutry, L, "Bottom Temperatures and Basal Low-Velocity Layer in an Ice Sheet," Journ. of Geoph., Res., 71, 1966, nr. 10, May, p. 2535-2545.

A theoretical treatment of the temperatures and flow velocities within a cold ice sheet is made, which takes into account the heat generated within the ice. Three cases may exist for given surface temperature and thickness: (1) ice sheet is cold throughout, bottom temperature arbitrary; (2) bottom at melting point, heat flux at this level arbitrary; (3) temperate bottom layer of arbitrary thickness.

229. Lliboutry, L., "The Crystalline Texture and Plastic Deformation of Ice," Journal of Hydraulic Research, IAHR, 2, 1964, No. 1, p. 41-49.

A brief description is given of the crystalline texture of ice, followed by the rheological properties of ice and a final word about the process of plastic deformation.

230. Lock, G. S. H., and others, "A Study of One-Dimensional Ice Formation with Particular Reference to Periodic Growth and Decay," International Journal of Heat and Mass Transfer, Vol. 12, No. 11, 1969, 1343-1352.

The paper considers one-dimensional ice formation near the surface of a semi-infinite domain. A series of experiments executed with water are described and the results compared with theoretical predictions for power law and sinusoidal variations in surface temperature. The theoretical study is divided into two parts - analytic and numerical. The former consists of approximate solutions developed from a perturbation expansion and the latter involves discretization of the space variables and the integration of the resulting set of first order non-linear equations.

231. Lofquist, "Studies of the Effects of Temperature Variations," ASCE Trans. No. 2656, 1954.

The problem relating to the magnitude of the horizontal ice pressure produced by a solid sheet of ice as a result of rapidly rising temperatures has not found a satisfactory solution. Investigations have yielded unreliable and somewhat contradictory results. This paper describes an investigation that was undertaken by the Swedish State Power Board. In the experiments, made with an arrangement installed in a freezing chamber, a pressure of 20 tons per m (13, 400 lb per lin ft) was obtained with ice 60 cm (23.62 in) thick. This result is somewhat unreliable, however, owing to the presence of certain additional effects during the experiment. From calculations made on the buckling of an ice sheet, a probable maximum ice pressure of from 30 tons per m to 40 tons per m (20,000 lb per lin ft to 27,000 lb per lin ft) is found. It would seem that an ice pressure of similar magnitude may also be set up under certain unfavorable local conditions in consequence of variations in the water level, with an ice sheet having a limited expanse of from 20 m to 40 m (65 ft to 130 ft).

232. Lofquist, B., "Lyftkraft och barformaga hos ett istacke," (Teknisk Tidskrift, Vol. 74, June 24, 1944, 761-766; discussion, p. 777-788. English translation made by Arctic Institute of North America, 46 East 70th St., N.Y. Also available as Translation No. TT-164 of the Canadian National Research Council. Ottawa, Canada. The English translation is not in the Engineering Societies Library.

Lifting force and bearing capacity of an ice-sheet. Observations in Northern Sweden show the destructive effects of an ice sheet on construction. The lifting force and the bending strength of ice on a long straight wall are derived assuming a linear temperature distribution, the coefficient of plasticity of ice, and a slowly rising water level. Ice deformations observed between level surveys agree well with those calculated for beams on elastic supports. An expression for the maximum lifting force is obtained as a function of the bending strength of ice. It is found to be largely independent of the modulus of elasticity. Calculations of the bearing capacity of ice are made for loads applied on a straight line and for loads spread over a circular area with a diameter equal to the thickness of ice.

233. London, A. L., and Seban, R. A., "Rate of Ice Formation," Transactions of the American Society of Mechanical Engineers, October, 1943, 771-776.

A general approximate method for the solution of the freezing problem is presented with applications to ice formation at spherical, cylindrical, and plane boundaries. The degree of approximation is investigated, and the results of the analysis are indicated to be of satisfactory accuracy for the solution of engineering problems. Utilization of the analytical results in the prediction of freezing times for actual systems produces good agreement with quoted performance.

234. Lonsdale, K., "The Structure of Ice," Proceedings of the Royal Society (Londan), Series A., Vol. 247, 1958, 424-434.

A consistent set of unit cell parameters at various temperatures is not yet available for ordinary ice, but the mean of the most precise measurements leads to a density of 0.9164 g/cm^3 at 0°C (atmospheric pressure) with a cubical expansion coefficient of 11×10^{-5}, increasing to 0.9414 and 21×10^{-5} at liquid air temperatures. Corresponding figures for heavy ice are 1.0172 g/cm^3 and 12×10^{-5} at 0°C, 1.0449 and 18×10^{-5} at -180°C. The hydrogen-bond lengths are not significantly different for ordinary and heavy ice, but in both cases the mirror-symmetric bond (along the principal axis) is about 0.01Å shorter than the centro-symmetric bond at 0°C. At low temperatures the bond lengths tend to equalize at a value some 1% lower than at 0°C. The hexagonal (tridymite-type) and cubic (cristobalite-type) forms of ice have approximately the same density and hydrogen-bond lengths at - 130°C, and both appear to have a statistical randomness of the water-molecule orientation, consistent with there being one hydrogen only (nearly or exactly) along each bond. The thermal vibrations of the hydrogen atoms in hexagonal ice are anisotropic, those of the oxygen atoms nearly spherical. The ranges of stability of hexagonal, cubic and amorphous ice are not exactly known, but cubic ice is only formed at low rates of deposition, low pressures and at temperatures of about -80 to -140°C.

235. Ludlow, William, "Observations on the Crushing Strength of Ice," Proc. Engrs. Club of Philadelphia, V. 4, 1884, p. 93-9.

To determine the resistance necessary to be provided against ice in constructing piers for an ice harbor at the head of Delaware Bay.

236. Mantis, H. T., "Review of the Properties of Snow and Ice," 156p. AD-696 397 167 refs. Minnesota University. Institute of Technology. Engineering Experiment Station 24-3003. Technical Report 4., July 1951.

Includes chapters on mechanical properties, strength of snow and ice, electrical properties, geometric properties, thermal properties, radiation properties, heat economy of the snow pack, phase relations, supercooling and ice formation in open water. An extensive bibliography with abstracts appears p. 108-156.

237. Marine Engineer 50: 142-5, "Ice Breaker Design Reaches New Levels in Coast Guard Ships. April 1945.

238. Matich, M. A. J., A. Rutka, and P. F. Andersen, "Foundation Aspects of the Rainy Lake Causeway," Engineering Journal, Vol. 46, Nov. 1963, p. 40.

Section on ice conditions. Contains a discussion of ice conditions, including compressive stresses of ice sheet, and observations on the action of ice on pile bents, although vertical movement is not mentioned.

239. Matlock, Hudson, Dawkins, William P., and Panak, John J., "Analytical Model for Ice-Structure Interaction," Journal of the Engineering Mechanics Division. ASCE, Vol. 97, No. EM4, Proc. Paper 8282, August, 1971, pp. 1083-1092.

In an effort to predict ice-structure interaction, a simple mechanism is proposed. The structure is represented by a spring-mass system and the ice is replaced by a succession of elastic-brittle elements which impinge on the structure at a rate determined by the relative motion between the ice and the structure. A computer program is used to solve for the dynamic response of the structure. A number of test cases and variations have been solved, and the results compared with limited laboratory and field measurements that are available. Interesting agreement has been obtained with observed behavior at various ice velocities. It is believed that the present approach can be used to determine reasonably well the response of a structure to an impinging ice sheet.

240. Mellor, Malcolm, and Smith, James H., "Creep of Snow and Ice," Cold Regions Research and Engineering Laboratory, Reprint from Physics of Snow and Ice, Proceedings of the International

Conference on Low Temperature Science, 1966, Vol. 1, Pt. 2, 1967, Hanover, N. H., 1967.

Constant load creep tests in uniaxial unconfined compression were performed on samples of sintered snow and bubbly polycrystalline ice. Nominal axial stresses were in the range 0.1 to 1.0 kg-wt/cm^2 for snow, and 0.5 to 20 kg-wt/cm^2 for ice. The range of temperatures investigated was from -0.5 to -34.5°C. Assuming creep to follow the Arrhenius relation, values of apparent activation energy for secondary creep under a nominal axial stress of 0.5 kg-wt/cm^2 varied from 10.7 kcal/mole for ice of density 0.83 g/cm^3 to 17.8 kcal/mole for snow of density 0.44 g/cm^3. The dependence of strain rate $\dot{\varepsilon}$ on stress σ for polycrystalline ice subjected to stresses in the range 0.5 to 20 kg-wt/cm^2 at temperatures of -4 and -10°C could best be described by a relation of the form

$$\dot{\varepsilon} = C_1\sigma + C_2\sigma^{3.5} ,$$

where C_1 and C_2 are constants for a given ice type. The behavior of sintered snow is probably similar, although the tests did not go to sufficiently low stresses to confirm this supposition. It is suggested that the creep of polycrystalline ice depends on at least two distinct mechanisms in the stress range studied. Possibilities include dislocation damping for the process dominant at high stress, and drift of dislocations pinned by stress induced order for the low stress mechanism. If each mechanism has its own characteristic activation energy, the apparent activation energy measured in creep experiments may well vary with stress level. In snow subjected to a given nominal stress, such an effect should be reflected in variation of apparent activation energy with bulk density, since true stress in the ice matrix will increase as density decreases when the nominal applied stress is fixed. The effect of bulk density on strain rate and the possibility of predicting creep rates for snow from data on creep of polycrystalline ice are discussed.

241. Mellor, M., Testa, R., "Creep of Ice Under Low Stress," Journal of Glaciology, Feb. 1969 8(52), p. 147-152, Summaries in Miscellaneous Publications 324.

Uniaxial compressive creep tests on fine-grained polycrystalline ice indicate that secondary strain-rate is proportional to sigma exp (1.8), where sigma is applied stress, for the range 0.1 smaller than sigma smaller than 0.5 kgf/sq cm (10 smaller than sigma smaller than 50 kN/sq m). On the basis of the present tests, earlier results suggesting linear viscous behavior at low stress are believed to be invalid.

242. Mellor, M., Testa, R., "Effect of Temperature on the Creep of Ice," Journal of Glaciology, Feb. 1969 8(52) p. 131-145, Summaries in French and German. 17 refs. 23-5464. Miscellaneous Publication 323.

Creep tests on homogeneous, isotopic polycrystalline ice gave an apparent activation energy for creep of 16.4 kcal/mol (68.8 kJ/mol) over the temperature range -10 to -60°C. Above -10C the Arrhenius relation for temperature dependence is invalid, and creep rate becomes progressively more temperature dependent as the melting point is approached. Between -20 and -50°C the apparent activation energy for creep of a single crystal of ice was found to be 16.5 kcal/mol. A complete creep curve for a single crystal loaded in uniaxial compression parallel to the basal plane was qualitatively similar to the classical creep curve; creep rate at all stages was very much faster than for polycrystalline ice under the same conditions. Creep tests on polycrystalline ice at 0°C gave a stress/strain-rate relation for that temperature, but its precise meaning is unclear, since recrystallization complicated the results.

243. Mellor, M. et al., "Ice Cap Strains and Some Effects on Engineering Structures," December 1967, 10p. AD-665 373 14 refs. Reed, S. C. 24-3149. CRREL Technical Report 202.

The components of strain for the upper layers of ice sheets are given in terms of ice flow velocity and show accumulation rate. Methods of estimating the components of strain rate which are necessary for design of engineering structures are outlined, and representative measured values are given. The relation between observed structural deformation and ice cap straining is discussed.

244. Mellor, M., Hawkes, I., "Measurement of Tensile Strength by Diametral Compression of Discs and Annuli," Engineering Geology, Oct. 1971 5(3) p. 173-225, 33 refs. 26-2867, Miscellaneous Publication 328.

The validity of diametral compression tests for indirect measurement of tensile strength is investigated theoretically and experimentally. Linear elastic theory for diametral compression of discs and annuli by oppossed strip loads is reviewed, and the significance of failure criteria in fracture initiation and test interpretation is considered. Results of careful tests are given for three types of rock, two plastics, glass, and ice, and the experimental results are compared with theoretical expectations. While there are very serious objections to the ring test, the Brazil test is capable of giving a good measure of uniaxial tensile strength for Griffith-type materials. Practical problems involved in diametral compression testing are considered in some detail. Special attention is given to contact stresses under the applied loads, and a design is given for a loading jig that reduces contact stresses.

245. Mellor, M.,"Snow Removal and Ice Control," April 1965, 37p. AD-615 795, 32 refs. 24-3416, CRREL Monographs III-A3b.

Climatology of snow cover in the northern hemisphere is briefly presented along with a description of significant snow properties. More extensively treated are the various equipments and methods used to control ice and snow. Snow plows, heating systems, and chemical means of snow removal are compared and details of costs and organization of removal techniques are presented.

246. Merriman, M., "Ice Pressure," 1920, Am. Civil Engr. Handbook, 4th ed. 1920.

P. 435. Example given of a sheet of ice 150 feet in width tipping a masonry bridge pier weighing 1000 tons two inches out of plumb. P. 709. Pressures due to ice have been found to be 30,000 lbs. per sq. ft. for field of meling ice 1 ft. thick, striking a pier and crushing its way past.

247. Meyerhof, G. G., "Bearing Capacity of Floating Ice Sheets," ASCE Transactions, Paper No. 3327, 1962.

The collapse of floating ice sheets under load is estimated on the basis of a rigid-plastic plate on an elastic foundation for various loading and boundary conditions. The results are compared with field observations in the operation of ice roads and floating airfields and some small-scale loading tests.

248. Michel, B. and Ramseier, R. O., "Classification of River and Lake Ice," Canadian Geotechnical Journal, 1971, 8, 36.

There is no classification of river and lake ice that simultaneously takes into account the history of ice formation, the structure of the ice cover, and the texture of the various ice types. Such fundamental information is a prerequisite to the determination and discussion of their physical and mechanical properties. The first part of this classification is a brief description of the formation and physical properties of the three important ice layers making up the ice cover. The second aspect of the classification deals with the texture of various ice types. It is possible to determine certain meteorological conditions which have occurred during formation of primary ice from on-site observations and the study of ice profiles. Hydrodynamic information can be obtained from the study of secondary or superimposed ice. Presently, major events causing layers of frazil slush, congealed frazil slush, and drained snow ice can easily be recognized and interpreted. The evaluation and eventual prediction of the mechanical properties of the various ice types according to such a classification will be helpful in solving engineering and navigation problems.

249. Michel, B., "Thrust Exerted by an Unconsolidated Ice Cover on a Boom," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851.

A theoretical discussion based on the theory by Caquot for estimating pressures in grain elevators, is presented on the forces acting on an unconsolidated ice cover held in position by a boom. Equations are developed for calculating the hydrodynamic force on the front edge of the cover and the tangential force due to the weight of the cover, the flow of the water and the wind. The theory shows that the force on the boom will not increase indefinitely with the upstream length of the cover, and that there is a critical discharge which, if exceeded, will cause the ice field to become unstable, and to break up and pass under the boom. The results of model studies are shown to be in agreement with the theory.

250. Michel, B., "New Technique of Total Simulation of Floating Ice," L'Ingenieur, No. 248, 1969, p. 16-20.

Les structures importantes de Génie Civil telles que les quais, les plate-formes de forage, les barrages et les ponts doivent être conçues dans les pays nordiques, pour résister aux forces exercées par la glace flottante. Ces forces sont importantes et jusqu'à maintenant n'ont pu être évaluées de façon certaine. Les caractéristiques de la glace flottante jouent aussi un rôle capital pour l'utilisation des voies navigables intérieures, comme c'est le cas pour le fleuve St-Laurent. L'épopée récente du Manhattan a aussi montré que l'exploitation des richesses pétrolifères du Grand Nord etait liée à la possibilité de naviguer à l'année longue au travers des champs de glace de l'Arctique. Pourtant la conception des brise-glaces a bien peu évolué depuis son empirisme initial et le Manhattan avait une proue guére différente de celle du Murtaja, construit en Finlande en 1890.

251. Michel, Barnard, "Ice Modeling in Hydraulic Engineering," IAHR Ice Sumposium, Reykjavik, Iceland, 1970.

This is a short summary of laws of similitude applied to problems of floating ice acting on structure where hydromechanical similitude has to be taken into account. We also discuss briefly the latest developments concerning the artificial material that can simulate ice on models.

252. Michel, Barnard, "Ice Pressure on Engineering Structures," Cold Regions Research and Engineering Laboratory, Monograph III-B1b, Hanover, N. H., June 1970.

This monograph summarizes existing knowledge on forces exerted by an expanding ice sheet, impact forces of ice on structures, and vertical forces exerted by ice on hydraulic structures. Sections are also devoted icebreakers and ice models.

53. Michel, B., "Ice Covers in Rivers," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

In this paper the more up-to-date knowledge on the formation of ice covers in rivers is reviewed. This knowledge has been accumulated mainly from observations and measurements in the field. The first part of the presentation will consider the methods of measuring the various parameters affecting the ice conditions in rivers and gives some of the results of these measurements. In the second part of the paper, the different ways in which an ice cover is formed in a river at the beginning of the winter will be described and analyzed. Although there have been many analytical developments on the mechanics of the phenomenon in the last few years, we will limit the theoretical presentation to the ideas that best represent the behaviour of nature.

254. Miloh, Touvia, "The Temperature Profile in Arctic Floes," Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa Association. Mem. ASME, an ASME Publication, 73-WA/HT-12, Manuscript received at ASME Headquarters August 8, 1973.

The problem of the unsteady temperature distribution in a floating ice field is considered in some detail. The nonlinear heat diffusion equation is solved by applying a perturbation method to give a closed form solution for the mean temperature throughout the ice sheet. This solution takes into account the dependency of the ice thermal conductivity and thermal diffusivity on both temperature and salinity, the effect of the short-wave radiation passing through the upper interface, the detailed temporal temperature variation at the ice-snow interface and the effect of the ice sheet thickness. The first-order solution considers the nonlinear steady state problem whereas the second-order considers a linearized non-steady problem. Based on some experimental data for the ice thermal conductivity as a function of salinity and temperature, a solution for the steady-state mean temperature as a function of salinity, the short-wave radiation at the snow-ice interface,the extinction coefficient and the average temperature at the ice-snow interface is also presented.

255. Minsk, L. D., "Survey of Snow and Ice Removal Techniques," Cold Regions Research and Engineering Laboratory, Technical Report 128, Hanover, N. H., December, 1964.

This report summarizes snow removal techniques, status of knowledge in this field as of 1960, and future considerations. During the winter of 1958-59, a comprehensive survey of snow and ice removal practices at eight Air Force bases, thirteen state highway departments, and one F.C.A.F. base in Canada was made. During Jan-March 1960, a similar survey was made in six European countries. Mechanical, chemical, and thermal methods of snow removal are discussed and extensive data are given on various types of snow and ice removal equipment.

256. Moor, Julius H. and Watson, Carl H., "Field Tests of Ice Jam Prevention Techniques," Journal of the Hydraulics Division, ASCE, Vol. 97, No. HY6, Proc. Paper 8179, June 1971, pp. 777-789.

Through a combined effort, the U. S. Army Corps of Engineers, U. S. Air Force, and the State of Alaska have for several years conducted a field research program in ice jam prevention with a goal of finding an economical and reliable jam prevention technique. The development of an operational technique would enable local interests to establish an annual spring jam prevention program in their area. Research efforts have been concentrated in Alaskan river reaches having a past history of ice jams resulting in high property damage in upstream communities. Efforts were directed toward obtaining either an ice free channel or an ice flow shear line by using a mechanical approach of ice weakening through the application of explosives or a physical approach of increasing the ice melt rate in a certain area by lowering the surface albedo. Albedo lowering was accomplished through the use of (1) large scale aerial ice dusting operations, (2) pumping of river bottom material onto the ice surface, and (3) river pressure flow over the ice surface.

257. Monfore, G. E., "Experimental Investigations," The Bureau of Reclamation.

The pressures produced by the thermal expansion of thick ice sheets are considered by the Bureau of Reclamation, U.S. Department of the Interior, in the designs of some dams and accessory structures. The Bureau conducted experimental investigations of ice pressure from 1946 to 1951. These investigation included field studies at several reservoirs located in the mountains of Colorado and laboratory studies performed in the Engineering Laboratories of the Bureau in Denver, Colo. The purpose of this paper is to summarize the more important findings of these field and laboratory investigations.

258. Morrison, C. B., and Brodie, O. L., "Masonry Dam Design," 1916, J. Wiley, N. Y. 267 p.

PP. 16-19 discuss the question of ice thrust in reservoirs and dams using specific examples. PP. 115-19 works out, according the formulae, the proper design for dams, allowing for ice pressure.

259. Moseley, H., "On the Mechanical Properties of Ice," Philosophical Magazine, Series 4, Vol. 39, (1970), 1-8.

Presents experimental values of specific heat, ultimate tensile strength, ultimate compressive strength and shear strength of ice.

260. Mukai, M. "On the Seiches of a Frozen Lake, and the Motion of Ice-Plate," Nippon Sugaku-Buturigakkwai Kizi, V. 14, March 1932, p. 108-111. In English.

The seiches of Lake Suwa, Japan, were determined with a limnimeter from the movements of a water surface kept clear of ice. The vertical motion of the ice sheet covering the lake was also recorded. The seiches of the frozen lake are quite similar to those of the unfrozen lake and synchronize accurately with the movements of the ice sheet.

261. Mulloy, J. F. and Allswede, "Ice Suppression Mats," Winter Navigation Season Extension, Dow Chem. Co. Midland, Mich.

The results of installing a 36'x40'x1-1/2" Ethafoam plastic foam insulating blanket on ice at the Oglebay-Norton Dock, Bay City, Michigan; demonstrate the technical feasibility of using insulating materials to control the formation of ice in dockside areas.

262. Murphy, J., "Ice Formation and Its Prevention," Canad. Engr. V. 40, 1921, p. 291-2, 294.

A review of the progress of investigations into methods for the prevention of the formation of ice in hydro-electric practice. States that it is possible to prevent ice from adhering to valves, gates, racks, penstocks, turbine runners and casings by the proper employment of heat.

263. Murphy, John, "The Ice Question" as it affects Canadian Water Powers, with special reference to frazil and anchor ice. Royal Society of Canada, Proc. and Trans., Ser. 3, Vol. 3, Trans. Sec. 3, p. 143-177, Ottawa 1910.

264. McCaig, I. W. and Haydock, J. L., "Prevention of Ice Formation in Low-Level Reservoir Outlets," IAHR 8th Congress Montreal 1959, Sem. 1, p. 14-SI-1-7.

Paper describes two different ice-prevention systems for low level reservoir outlets, each of which was selected and designed to suit the particular application.

265. McClelland, Bramlette, Focht, John A., Jr., and Emrich, William J., "Problems in Design and Installation of Offshore Piles," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 95, No. SM6, Proc. Paper 6913, November 1969, pp. 1491-1514.

Offshore structures in water up to 385 ft deep require long pipe piles with ultimate compressive and tension capacities up to 3,500 and 2,000 tons, respectively. Static analysis is the most reliable and widely used method for predetermining pile penetrations and predicting pile capacity. Significant design uncertainties result, however, from dependence on

empirical data derived from short, lightly loaded piles driven and tested on land. Pile loads have increased faster than the driving capability of available pile hammers, which include some with rated energy of 180,000 ft-lb. Larger hammers are needed to achieve a higher percentage of successful installations by driving alone. Wave-equation analysis may aid selection of optimum pile wall thickness to improve drivability. Pile installation aids, including jetting, drilling, and grouting, are useful but increase design uncertainty. Four case histories illustrate the problem of both design and installation of offshore piles.

266. McKay, Alexander R., "Man-Made Ice Structures for Arctic Marine Use," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The thermal aspects of mad-made ice structures for artic offshore use are considered. A two-dimensional ice model grounded in various depths of sea water is presented. Isotherm and time-temperature plots indicate that such a structure is thermally feasible for the geometry and climatic conditions considered. Possible areas of weakness are commented upon and recommendations for further areas of study are made.

267. Nakaya, U. and Matsumoto, A., "Evidence of the Existence of a Liquidlike Film on Ice Surfaces," U.S. Army Snow Ice and Permafrost Research Establishment, Corps of Engineers, Research Report 4., 1953.

Experiments were made on the adhesive force between 2 ice spheres, 1.5-4.0 mm. in diam., suspended on thin cotton filaments. The normal adhesive force, which tends to decrease with decreasing temperature, was measured by the inclination of a filament as the spheres separated. The ice spheres occasionally rotated before separation, and 2 or 3 successive rotations were noted with a 0.1 percent solution of NaCl. The phenomena may be explained by assuming the existence of a liquid film on the ice surface.

268. Neill, C. R., "Ice Pressure on Bridge Piers in Alberta, Canada," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

Devices designed to measure total ice force during river break-up have been built into two bridge piers. Measurements over a four-year period have yielded unit pressures from moving ice-sheets in the range of 100 to 160 lb/in^2 (7 to 11.3 kg/cm^2), for ordinary to moderately severe conditions. Analyses have been carried out of the probably ultimate strengths of several old piers that have successfully withstood ice for many years. Estimated unit pressures for structural failure are in the range of 150 to 250 lb/in^2 (10.5 to 17.5 kg/cm^2). It is concluded that the ice pressure of 400 lb/in^2 (28 kg/cm^2) specified in Canadian codes may be unnecessarily conservative for bridges in inland rivers where the most severe conditions are associated with spring break-up. Recommendations are offered for the design of force-measuring devices.

269. Neumann, G. and Pierson, W. J., Ice, Principles of Physical Oceanography, Englewood Cliffs," Prentice-Hall Inc., 1966, Chapter 4, pp. 70-87.

This chapter contains: forms of ice, icebergs, the geographical distribution of ice in the sea, some physical properties of sea ice, and an approximate computation of the growth of thickness of an ice sheet.

270. Nevel, D. E., "Time-Dependent Deflection of a Floating Ice Sheet," U.S. Army Cold REgions Research and Engineering Laboratory (USA CRREL) Research Report 196, 1966, AD 638717.

A solution for a viscoelastic plate on an elastic foundation is presented for an infinite bulk modulus and a shear modulus which obeys Maxwell's model. Observed deflections of a floating ice sheet agree with this solution. A solution for a viscous shear modulus is also presented.

271. Nevel, D. E., and Assur, A., "Crowds on Ice," Cold Regions Research and Engineering Laboratory, (Technical Report 204), Hanover, N. H., October, 1968.

This report considers a floating ice sheet supporting a crowd of people who are free to assume any distribution. The problem is analyzed when the people gather into a long strip, two strips, or a circular area, all of which may vary in size. The worst possible size is determined for the safe bearing capacity in each case. Upon comparison of the results, a single equation is suggested for practical use.

272. Nevel, D. E., "Lifting Forces Exerted by Ice on Structures," Cold Regions Research and Engineering Laboratory (Reprint from Proceedings of conference on Ice Pressures Against Structures, Laval University, Quebec, Canada, November 1966) Hanover, N. H.

If a floating ice sheet is connected to a structure when the water level is increased, the ice sheet will be bent and a lifting force will be exerted on the structure. In this paper, cylindrical bending of the ice sheet is considered such as occurs near a long structure and symmetrical bending such as occurs near an isolated pile. The ice sheet is considered as a homogeneous isotropic plate resting on an elastic foundation of the Winkler type. The deflections and thickness of the plate will be assumed to be small. The ice is considered as a linear viscoelastic material that has an infinite bulk modulus and a shear model which obeys a Maxwell model. A solution is given of the problem when the rise in water level is composed of a linear combination of ramp functions of time which can be made to approximate any function. In order to easily determine the long time effects, the ice is considered viscous under shear. For this case solutions are given when the change of water level is a ramp function, a step function, and a sine function. In addition to the above subject, a brief note is

presented on thermal stresses in a floating ice sheet when the ice is considered viscoelastic.

273. Nevel, D. E., "Lifting Forces Exerted by Ice on Structures," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851.

If a floating ice sheet is connected to a structure when the water level is increased, the ice sheet will be bent and a lifting force will be exerted on the structure. In this paper, cylindrical bending of the ice sheet is considered such as occurs near a long structure and symmetrical bending such as occurs near an isolated pile. The ice sheet is considered as a homogeneous isotropic plate resting on an elastic foundation of the Winkler type. The deflections and thickness of the plate will be assumed to be small. The ice is considered as a linear viscoelastic material that has an infinite bulk modulus and a shear model which obeys a Maxwell model. A solution is given of the problem when the rise in water level is composed of a linear combination of ramp functions of time which can be made to approximate any function. In order to easily determine the long time effects, the ice is considered viscous under shear. For this case solutions are given when the change of water level is a ramp function, a step function, and a sine function.

274. Nevel, D. E., "Narrow Free Infinite Wedge on an Elastic Foundation," July 1961, 11p. plus 3p. appendix plus 12p. graphs plus 24p. table. AD-277 538 3 refs. 24-3236 USA-CRREL Research Report 79.

The theory of a plate on an elastic foundation will closely predict the radial cracks observed in loading tests on floating ice sheets. However, the plate theory does not predict accurately the circumferential crack which forms ultimately with increased loading. The wedge theory is developed in an attempt to better predict the location and magnitude of the stresses causing the circumferential crack. The results obtained can be applied to help predict the ultimate bearing capacity of an ice sheet, provided the modulus of elasticity and flexural strength of the ice are known.

275. Nuttall, J., "Model Study of Ice Pressures," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Tech. Mem. No. 22, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851.

It is often assumed in calculations of maximum ice pressures against structures that the crushing strength of ice is 400 psi. A model study was undertaken to determine if ice could sustain this stress when loaded in a manner similar to that which would be associated with piers. Columnar-grained ice blocks

about 5 in. thick and 24 in. diameter, with the long direction of the grain perpendicular to the face of the block, were used in the study. The load simulating the pier situation was applied to the edge of the block perpendicular to the long direction of the columns. It was observed that, with this geometry of loading, ice could sustain a stress of 400 psi for period exceeding two days without failing.

276. Nuttall, J. B., "Observations on Break-up of River Ice in North Central Alberta," Canadian Geotechnical Journal, Vol. 7, No. 4, November 1970.

The break-up process on the North Saskatchewan and Pembina Rivers in north central Alberta during 1969 is discussed here. It is shown that the maximum size of moving can approach the river's width and have a length of four or five times this depending on the channel geometry. A case of radial cracking of an ice sheet at a bridge pier when the sheet was subject to the drag force of high velocity river flow is reported. The rate of progress of a break-up wave on the Pembina River was found to have been approximately that of a free surface water wave of the same height.

277. Nybrant, G., "Investigations on the Water Temperature at Air Bubbler Systems in Lakes," IAHR 8th Congress Montreal 1959, Sem. I, p. 28-SI-1-4.

At the pre-investigations of the so-called Malarpassage-project, the Meteorological and hydrological institute of Sweden was charged with the task of making a closer investigation on the distribution of water temperature above and on the sides of a bubble hose lying on the bottom of a lake. From these investigations, the institute was then to conclude about the kind of circulation of water. A description of the measuring equipment is also given.

278. Nybrant, G., "Water-Temperature in Winter in a Pond and its Dependence Upon the Flow," IAHR 8th Congress Montreal 1959, Sem. I, p. 24-SI-1-5.

Limnological considerations on the water- and heat balance of a pond with temperatures below the freezing point of water. A formula for the calculation is given.

279. O'Hare, Norbert W., and Ayers, John C., "Shore Ice Formation and Destruction on Eastern Lake Michigan." Great Lakes Research Division, University of Michigan Ann Arbor, Mich.

During the winter of 1969-70 and 1970-71 field observations were conducted to determine the sequence of events contributing to the annual mode of formation and destruction of the ice barrier on the shore of eastern Lake Michigan. Results from the two winter observations, carried out along the eastern Lake Michigan beach and at the Donald C. Cook Nuclear Power Plant south of Benton Harbor, identify a sequential pattern of events in the development of shore ice structure.

280. Ohashi, Koji, "Flow Measurements of Ice-Covered Rivers on Hokkaido," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The authors describe the methods and results of the ice-covered river flow measurements carried out in the streams with comparatively small catchment area on Hokkaido, Japan. They study the interrelationship among velocity distribution, irregularity seen in the cross-sectional form and roughness coefficient of stream flow under the ice cover, and assume that roughness of the underside of the ice cover depends upon the hydraulic and climatic conditions as well as the form effect of the river section. The necessity of conducting further field measurements is emphasized to establish the correlation prescribing roughness factor under the ice cover.

281. Otsubo, K., "Ice Problems of Gates at Hydro-Electric Plants in Northern Districts of Japan." IAHR 8th Congress Montreal 1959, Sem. I, p. 2-SI-1-2.

Several methods of preventing gates from ice troubles have been attempted at power stations in Hokkaido. Descriptions of the techniques used are presented with the respective local situations: hot-air blower, pipe heater, infra-red lamp, vinyl-covered electric steel wire, portable crude burner.

282. Palmer, W. T., "On the Analysis of Floating Ice Plates," 94p. Ph.D. thesis, N.Y. University School of Engineering and Science. 47 refs. 26-5133, July 1971, Unpublished Internal Report 133.

The deformation of an ice plate floating on a liquid is discussed. Since there is a vertical temperature gradient in a floating ice plate, there is also a vertical variation in its material properties. The differential equation and boundary conditions for a floating ice plate with a constant Poisson's ratio but a vertically varying Young's modulus are obtained using the principle of virtual displacements. The case of a floating ice beam with a constant Poisson's ratio and a vertically varying Young's modulus is also considered. The results indicate that if the flexural rigidity D of classical plate theory is replaced by a new constant D sub 1, then the differential equation and boundary conditions for a plate with a vertical variation in Young's modulus are identical in form to those of a plate with a constant Young's modulus. A similar result is obtained for a floating beam with a vertical variation in Young's modulus.

283. Palosuo, E., "Ice in the Baltic," Oceanography and Mar. Biol. Annual Rev., 4, 1966, p. 79-90.

Loss of heat through the surface in autumn, the onset of freezing and development of the ice cover. Retreat and melting of ice. The length of winter, the ice forms, and thickness and structure of the ice.

284. Panfilov, D. F., "Experimental Investigation of the Carrying Capacity of an Ice Cover," Jan. 1972, 20p. AD-737 811, Translation of Vsesoiuznyi nauchnoissledovastel'skii institut gidrotechniki. Izvestiia Vol. 64, 1960, p. 101-115. 9 refs. 26-3364. CRREL Draft Translation 99.

285. Panfilov, D. F., "On the Determination of the Carrying Capacity of an Ice Cover for Loads of Long Duration," Jan. 1972, 14p. AD-737 812, Translation of Russia. Ministerstvo vysshego i srednego spetsial'nogo obrazovaniia. Izvestiia vysshikj uchebnyk zavedenii, No. 6, 1961, p. 47-57. 12 refs. 26-3363. CRREL Draft Translation 67.

286. Pariset, E. and Gagnon, A., "Formation of Ice Covers and Ice Jams in Rivers," Journal of the Hydraulic Div., ASCE, Vol. Hy 6, 1966, p. 1-24.

Ice covers on rivers are stressed in the downstream direction mainly by the friction of the under flow and the effect of the slope of the water line. Analysis show that in wide rivers, these stresses are the main factor governing the equilibrium thickness of the cover. This analysis allows forecasting of ice covers evolution, including the formation and size of ice jams, losses of head and ice thrust on retaining booms. Laws of similitude derived from the basic equations allow the operation of scale models when the complexity of the topography renders numerical calculation impossible. Description of several practical applications shows good agreement between model or theoretical prediction and prototype measurements.

287. Pariset, E. and Hausser, R., "Frazil Ice and Flow Temperature under Ice Covers," Engineering Journal, Montreal, 44, 1961, No. 1, pp. 46-49.

The role of an ice cover in preventing frazil ice to reach a turbine. a. The deposit of frazil ice (suspended ice-particles) on an ice cover. Results of theoretical considerations are in good accordance with prototype measurements. b. Computation of the increment of water temperature when the water is passing an ice cover. The heat (mainly supplied by head losses) reduces the amount of frazil ice considerably.

288. Pariset, Ernest and Hausser, Rene, "Formation and Evolution of Ice Covers on Rivers," Transactions of the E.I.C., Vol. 5, No. 1, 1961.

By logical application of basic hydraulic and mechanic laws, the LaSalle Hydraulic Laboratory staff was able to derive theories for predicting conditions of formation and evolution of ice covers. The main results are: (1) Ice cover thickness during its progression can be determined by the fact that its upstream edge must not be submerged. This case corresponds to "narrow rivers." (2) Ice cover thickness in "wide rivers"

is governed by ice thrust from the progressing cover. (3) Rate of progression of the cover is governed by its thickness, and the difference between incoming ice discharge and ice discharge carried downstream under the ice cover. (4) Ice cover progression can be stopped when incoming ice discharge is not large enough to overcome the discharge of ice carried under the cover or when velocity of flow is too high, so the non-submersion conditions cannot be (narrow rivers), or the cover thickness cannot support the ice thrust (wide rivers). In both cases ice jams are formed. Theories were derived to cover these various cases and values of coefficient derived by checking calculation with field measurements.

289. Pariset, E. and Michel, B., "Ice Spillways for Run-of-River Power Plants," IAHR 8th Congress Montreal 1959, Sem. I, pp. 7-SI-1-3.

On some sites for hydro-electric developments in northern countries, it is not possible to obtain adequate pondage or consider economic excavations that would permit the formation of a continuous ice cover upstream of the dam. For these sites one solution would be to discharge the ice floes over the dam and let frazil ice through the turbines. Among problems brought up by this scheme is the design of ice spillways in front of a powerhouse.

290. Pariset, E. and Hausser, R., "Evolution of Ice Covers During Their Formation," IAHR 8th Congress Montreal 1959, Sem. I, pp. 4-SI-1-4.

Results given in the paper concerning the formation of ice covers in rivers (card 9) show that several cases may be expected (and in this paper discussed): 1. normal ice covers. 2. hanging dam. 3. ice jam. 4. formation of dunes. A table with average velocity in front of the cover, has been added.

291. Pariset, E. and Hausser, R., "Formation of Ice Covers on Rivers," IAHR 8th Congress Montreal 1959, Sem. I, pp. 3-SI-1-5

It can be concluded that the progression of an ice cover is stopped either if the critical velocity is attained or if the amount of ice transported under the cover is bigger than the discharge of ice feeding its upstream edge. So, we introduce again the well-known fact that the velocity against which an ice cover can progress is up to a large extent governed by meteorological conditions. Other studies are still in progress to specify the theory and allow more precise forecasting of ice cover progression.

292. Parrott, W. H., and Fleming, W. M., "The Temperature Structure of a Mid-Latitude, Dimictic Lake During Freezing, Ice Cover and Thawing," Cold Regions Research and Engineering Laboratory, Hanover, N. H., November, 1970. Research Report 291.

The temperature structure of Post Pond, in west central New Hampshire, was studied during autumn, winter and spring of 1968-69. The lake was instrumented over its max. depth (11.7 m) with a string of 24 thermocouples. Temperatures in 9 m of sediments were measured with a termistor probe. Secondary and tertiary thermocline development in the epilimnion occurred during short warming periods in the early autumn. The autumn lasted 25 days, whereas the spring overturn lasted only 4 days. The entire lake mixed isothermally in the autumn to 3.2C. During the period of ice cover, the lower 5 m of water gained approximately 51.5 cal/sq cm from the bottom sediments. A thermal gradient of 0.07 c/m was found for the deeper sediments during ice cover. Late winter cooling of bottom water under the ice cover may be the result of snowmelt.

293. Patton, W. M., Practical Treatise on Foundations, Second Edition, Wiley, New York, 1906, p. 49-, 107-113.

Gives brief description of several cases showing effect of drift ice on the stability of piers.

294. Pessl, Fred Jr., "Formation of a Modern Ice-Push Ridge by Thermal Expansion of Lake Ice in Southeastern Connecticut," Cold Regions Research and Engineering Laboratory, Research Report 259, Hanover, N. H., August, 1969.

A modern ice-push ridge on the northwest shore of Gardner Lake in southeastern Connecticut is 0.6-1.2 m high and 1.2-3.1 m wide. In February and March 1967, the positions of survey stakes placed on the lake ice were measured periodically. During the same period, air and ice temperature and solar radiation intensity were also recorded. Analysis of the data supports the hypothesis that thermal expansion of the lake ice rather than wide action, was the principal cause of ice push. An ice-temperature change of approximately 1C/hr increase for 6 hr was sufficient to induce ice thrust. In a 30-day period, the average net shoreward movement of the surveyed area of the ice surfacewas 1.0 m. During the 1966-67 winter, approximately 14 m^3 of beach material was reworked and deposited, forming a discontinuous ice-push ridge along 260 m of shoreline.

295. Petrunichev, N. N.,"Dynamics of Ice Pressure on Hydraulic Structures," Cold Regions Research and Engineering Laboratory, Draft Translation 310, Hanover, N. H., January, 1972.

From our analysis of existing formulas for finding ice impact force on a structure it follows that the majority of them contain ice or ice field dimensions which, in the conditions of the above-mentioned future water flow situations, are very indefinite. We must, with no justification, assume ice forms for which the final results may change by several times. Corrections of the formulas through factual observations in the

field are thus far inaccessible due to the limited number of cases in which ice impact force on a structure has been measured. Laboratory investigations are also very small in number and have been conducted without consideration of the conditions of similarity in a model and in the field. We recommend finding impact force by starting from the extreme loads causing destruction of ice fields. The solution is sufficiently accurate for the case of a sloping structure face. For a vertical structure face one must find the numerical value of a correcting multiplier by the use of laboratory experiments.

296. Peyton, H. R., "Sea Ice Forces," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Technical Memorandum No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851.

A description is given of the measurements made to establish design criteria for drilling platforms constructed in Cook Inlet, Alaska. Field and model studies showed that the ice in the inlet failed by the crushing mode when forced past the circular legs of the platforms. Vibration associated with the ice load had a frequency of about one cycle per second. It is considered that this frequency is primarily determined by the properties of the ice rather than the natural frequency of vibration of the structure. Information is presented in the figures on the dependence of the failure stress for ice on rate of loading, brine volume and temperature. Field and laboratory results are presented showing that for high rates of loading, the load on the platform legs decreases with increasing rate of loading.

297. Pierson, W. J., "Methods for the Time Series Analysis of Water Wave Effects on Piles," U.S. Navy Project Y-R011-01-051, June 1963, AD 409966.

The object of the task is to obtain coefficients of drag and mass for vertical circular piles in a hurricane wave environment by the analysis, using non-periodic techniques, of force and water level measurements versus time as obtained in the open Gulf of Mexico. Three methods for the analysis of water wave effects on piles are outlined and compared, namely, bump-counting, time domain operations, and spectral operations. Computational requirements of the time-domain representation as introduced by Reid (1958) are contrasted with those required by the corresponding spectral representation. The joint distribution of the velocity (u) and the acceleration (DU/DT) is given, from which the probability density function of the horizontal component of the force on the pile, F(T)=K1 U U +K2U, is derived where K1 and K2 are constants containing respectively coefficients of drag and mass. From N-479.

298. "Planning the Modern Marina," Presented to Dock and Marina Design Seminar conducted by the University of Wisconsin-Extension in cooperation with the UW Sea Grant Program, May10-11, 1973, The Wisconsin Center, Madison, WI. Presented by J. L. "Larry" Donoghue, President, Ralph H. Burke, Inc. Engineers - Architects - Park Consultants, 20 No. Wacker Drive, Chicago, Illinois 60606.

299. Porte, H. A. and Nappier, T. E., "Coating Material for Prevention of Ice and Snow Accumulations, A Literature Survey Project," Y-R007-08-410, November 1963. BP. AD 423715.

The known principles and materials which have applications in preventing the formation of ice and snow on outside surfaces have been reviewed. Field experience has shown that there are no coatings presently available which are effective over extended periods of time. On the basis of the ice adhesion strength of the various coatings, it appears that it would be very difficult if not impossible, to obtain a material with the necessary physical properties to eliminate the accumulation of ice. From N-541.

300. Pounder, E. R., The Physics of Ice with Applications to Sea, Lake and River Ice, Oxford, Pergamon Press, 1965, 151 pp.

A general review of the physical properties of ice, with information on its natural occurrence and movement. The emphasis is laid on the scientific rather than the engineering aspect of the subject. An important feature of the book is a marked emphasis on the crystallographic structure of pure ice and on a model for the structure of sea ice and the author attempts to relate the bulk properties of ice to the fine details of its structure. The book is intended for glaciologists, hydrologists, geophysicists, oceanographors and general undergraduates in science.

301. Pounder, E. R., "The Physcis of Sea Ice," (Sect. VII), The sea, Vol. 1, Physical Oceanogr., ed. M. N. Hill, New York, Interscience Publishers, 1962, pp. 826-838.

1. Introduction. 2. Mechanical properties. 3. Thermal properties. 4. Electrical properties. 5. Growth and disintegration of an ice cover. 6. Theory of sea-ice structure and properties.

302. Pounder, E. R., "Thermodynamic Considerations on the Use of Air Bubbling Systems in Salt Water," Proceedings of the Symposium on Air Bubbling, NRC TR70, Ottawa, May 11, 1961.

Air bubbling systems can be expected to maintain an open water pool provided there is sufficient current. The magnitude of the current needed will depend on the extent of a positive salinity gradient, on the degree to which turbulant salt water can be supercooled, and on the size of the pool to be kept open. In the case of an ice cover, the situation is quite

different. Because of the greatly reduced evaporation, the insulating effect of the ice cover, and the lack of any temperature gradient in the water under the cover, this water will all be at the freezing point. If the salinity is uniform, it appears that the air bubbling should have no appreciable effect in reducing the ice cover.

303. Powell, R. W., "Preliminary Measurements of the Thermal Conductivity and Expansion of Ice," Proceedings of the Royal Society, London, 1958, series A., Vol. 247, No. 1251, 464-466.

An experimental investigation was conducted to determine the thermal conductivity and coefficience of thermal expansion of ice.

304. Proskuryakov, V. S., "Investigational Work Carried Out in the USSR with Regard to Ice Engineering Problems in Hydro-Electric Construction," IAHR 8th Congress Montreal 1959, Sem. I, pp. 17-SI-1-3.

Paper presents a brief description of the results by the Soviet ice-engineers achieved on various subjects: main construction methods in winter time; excavation; winter concreting; design methods of water temperatures in reservoirs and stream flows; ice processes in rivers, reservoirs and channels.

305. Pruden, F. W., Wardlaw, R. L., Baxter, D. C., and Orr, J. L. 1954, "A Study of Wintertime Heat Losses from a Water Surface and of Heat Conservation and Heat Addition to Combat Ice Formation in the St. Lawrence River." National Research Council of Canada, Report No. MD-42, Ottawa.

306. Ragle, R. H., "Formation of Lake Ice in a Temperate Climate," August 1963, 22p. AD433 794, 13 refs. 24-3259, CRREL Research Report 107.

The formation of lake ice in a temperate continental climate was studied during the winter of 1956-57 at Post Pond, Lyme, New Hampshire. In the thirty-six blocks of ice studied, four textures and three structures were observed. The textures, tabular, columnar, granular, and credulate, are discussed in terms of relative growth velocity. The structures were Forel striations, Tyndall figures, and bubbles. Strain shadows, a structural feature, were also observed. The average crystal area increased with increasing ice thickness. Generally the rate of increase was greater toward the center of the lake. However, within a pronounced bubble layer, which was continuous through a horizontal plane in the lake-ice sheet, the average crystal area ceased to enlarge. The lake-ice sheet grew both from the top and bottom with individual crystals growing most rapidly in the direction of their a-axes. Downward growth was by crystals which had the plane of their a-axes approximately vertically oriented.

307. Raraty, L. E. and Tabor, D., "Adhesion and Strength Properties of Ice," Proceedings of Royal Society, A 245, 1958, 184-201.

This paper describes a study of the adhesion of ice to various solids. If water is frozen on a clean metal surface the interface is stronger than the ice and fracture occurs within the ice itself. The detailed behaviour depends on the stresses developed near the interface. If tensile stresses are high the failure is brittle and the breaking stress is temperature independent. If the tensile stresses are below a critical limit the failure is ductile, and the breaking stress increases linearly as the temperature is reduced below 0°C. Ductile failure appears to be determined by the onset of a critical creep rate and the variation of breaking stress with temperature may be explained in this way. This view is supported by the observation that small quanitites of dissolved salts which increase the creep rate of ice produce a parallel reduction in the adhesive strength.

308. Rausche, Frank, and Goble, George G., "Performance of Pile Driving Hammers," Journal of the Construction Division, ASCE, Vol. 98, No. CO2, Proc. Paper 9188, Sept. 1972, pp. 201-218.

Using results from both theory and measurements the action and behaviour of hammer-pile systems are considered. Three types of models are used to describe the behavior of a hammer-pile system. One is the wave solution of St. Venant for a pile struck by a rigid body. The two other models use a mass and a spring to describe the effects of blocks and cushions, respectively. The interpretation of measured quantities using such models allows conclusions to be drawn regarding the driving ability of a hammer, situations involving pile damage, energy losses and transfer and characteristics of certain measured quantities. As a result it is shown that more meaningful quantities. Diesel hammer performance and energy output is analyzed and it is shown that these hammers perform adequately.

309. "Report on Ice-Harbor at the Head of Delaware Bay," 1882, Annual Report, Chief of Engineers, Pt. 1, p. 785-90.

Several paragraphs on ice pressure, followed by tables on crushing strength of ice, from experiments at Frankford Arsenal, Philadelphia and at Fort Tompkins, Staten Island, New York.

310. Rohsenow, Warren M., Clark, John A., and Van Alstyne, Paul C., "An Analysis of Errors in Ground and Air Temperature Measurement," Corps of Engineers, U.S. Army, (Frost Investigations), October, 1954.

This report is a discussion of various thermal errors associated with the measurement of ground and air temperatures. Errors associated with the digging of a pit and plunging temperature measuring devices into the ground through the side walls are considered. The effect of electric currents in resistance thermometers and in thermistors and the effect of radiation penetration in the ground are discussed. The types of errors associated with a long vertically installed temperature sensing unit are mentioned. Steady-state and transient errors associated with air temperature measurement under various conditions are presented.

311. Rose, E., "Thrust Exerted by Expanding Ice Sheet," ASCE, Transactions, V. 112, 1947, p. 871-885.

Presents a general guide for determination of design load, based on analysis applying available laboratory test data, so that a reasonable estimate can be made by interpretation of local conditions of maximum thickness, restraint, and temperature variation. Contains a bibliography of 22 references.

312. Rose, L. B., and Silversides, C. R., "The Preparation of Ice Landings by Pulp and Paper Companies in Eastern Canada," Transactions of the E.I.C., Vol. 2, No. 3, Sept. 1958.

The Woodlands Operating Departments of the pulp and paper companies in Eastern Canada have found lake and river ice landings very advantageous as storage areas and as transfer points in their pulpwood transport operations. Considerable empirical experience has been gained in the preparation and maintenance of landing areas as well as ice roads and bridges. The main problem is to greatly increase the ice thickness and its bearing capacity early in the winter season. Another aspect of operating vehicles on ice is that of salvaging those that break through and are submerged.

313. Royen, N., "Ice Pressure With Increasing Temperatures," August 1955, 11p. TT-60 13693, Translation from Hyllningsskrift tillagnad F. Vihl. Hansen. Stockholm, Gunnar Tisells Tekniska Forlag, 1922, p. 357-371, 7 refs. 25-4103, SIPRE Translation 45.

The ice pressure resulting from temperature increases in a confined ice cover is discussed. Results of earlier investigations on the mechanical properties of ice are reviewed. The relationships between time, stress, temperature and compression for ice and paraffin were studied, equations expressing the various relationships are given. The maximum ice pressure for conditions occurring in Sweden cannot exceed 30 tons/m. for an ice cover 1 m. thick or 22 tons/m. for an ice cover 0.75 in. thick. Factors serving to reduce the ice pressure are presented.

314. Samochkin, V. M., "Thermal Exchange Between Water Currents and Atmosphere in Winter Time," 1970, 5p. AD-715 048, for original Russian article see 23-0619. 9 refs. 25-2373, CRREL Draft Translation 136.

The thermal exchange processes on the boundary between water and air play an important part in the formation of ice layers. If the incoming or consumed heat resulting from radiation processes were determined by a uniform method, even if not very accurately, or if those components of the heat exchange could be measured, there are a number of formulas that could be used for calculating the loss of heat by evaporation and convection. Formulas developed by several authors to calculate heat losses are discussed.

315. Sanden, E. J. and Neill, C. R., "Determination of Actual Forces on Bridge Piers Due to Moving Ice," Proceedings of 1968 Annual Convention, Canadian Good Roads Association, Ottawa, p. 405-420.

316. Santema, P. and Svasek, J. N., "The Effect of Damming-Up of the Tidal Estuaries on the Ice in the Rivers of Zeeland and Zuidholland," Rep. Delta Committee, 1961, pt. 5, contr. IV, 5, pp. 295-325.

The formation and movement of floarint ice in the Dutch river system: Zeeland lake, Haringvliet basin and the other waters of the Delta-area are studied. A number of conclusions on the effects of damming up the estuaries and preventive measures to be taken are discussed. (In Dutch, with summaries in English and French).

317. Sauberer, F., "Oberflachenseiches am zugefrorenen Lunzer Untersee," Meterorologische Zeitschrift, V. 59, Nov. 1942, p. 379-381.

Surface seiches on the frozen Lunzer Untersee. Fluctuations of the frozen lake surface were observed. Seiches occur even when the lake is completely frozen. The results indicate that the motion of the ice, 14-18 cm. thick, was plastic, reference not in Engineering Societies Library and not verified.

318. Scheidegger, A. E., Theoretical Geomorphology, Springer Verlag, Berlin, 1961, 333pp.

Chapter 2.3 deals with the dynamics of flowing ice. Chapter 7 deals with niveal effects: principles of ice action, longitudinal movement of glaciers, three-dimensional movement of ice, and other niveal effects.

319. Sheng, P. and Lick, W., "The Wind-Driven Currents in a Partially Ice-Covered Lake," Case Western Reserve University, Cleveland, Ohio.

The steady-state, wind-driven currents in a partially ice-covered lake have been calculated numerically. Two cases have been studied extensively, (1) a rectangular, constant depth basin, and (2) a realistic model of Lake Erie with variable depth and geometry.

320. Schenker, Eric, and Kochan, James, "Preliminary Investigation Extending the Shipping Season on the St. Lawrence Seaway," Grant Technical Report #2, June, 1970.

This paper is a preliminary investigation into the problems of extending the shipping season on the St. Lawrence Seaway and the impact such an extension would have upon the Great Lakes region. We begin with a summary of the technical problems associated with extending the shipping season, i.e., controlling the ice in the Seaway. Next we present data for alternative improvement programs, utilizing cost projections of the U.S. Coast Guard. Finally, we introduce some questions that must be considered before an informed decision can be made regarding the feasibilty of extending the Seaway navigation season.

321. Schenker, Eric, "Present and Future Income and Employment Generated by the St. Lawrence Seaway," The Seaway Review, (reprinted), Vol. 1, No. 3, Autumn, 1970.

It is estimated that a six week extension of the St. Lawrence Seaway shipping season would bring about an increase in seaway traffic of 1.6 million tons of bulk cargo and 367,000 tons of general cargo by 1980. Such an increase would add approximately 35 million dollars in direct income and over 70 million dollars in total income to the regions's economy.

322. Scherman, K. A., "On Ice Difficulties of Open Water Courses of Hydro-Electric Plants," IAHR 8th Congress Montreal 1959, Sem. I, pp. 25-SI-1-9.

Both the river regulations and the power plants will change the water flow and water level, so that ice conditions more or less will change too. Sometimes this will cause troubles. One of these troubles is the forming of ice and frazil ice in streaming water of head races. This paper deals with this special problem. A calculation for assumed severe winter conditions is made.

323. Schwarz, J., Treibeisdruck auf Pfahle, "Pressure of Drift-Ice on Piles," Mitt. Franzius-Inst., Grund - U. Wasserb, TU Hanover, No. 34, 1970, pp. 89-193.

Because of the importance of stability of structures in the water the author attempts to calculate the conditions for possible - pressure forces - particularly drift-ice - on piles, and he makes use of strength tests on ice cubes as well as actual tests on the site measurements. He gives an up-to-date picture of ice research today followed by a report on a series of experiments with different types of ice on the pressure resistance of ice cubes. Details are given of ice pressure measurements taken at an experimental site at a completed bridge leading to the Island of the Elder Dam. It can be assumed that the ice pressure of drift-ice flows will not be greater than that transmitted by the compactness of the ice. An ice pressure equation is given, based on the laboratory results of the in site measurements, from which the maximum drift-ice forces on piles and on smaller areas can be calculated, depending on local conditions.

324. Schwarz, Joachim, "The Pressure of Floating Ice- Fields on Piles," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

The investigation of the pressure of floating ice fields against piles has been started from the assumption that the maximum pressure of ice is limited by its compressive strength. Therefore this strength was first of all ascertained by laboratory tests on cubes of several ice species. The results contain the influence of temperature, velocity of deformation and direction of pressure on the cubic strength. In order to employ these laboratory results for the calculation of structures, a relationship between the strength in laboratory tests and in nature was derived by measuring the pressure of floating ice-fields on a pile of a bridge, which crosses the tidal estuary of the EIDER river. The investigation leads to an equation, which allows the calculation of ice pressure againt piles.

325. Schwerdtfeger, Peter, "The Thermal Properties of Sea Ice," Meteorology Dept., University of Melbourne, Australia, Journal of Glaciology, Vol. 36, 1963, Pp. 789-807.

Compared with freshwater ice, whose physical properties are well known, sea ice is a relatively complex substance whose transition to a completely solid mixture of pure ice and solid salts is completed only at extremely low temperatures rarely encountered in nature. The physical properties of sea ice are thus strongly dependent on salinity, temperature and time. Many of these properties are still not fully understood or accurately known, particularly those important for the understanding of a natural ice cover. The specific heat for example is an important term in the calculation of the heat energy content of a cover. However, Malmgren (1927), whose calculated values of the specific heat of sea ice are in general use, neglected the direct contribution of the brine present in inclusions. Re-examination of the question of specific and latent heats of sea ice has led to distinguishing between yhe freezing and melting points and enabled significant observations in this range.

326. Scott, I. D., "Ice-Push on Lake Shores," Michigan Academy of Sciences Papers, v. 7, 1927, p. 107-123.

Discusses mechanics of ice push due to both expansion and ice jam. Expansion occurs in small lakes when a complete thick ice cover forms with little or no snow cover under conditions of large and relative rapid changes in temperature. Ice jams occur on large lakes in regions of heavy snowfall. Reference not in Engineering Scoieties Library and not verified.

327. Semenescu, M., "The Freezing Phenomenon in the Iron Gates Sector of the Danube," Meteorologia Hidrologia Sigospodarirea Apelor 1960, No. 4, pp. 243-258.

The paper deals with the incidence and evolution of the freezing phenomenon in the Iron Gates sector of the Danube, based on certain theoretical considerations on the regime of ice and the physical characteristics of the area (in Rumanian, with summaries in Russian, French and English).

328. Senior, Charles W., "A Model Describing the Physical Process of Project Polynya," Proceeding of the Symposium on Air Bubbling, NRC TR70, Ottawa, May 11, 1961.

Successful application, during the fall of 1958, of the air bubbling technique for preventing ice formation enabled the Military Sea Transportation Service to extend the shipping season into the port at Thule Air Base, Greenland. Although the technique had originally been developed in fresh water, an ice free area of "polynya" was maintained adjacent to Delong Pier at Thule Harbor despite normal ice formation in the surrounding waters of North Star Bay. The unique properties of fresh water make the compressed-air bubbling system highly suitable for use in lakes and rivers. The fact that for water of any given salinity in excess of 24.7 parts per thousand the maximum density it attained at the freezing point makes the system less effective for use in salt water. In this case and in other regions where upward circulation of sensible heat is not a factor, the maintenance of a polynya is predominantly dependent upon the velocity and density of the induced currents. The compressed-air bubble system is the most efficient method of inducing vigorous vertical currents and tests conducted at McMurdo Sound indicated the marked superiority of the propeller technique.

329. "Severe Test of Bridge Masonry," Engng. Res., v. 40, 1899, p. 554.

Effect of a mass of ice sweeping against a bridge, carrying away a span and moving a pier off its foundations.

330. Shimuskii, P. A., Principles of Structural Glaciology, 1964 Edition, 124 figures, xiii + 497pp.

Systematic treatment of mineralogy and crystallography of ice, petrology of ice, nature of ice formation processes, zones of formation, structure of cryosphere, similar topics. Indispensable, definitive study. Translated by David Draus.

331. "Shore Protection, Planning and Design," U.S. Army Coastal Engineering Research Center (formerly BEACH EROSION BOARD) Technical Report No. 4, Third Edition.

First Edition, June 1954; Revision and Addenda, August 1957; Second Edition, May 1961; and Third Edition, June 1966.

332. Siegfried, R., Le gel d'eau, avec formation de glaces et creation de prises totales ou d'aubacles, cree de graves perturbations et des interruptions totales de navigation sur les voies navigables et dans les ports, 19th Assembly of the P.I.A.N.C. London 1957, SI, C3, pp. 95-120.

Description of difficulties caused by the freezing of water, on the large rivers and the network of canals and rivers of the North, East and Center of France. The fight against ice formation. Action by navigation structures. Protection of vessels (in French, with summary in English).

333. Sikora, A., "The Winter Regime of Low-Head Hydraulic Installations," Vyskumny Ustav Vodohospodarsky, 1962, No. 19, 101p.

The ice processes and phenomena that may occur on hydraulic installations and the adjacent reservoirs are briefly described. The arrangement of different structures of low-head hydraulic installations built on rivers with regard to a reliable and undisturbed passing of ice from the reservoir and with the protection of hydro-electric power stations against direct action of ice floes is indicated. Furthermore the treatise communicates prototype experience concerning the preparation of a reservoir for the discharge of ice and the passing of ice-floes from the reservoirs of low-head hydro-electric power stations built on rivers. (In Slovenian with summary in English.)

334. Simmonds, Arthur T. "Prevention of Ice Formations by Air Bubbling: A Cold Weather Hydraulic Operation of the New England Electric System," Proceedings of the Eastern Snow Conference, 10th/11th meetings, 1953 and 1954.

A brief history of air bubblers is given here with a description of the apparatus used at each of the installations. A detailed account of the construction, air requirements and experiences involved in the operation of a bubbler system at Wilder Plant on the Connecticut River near White River Junction is given. It was concluded that the system was workable, satisfactory to the operating personal of the plant, and economically justified.

335. Smallridge, C. G., "Ice Problems at the Corner Brook Development," IAHR 8th Congress Montreal 1959, Sem. I, pp. 23-SI-1-2.

Description of measures preventing the freezing of gates.

336. Smith, C. W., Construction of Masonry Dams, McGraw-Hill, N.Y. 1915, 272 pp.

The subject of ice thrust is discussed on p. 117-126, giving specific example of dams and reservoirs which have been successful and others which have failed.

337. Smith, E. A. L., "Pile-Driving Analysis by the Wave Equation," Transactions, ASCE, Volume 127, Part I, 1962, with discussions. p. 1145-1193.

There are a great many different pile-driving formulas in use, and engineers have never been able to agree as to which one is best. This situation has arisen primarily because, until recently, the mathematics of pile-driving action could not be solved in any practical manner. As a result all pile-driving formulas are partly empirical and, consequently, apply only to certain types or lengths of pile. This paper is presented with the purpose of giving engineers a mathematical method of wider application, depending on the use of electronic computers and numerical integration. The method is also applicable to other impact problems.

338. Smith, E. A. L., "Pile-Driving Analysis by the Wave Equation," J. Soil Mech. and Foundations Div., No. SM 4, Proc. ASCE, Paper 2574, August 1960, p. 35-61.

There are a great many different pile-driving formulas in use, and engineers have never been able to agree as to which one is best. This situation has arisen primarily because, until recently, the mathematics of pile-driving action could not be solved in any practical manner. As a result all pile-driving formulas are partly empirical and, consequently, apply only to certain types or lengths of pile. This paper is presented with the purpose of giving engineers a mathematical method of wider application, depending on the use of electronic computers and numerical integration. The method is also applicable to other impact problems.

339. Snider, C. Robert, "Techniques for Predicting Great Lakes Ice Cover," NOAA National Weather Service, Detroit, Michigan.

Prediction of ice cover requires knowledge of the temperature distribution throughout the body of water and an estimate of future heat exchange among different portions of the water with adjacent bodies of water, with the atmosphere, with the shore and the bottom, without space, and due to man's activities; and conversion of heat to or from other forms of energy. Routine observations of most of these parameters are not available. Indirect methods have been developed for deriving the needed data from meteorological observations regularly made for the use in weather forecasting. The resulting ice forecasts have proven useful in planning wintertime navigation.

340. Sohlberg, E. T., "Strain Gage Instrumentation of Steel Piles in Snow," April 1965, 30p. AD-615 996 7 refs. 24-3108, USA CRREL Technical Report 152.

This report describes instrumentation for a preliminary test of friction piles in snow. Dynamic measurements of strain

were made during driving by means of a dual oscilloscope fitted with a Land camera. The larger of the two H piles tested was an 8x8 WF 35 section and the smaller was a 6x6 M 20. Both were 30 ft. long, driven in September 1962, and left unloaded until the 1963 summer. A switch box was constructed and used during static tests, which allowed a forward, reverse, and calibration reading to be taken at each gage position in a minimum of time. Immediately after the load was applied, the upper section of the pile took most of the load. After the load was held in place for several weeks, each unit length of the pile had accepted an equal share of the total load. The 8x8 WF 35 pile was loaded to 40,000 lb and the 6x6 M 20 to 28,000 lb. Immediately after removal of the load, the upper section of the pile was relieved but most of the loaded strain remained in the bottom section.

341. Sommerville, R. C., and Burns, G. E., "Damage to a Winnipeg Reservoir Due to Ice," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Tech. Memo. No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Ottawa.

On 5 February 1963 damage occurred to two cells of a reservoir in Winnipeg which resulted in a marked increase in the rate of leakage. Observations and calculations are presented that indicate the damage was caused by vertical and horizontal forces exerted by the 3-ft ice cover on the upper row of slabs lining the reservoir. The forces are considered to be due to changing water level and thermal expansion of the ice cover caused by a marked increase in temperature prior to the detection of the damage. The paper also describes the construction of the reservoir and the action taken to prevent damage in the future.

342. Stanislav, J. and Mohtadi, M. F., "Mathematical Simulation of Dispersion of Pollutants in a Lake with Ice Cover," Water Research, Pergamon Press 1971, Vol. 5, p. 401-412.

Mathematical simulation has been used to predict the mode of dispersion of a pollutant stream entering a lake. The model used is based on certain simplifying assumptions but it is versatile enough to allow the magnitude of dimensionless parameters, source terms and boundary and initial conditions to be altered. Furthermore, by imposing a laminar velocity distribution on the system the model can be used to simulate the dispersion pattern in a lake where there is a slow bulk flow. The method developed can be employed as a useful tool for the preeiction of the extent of pollution in a lake under specific conditions. Experimental verification of the utility of the model is now being attempted.

343. Starosolszky, O., "Scale Models for Investigation of Ice Phenomena," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

Hydraulic model experiments may be resolved into two groups, using actual ice in a cooled hall or performed with ice substituents. In both cases difficulties are bound to arise in the determination of scales. The effect of distortion is investigated on the basis of the non-dimensional relation of Pariset, Hausser and Gagnon concerning the stability of the ice cover. Distorted models do not yield numerically correct values.

344. Stehle, N. S., "Holding Strength of Piles in Ice," U.S. Naval Project YF 38.536.003.01.001. October 1970 AD 714165.

Tests were conducted at the Naval Civil Engineering Laboratory to determine the influence of pile material, shape, ground temperature, and backfill on tangential adfreezing strength in ice. General criteria for application were developed based on laboratory and field information.

344.5 Striegel, A. R., "Ice on the Great Lakes and Its Engineering Problems," Paper presented at Joint Meeting of American Meteorological Society and Geophysical Union, Sept. 11, 1952, Chicago.

The paper discusses ice types, formation and thickness on the Great Lakes. Certain engineering problems associated with the design of structures to withstand ice forces are given as well as design criteria that can be applied in designing such structures. Also presented in this paper are specific ice associated problems occurring at various geographic locations in the Great Lakes region.

345. Strong, R.,"Compiler, Bibliography on lake ice," University of Michigan Department of Engineering Research, Ann Arbor, Mich. May 1948, 88p.

A bibliography of 150 items listed under the following subjects: general; formation and structure of lake ice; strength of ice; ice friction; hardness of ice; elastic constant, viscosity and plasticity of ice; ice breakers and ice breaking.

346. Strowger, E. B., "Ice Problems in Hydraulic Structures," IAHR 8th Congress Montreal 1959, Sem. I, pp. 15-SI-1-8.

Article discusses the design of structures and equipment in relation to ice problems in operating hydro-electric generating stations, giving consideration to the intake structure, rack design, penstock air vents, pipe lines, surge tanks, crest gates, ice sluices and dams, with emphasis placed on practical and economic design.

347. Su, Chih-Lan, "Asymptotic Solutions of Resonances in Harbors with Basins," Journal of the Waterways, Harbors and Coastal Engineering Division, ASCE, Vol. 99, No. WW3, Proc. Paper 9954, August, 1973, pp. 375-392.

Asymptotic formulas for the resonant wave numbers are obtained for harbors with connected basins. The number of basins is

taken to be two in this paper. However, generalization of the formulas for harbors with more than two basins can easily be obtained. The harbor and the ocean are assumed to have a constant depth. The coast is assumed to be straight but the boundaries of the basins can assume arbitrary shapes. In deriving the asymptotic formulas, the widths of the entrances to each basin are assumed to be small compared with the incident wave length and also with the dimensions of the basins. Comparisons with existing numerical results, however, indicate that these formulas are good even when the entrance widths are comparable to the incident wave lengths and to the dimensions of the basins. The formulas depend only on the eigenvalues of the closed basins and the corresponding normal mode solutions as at entrances. Furthermore, each resonant wave number depends only on the normal modes with wave numbers close to it.

348. Sullivan, Richard A., "Behavior of Wharf Affected by River Fluctuations," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 09, September 1970.

Fluctuations of water levels in the Houston Ship Channel caused movements and some structural damage to a pile-supported wharf constructed in over-consolidated plastic Pleistocene clay. During the winter after dredging to deepen the ship channel and again during the next winter. movements occured when lower than normal water levels were produced by short-duration strong northerly winds. Dredging of the channel initiated a progressive type of soil failure in the high swelling Beaumont clay. The lower than normal water levels caused repeated temporary overstressing and spreading of the failure surface behind the wharf. The initial slide movement occured when an extreme low water level created sufficient overstress for a long enough period to cause rapid progressive failure. Analyses of the movements revealed that the long-term stability of the wharf built in expansive over-consolidated clay should be based on effective stress parameters significantly less than the peak values. The wharf was successfully renovated without disrupting loading operations of vessels.

349. The Task Committee on Hydromechanics of Ice, "River-Ice Problems: A State-of-the-Art Survey and Assessment of Research Needs," Journal of the Hydraulics Division, January 1974.

The Task Committee on Hydromechanics of Ice was organized to examine the state of development of river-ice mechanics, and to delineate the problem areas in which there exists an acute need for research leading to the development of improved engineering tools. This report is a summary of the committee's findings. The committee concluded that the highest research priorities should be given to the following topics: (1) Formation processes of river ice; (2) ice jams; (3) ice forces; (4) heat exchange processes and the effects of thermal enrichment. Other problems that the committee gave a lesser priority to are ice formation on submerged surfaces, properties of ice,

friction factors, sediment transports in rivers with ice, design or water intakes for ice conditions, formation of icings and river glaciations, glacier outbursts, ice at navigation looks, and computer simulations.

350. Thorn, B. J., "An Engineering and Economic Evaluation of Floating Fender Concepts," San Marino, California, Science Engineering Associates, June 1966. Contract NBY-62205, AD 640979.

This report contains an engineering and economic evaluation of eight different concepts of floating fenders to be considered for Navy docks. The engineering aspects involve discussion of different design criteria, such as vessel approach velocities, acceptable lateral dock loads, hull loads and stresses in structural timber. A description of they dynamics of a berthing ship is given, including a discussion of the various energy correction coefficients to be used. The hydrodynamic mass coefficient is especially emphasized. The results obtained on this coefficient by many different investigations are summarized, showing that large unexplained discrepancies exist. The economic criteria employed are stated and summarized. A short discussion on deterioration of camel materials is also included. From CR-66.008.

351. Thurman, A. G., and D'Appolonia, E., "Computed Movement of Friction and End-Bearing Piles Embedded in Uniform and Stratified Soils," Proceedings of the Sixth International Conference on Soil Mechanics and Foundation Engineering, Vol. 2, Montreal, 1965, p. 323-327.

A computational method, suitable to electronic computers, was used to predict pile movement under any load. Friction or end-bearing elastic piles embedded in uniform or stratified elastic soils were considered. Friction forces were assumed to be replaced by a series of point forces on pile increments. Slip without change by a Coulomb failure criterion. Elastic-plastic tip movements were based upon published tests. A compatible force-deformation relationship was maintained between non-failed increments and the surrounding soil at all times. Ultimate load was defined by slip at all increments and plastic punching at the tip. Examples of computed results are presented for tip movement, butt movement, and load transfer from the pile to the soil. It was concluded that the computational method can be applied successfully to a wide range of pile-soil problems.

352. Tien, Chi and Yen, Yin-Chao, "A Theoretical Investigation of the Effect of Melting on Forced Convection Heat Transfer," Research Report 172, U.S. Army Cold Regions Research and Laboratory, Hanover, New Hampshire, October 1965.

The effect of melting on convective heat transfer between a melting body and surrounding fluid was studied quantitatively from the point of view of boundary layer theory. These studies indicate that melting retards the rate of heat transfer and the decrease in heat transfer coefficient is found to be a unique function of the parameter CpT/H_M, where T is the temperature difference between the fluid and melting body, C_p is the heat capacity of the fluid, and H_M is the enthalpy change due to melting.

353. Tien, C., Yen, Y. C., "Additional Note on the Modified Leveque Problem," Journal of Geophysical Research, April 15, 1964 69(8) p.1672-1673 1 ref. Microform No. SIP 22125. 25-2068. Miscellaneous Publication 434.

In an earlier paper (SIP 21848) the problem of laminar heat transfer over a melting plate was studied under the assumption that the flow near the interface could be considered as $v(x)$ equals cy, where $v(x)$ is the velocity along the plate, y is a coordinate normal to plate and c is a constant in velocity distribution. The assumption simplified the subsequent analysis but there is doubt as to the validity of the simplification. This note investigates the same problem without this arbitrary assumption. In this investigation c is considered to be a function of the longitudinal distance. It is concluded that the results obtained earlier on a restricted assumption are applicable to more realistic cases.

354. Tien, Chi and Yen, Y. C., "Condensation-Melting Heat Transfer," Syracuse University, Syracuse, N.Y., Y. C. Yen is with the U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N. H.

Consideration is given to the heat transfer problem involving condensing vapor onto a melting surface. Because of the simultaneous condensation and melting, a liquid film is formed along the melting surface and flows under gravitational force. It is assumed that the condensing vapor and the melted liquid are the same substance, such as condensing steam onto ice, or they are completely miscible with negligible concentrative gradients across the film. Based on the assumptions that the shear stress at the vapor liquid film interface is negligible, the geometry change of the melting surface due to melting can be ignored, and the Prandtl number of the fluid is sufficiently large so that the inertial forces are insignificant as compared with viscous forces, the heat transfer problem was solved by using similarity transformation. In addition, a closed-form solution was obtained by using integral approximations. Both results were found in substantial agreements.

355. Tien, Chi, and Yen, Yin-Chao, "Approximate Solution of a Melting Problem with Natural Convection," Heat Transfer-Los Angeles Chemical Engineering Progress Symposium Series, Vol. 62, No. 64, 166-172.

Approximate solutions of temperature distribution and melting rate have been obtained for cases where the mode of heat transfer is natural convection due to the hydrodynamic instability caused by the heated lower surface. Extensive numerical solutions were given for water-ice systems corresponding to various conditions.

356. Tien, C., "Preliminary Calculation of the Energy Requirement for Placing an Instrument Package Under Ice," Nov. 1965, 20p. AD-630 982, 3 refs. 24-3295, USA-CRREL Research Report 146.

The energy requirement for dispatching an instrument package through ice by thermal heating was estimated, and the feasibility of such an undertaking was determined. Heat fluxes were supplied throug the bottom surface of the package as well as through the circumferential surfaces. The ice in contact with the package melts after sufficient heating, and as a consequence the package moves downward. With given assumptions, the energy requirement was estimated first by expressing the rate of melting (downward velocity of the package) in terms of the heat supplied through the bottom surface. With this information, the heat loss through the cylindrical surface was calculated. The sum of these two energy terms gives the total heat required.

357. Tien, C., et al, "Theoretical Investigation on the Effect of Melting on Forced Convection Heat Transfer," Oct. 1965, 10p. Ad-629 066 10 refs. Yen, Y.C. 24-3319, USA-CRREL Research Report 172.

The effect of melting on convective heat transfer between a melting body and surrounding fluid was studied quantitatively from the point of view of boundary layer theory, film theory and penetration theory. These studies indicate that melting retards the rate of heat transfer and the decrease in heat transfer coefficient is found to be a unique function of the parameter C sub p delta T over delta H sub m, where delta T is the temperature difference between the fluid and melting body, C sub p is the heat capacity of the fluid, and delta H sub m is the enthalpy change due to melting.

358. Tryde, Per, "Forces Exerted on Structures by Ice Floes," S II-4 Paper, Asst. Professor, M.Sc., Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark.

359. Tryde, Per, "Ice Forces on Steel Sheet Piles," Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, Building 115, DL-2800 Lyngby/Copenhagen, Denmark.

360. Untersteiner, N., "Calculations of Temperature Regime and Heat Budget of Sea Ice in the Central Arctic," Journal of Geophysical Research, Vol. 69, No. 22, 1964, pp. 4755-4766.

The equation of heat conduction, including variable thermal conductivity and specific heat, an internal heat source diminishing with depth, and an advective term, is integrated numerically for sea ice of equilibrium thickness. The annual cycle of thickness (ablation-accretion) is imposed as an external parameter. The boundary values for temperature and the vertical distribution of ice salinity are taken from empirical data. The computed temperature field is in good agreement with observations. The thermal history of individual particles of ice, the relative effect of the internal heat source (penetrating solar radiation), heat storage, and the annual cycle of heat flux by conduction at various depths are described. The observed maximum of brine volume at 40- to 70-cm depth is explained as the combined effect of salinity profile and internal absorption of radiation. The requirement that heat flux in the atmospheric boundary layer is well met by Badgley's values of radiative and turbulent heat transfer.

361. U.S. Army Corps of Engineers, "Mississippi River Year-Round Navigation," April, 1971.

The U.S. Army Corps of Engineers investigated means of recessing lock miter gates. They came to the following conclusions. (1) An Aqua-therm velocity system was successful in keeping ice from forming in the recess area during mild temperatures but at below zero temperatures, the open water did freeze over. (2) They do not believe that there is enough thermal reserve in the Mississippi River for a velocity system of this size to be successful in keeping the recess area ice-free. Therefore, either a heat source must be added or larger units must be used. (3) This type of unit does have a potential use as a bulking system for moving ice and debris from recess area during lockage. (4) A larger system of this type, running continously, may keep ice from forming on the recess wall.

362. Uzuner, Mehmet S., and Kennedy, John F., "Stability of Floating Ice Blocks," Journal of the Hydraulics Division, ASCE, Vol. 98, No. HY12, Proc. Paper 9418, December, 1972, p. 2117-2133.

The critical conditions at which buoyant blocks on a flowing stream are swept under a downstream floating cover are investigated analytically and experimentally. The mathematical model of block stability is based on a one-dimensional hydrodynamic analysis of the flow passing beneath the upstream end of a floating cover, and the force and moment equilibrium of the block. It is argued that the condition of incipient submergence is reached when the block sinks and rotates until the stagnation water surface elevation equals that of the top upstream edge of the block. Experiments to verify the analysis were conducted in a 1-ft wide laboratory flume using right parallel piped blocks with three different specific gravities and a range of length-thickness ratios. The moment coefficient which arises in the analysis was evaluated by means of the

experimental data, which were found to be in good agreement with the analytical results.

363. Uzuner, Mehmet S. and Kennedy, John F., "Stability of Floating Ice Blocks" Final report submitted to Rock Island District U.S. Army Corps of Engineers Contract No. DACW 25-61-C-0005 IIHR Limited Distribution Report No. 7, December 1971.

The critical conditions at which buoyant blocks on a flowing stream are swept under a downstream floating cover are investigated analytically and experimentally. The mathematical model of block stability is based on a one-dimensional hydrodynamic analysis of the flow passing beneath the upstream end of a floating cover and the force and moment equilibrium of the block. It is argued that the condition of incipient submergence is reached when the block sinks and rotates until the stagnation water surface elevation equals that of the top upstream edge of the block. Experiments to verify the analysis were conducted in a one-foot wide laboratory flume using right parallelpiped blocks with three different specific gravities and a range of length-thickness ratios. The moment coefficient which arises in the analysis was evaluated by means of the experimental data, which were found to be in good agreement with the analytical results. Available field data are examined within the framework of the analytical model, and a conjecture concerning the evolution of ice jams to equilibrium is put forth.

364. Vanier, C. R., and Tien, Chi, "Free Convection Melting of Ice Spheres," American Institute of Chemical Engineers Journal, Vol. 16, No. 1, January 1970, 76-82.

Experimental results have been obtained for heat transfer to melting ice spheres by measuring the rate of change of apparent weight. It is found that the traditional correlation format of Nusselt numbers against Rayleigh number is satisfactory only for bulk temperatures above 7°C. Average Nusselt numbers obtained from the sphere experiments are closely related to previous theoretical work with vertical flat plates.

365. Vanier, C. R., and Tien, Chi, "Further Work on Free Convection in Water at 4°C," Chemical Engineering Science, Vol. 22, 1967, 1747-1751.

Previous theory has estimated heat transfer coefficients for natural convection in water at its maximum density; they are found to be too low by 15 percent and restricted to plate temperatures of less than 8°C. By deriving more accurate density-temperature relationships and by taking some account of the variation in Prandtl number, new solutions have been found for plate temperatures of up to 35°C.

366. Vanier, C. R., Tien, C., "Effects of Density Inversion and Melting On Free Convection Heat Transport and Hydrodynamic Stability," Feb. 1968, 179p. Contract DA-AMC-27-021-65-G16, Contract DA-AMC-27-021-65-G20, 55 refs. 26-5235, Unpublished Internal Report 135.

The major phase of this investigation is the study of the effects of density inversion and melting on free convection from bodies of simple geometry. Both theoretical analysis and experimental measurements were carried out. A detailed account of this work is given in Part II. In Part III, an analysis on the free finite vertical flat plate in water at 4°C is given. This work represents a necessary complement to the more general study given in Part I. The study made in Part I requires the use of references temperature at C and therefore has a singularity at 4C which does not permit solution to be formed. In Part IV, the effect of density inversion on the hydrodynamic stability of a layer of fluid subject to a temperature difference is given. The stability criteria is found to be of two parameters and modified Rayleigh number and a ratio of temperature differences.

367. Vanier, C. R., Tien, C., "Effect of Maximum Density and Melting on Natural Convection Heat Transfer From a Vertical Plate" Chemical engineering progress symposium series 1968 64(82) p.240-254, 33 refs. 26-2869. Miscellaneous Publication 448.

A method has been indicated which gives accurate results for natural convection heat transfer to vertical plates in regions of anomalous density behavior. The particular case of water has been analyzed, and good agreement with existing experimental heat transfer data has been found. Two equations have been given which predict the onset of various flow regimes; these conditions remain to be experimentally verified. A physical rationale has been advanced for the effects of a maximum density, and it is suggested that the boundary-layer assumptions are a good physical model except in two temperature zones. The effect of melting on the heat transfer was found to be small.

368. Van Wijk, M. C.,"The Use of Photogrammetry for Measuring the Movement of Ice Covers," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Tech. Memo. No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968 NRC No. 9851, Ottawa, Ca.

A stereophotogrammetric method for determining the movement of ice covers is described. The method was used to measure the movements about a pier of the MacDonald-Cartier Bridge, spanning the Ottawa River at Ottawa. Information is presented on the field installation and on the accuracy of the observations.

369. Vialov, S. S., "Laws Of Ice Deformation," 1970, 15p. AD-715 032, Translation of Zakonomernosti deformirovaniia l'da. Sov. antarktich. eksp. 2nd, Gliats, issled., 1960, No. 10:239-248 25-2406. CRREL Draft Translation 172.

During the Second Continental Expedition, a special laboratory was created to carry out ice deformation tests. These included compressive tests with and without laternal extension, shear tests and hardness characteristics was investigated. An analysis including plots of ice compaction and flow as functions of crystal orientation, time, and loading conditions, is presented. Elastic deformations in ice have a twofold nature - pure elastic deformation occurring instantly and an elastic aftereffect developing with time.

370. Volpe, John A., "Policy for the Seaway," Seaway Review, Vol. 1, No. 2, 1970.

The possibility of lengthening the Great Lakes Seaway season is of great interest because it results in more effective use of facilities, better utilization by vessel owners of their fleets, a longer revenue-producing season for commerical interests, and extension of the period of employment for persons involved in Great Lakes maritime activities. There are a number of efforts being pursued to lengthen the season. There is work on an agreement with power authorities to permit the early removal of ice booms, boom designs are being modified to permit a longer navigation season, and there is also the possibility of modifying locks and gates to facilitate the disposal of ice coming into the locks from the channels. Finally the Seaway Corporation and the Coast Guard are working with various Great Lakes interests in putting together a pilot project to permit the winter navigation of vessels.

371. Voltkovsky, K. F., "The Relaxation of Stresses in Ice," Proceedings of International Conference on Low Temperature Science, Sapporo, Japan, Vol. 1, 1966.

The rate of stress relaxation in ice is determined by its structure, its temperature and the magnitude of the initial stress applied. The rate depends also upon the time interval between the moment of shear stress application and the time of initiation of the stress relaxation process. Theoretical and experimental investigations showed that this time interval is of substantial importance, though usually little or no attention has been paid to it. When the deformation of ice is held constant, the shorter the above mentioned time interval is, the more rapidly the resistance of ice decreases, and, when the deformation of ice is increased by creep, the longer the time for the preliminary creep is, the more slowly the stress relaxation occurs. For example, a series of experiments gave the following results; three identical ice cylinders of deformation was stopped in the respective cylinders for 6 minutes, 1.4 hours and 8 hours after the application of the

initial load. The time required for the stress in ice to be reduced to half the initial value was found to be 6, 58 and 102 minutes for the first, the second and the third cylinders. Thus the stress relaxation in the third cylinder.

372. Vyalov, S. S. and Ermakov, V. F., "Simplified Method of Testing Ice for Creep and Relaxation," Proceedings of International Conference on Low Temperature Science, Sapparo, Japan, Vol. I, 1966.

Creep experiments usually consist of testing a series of specimens under different loads, which are, however, constant for each specimen. Generally a group of creep curves are obtained as a result of tests, and the curves are used to determine the relationship between the stress and the deformation or its rate and time. The above method, however, is rather time-consuming. The authors suggest a method substantially simplifying and speeding up the tests and enabling them to be carried out on two specimens.

373. Wagner, W. Philip, "Ice Movement and Shoreline Modification, Lake Champlain, Vermont," Cold Regions Research and Engineering Laboratory, Hanover,NH, Geological Society of America Bulletin, Vol. 81, January 1970.

Measurements and observations of ice movements and shoreline modifications were made in 1968 on Lake Champlain, with detailed study on Shelburne Bay, near Burlington, Vermont. These investigations showed that distinctive ice movements on Shelburne Bay were caused by lake level rises, ice and snow ablation, and ice temperature fluctuations during the period of complete ice cover, and by wind action during ice breakup. Measured ice expansion and contraction movements can be approximated by theoretically considering the ice cover as a uniformly heated plate. Exact agreement between the observed and calculated values was not found, however, due to the complicating effects of snowfalls during ice contractions and varying lengths of the period of temperature increases during ice expansions. Shoreline modification, in particular ice rampart formation, is very limited on Lake Champlain due to the continuous snow cover, the development of numerous pressure ridges, the relatively short period of partial open water, and the weakened condition of the ice during ice breakup. Factors controlling ice-sediment interactions on Shelburne Bay are particle size, steepness of bottom slope, and shoreline configuration. Fine particle size, gentle bottom slope and shoreline configuration. Fine particle size, gentle bottom slope, and shoreline embayments together are associated with unrestricted ice movements and only minor ice ramparts. Relatively straight shorelines with intermediate particle size and bottom slope are most favorable for ice ramparts. Shoreline convexities with relatively steep bottom slope and coarse particle size favor pressure ridges.

374. Wagner, W. P., "Ice Movement and Shoreline Modification, Lake Champlain, Vermont," Geological Society of America, Bulletin, Jan. 1970 81(1), P. 117-126.

Measurements and observations of ice movements and shoreline modifications were made in 1968 on Lake Champlain, with detailed study on Shelburne Bay, near Burlington, Vermont. These investigations showed that distinctive ice movements on Shelburne Bay were caused by lake level rises, ice and snow ablation, and ice temperature fluctuations during the period of complete ice cover, and by wind action during the period of ice breakup. Measured ice expansion and constraction movements can be approximated by theoretically considering the ice cover as a uniformly heated plate. Shoreline modification, in particular ice rampart formation is very limited on Lake Champlain due to the continuous snow cover, the development of numerous pressure ridges, and the relatively short period of partial open water, and the weakened condition of the ice during ice breakup. Factors controlling ice-sediment interactions on Shelburne Bay are particle size, steepness of bottom slope, and shoreline configuration.

375. "We Can Keep Our Harbors Open," The Seaway Review, Vol. 2, No. 1, 1971, 24-26.

Maine engineers who conducted a deicing project at the Port of Duluth-Superior agree that a bubbler system can keep most of the harbors in the Great Lakes - St. Lawrence Seaway open all year long and do it economically. The bubbler used opened up 30 feet of water along two parallel lines melting approximately 400,000 tons of ice and reducing the ice thickness in the surrounding area from 24 to 12 inches. Engineers estimate that bubbler systems can be used in the Great Lakes harbors and connecting waterways at a cost of less than five thousand dollars per mile including installation and materials. It must be pointed out that numerous other problems must be overcome before year-round shipping becomes a reality, particularly Lakes-Seaway system where bubblers can't completely solve the problem.

376. Webb, Michael, "Surface Water Temperature and Ice Regimes of Georgian Bay," Water Resources Research, 8(2), March 1972, 372-389.

Data from 38 airborne radiation thermometer (Art) surveys of Georgian Bay (a part of the Laurentian Great Lakes System) over a 4-year period have been used to determine the areal patterns of surface water temperature and their seasonal variation. Although the limited observational period makes the resulting maps tentative, nevertheless definitive patterns have emerged. Of particular interest are the marked control of surface water temperature by water depth and the influx of cool surface water from Lake Huron during July and August. Ice is found on Georgian Bay from about mid-December through to late April. The areal extent showed wide year to year variation with the maximum area ranging from 40 to 90% of the whole.

377. Weeks, W. F. and Assur, A., "The Mechanical Properties of Sea Ice," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Tech. Memo. No. 92, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851. Ottawa, Canada.

Historical aspects of sea ice strength studies and their underlying philosophy are reviewed. Published results that contain sufficient supplementary information on ice temperatures, salinities and densities to permit an adequate analysis are discussed in detail. The structural aspects of the formation of sea ice are discussed with emphasis on the vertical variation in grain size and the interrelations between growth conditions and the spacing of substructures associated with brine pockets. The development of formal strength models which are a function of the void geometry is outlined. It is shown that both ring tensile and compressive strengths of sea ice are linear functions of the square root of the brine volume while Young's modulus is a linear function of the brine volume. The question of whether the reinforcement of the brine pockets by the precipitation of solid salt causes an appreciable increase in the strength of sea ice is shown to be still unresolved.

378. Weeks, W. F., Assur, A., "Fracture of Lake and Sea Ice," Sept. 1969, 77p. AD-697 750, 175 refs. 25-990, USA-CRREL Research Report 269.

The increased activity in cold regions has made a thorough understanding of fracture in lake and sea ice quite desirable, inasmuch as this information has application to a number of problems of geophysical as well as engineering importance. This survey starts with a discussion of the structure of ice I and the macro- and microstructures of sea and lake ice as well as their chemistry and phase relations. Recent work on the direct observation of dislocations as well as the formation of cracks in ice is summarized. Formal ice-brine-air models for analyzing variations in ice strength are also reviewed. The results of the different types of tests are discussed and compared (compressive, indentation, direct and simple beams, shear and impact). Scale effects are considered as well as the rapid strength deterioration experienced by ice sheets in the spring. Finally, a number of recommendations are made concerning future research in this field.

379. Weeks, W. F., "Studies of Salt Ice, I: The Tensile Strength of NaCl Ice," August 1961, 30p. plus 23p. appends. AD-277 540 Contract DA-11-190-ENG-64 26 refs. 24-3237, USA-CRREL Research Report 80.

Ice samples from fresh water and at salinities ranging from 1 - 22 per mill were prepared in a tank designed to simulate the one-dimensional cooling of natural water bodies. Phase and density relations were computed for these salinities in the

temperature range 0 to -35°C and a determination made of the dependence of ring-tensile strength of the ice samples on temperature, brine volume, $NaCl.2(H_2O)$ volume, and thermal history. The results indicate that the strength of fresh water ice is essentially temperature independent in the temperature range -10 to -30C; the strength of ice containing crystals of $NaCl.2(H_2O)$ in the ice. The strength of salt ice at temperatures between -5C and the eutectric point(1-21.2C) decreases with an increase in the volume of brine in the ice and can be considered a unique function of the brine volume, independent of the individual temperature and salinity values. It is suggested that the strength of fresh water ice should be considered as a limit which is approached but not exceeded by salt ice.

380. Weeks, W. F. and Assur, Andrew, "The Mechanical Properties of Sea Ice," Conference on Ice Pressure Against Structures, National Research Council, Canada, Laval University, Nov. Associate Committee on Geotechnical Research. Tech. Memo. March 1968, No. 92, Ottawa.

Discussion P. 78. For another version of this paper and abstract see 24-3410. Assur, A. 23-4224 ICE STRENGTH, ICE MECHANICS, SEA ICE, SHEAR STRENGTH, ICE CRYSTAL STRUCTURE, TENSILE STRENGTH, ELASTIC PROPERTIES.

381. Weertman, J. "Bubble Coalescence in Ice as a Tool for the Study of Its Deformation History," CRREL, Hanover, N.H., Journal of Glaciology, Vol. 7, No. 50, 1968.

An analysis is made of the rate of bubble coalescence in an ice mass that is deforming. A total strain of at least 8 is required before appreciable coalescence occurs. The analysis has been applied to deforming ice shelves and ice sheets. No appreciable coalescence is expected in ice shelves but coalescence should occur in ice sheets (or glaciers) if the shear strain-rate at the bottom surface is of the order of 0.075/year or larger. Measurements of bubble concentration are capable of setting limits on paleo-strain-rates of the present ice sheets. Bubble migration down temperature gradients presents complications to the study of bubble coalescence.

382. Weertman, J., "Equilibrium Profile of Ice Caps," September 1961, 12p. AD-277-542, 13 refs. 24-3240, USA-CRREL Research Report 84.

Nye's theory of the equilibrium surface profile of a two dimensional ice sheet lying on a horizontal bed is modified to include the effect of the presence of a longitudinal stress. It is shown from 2 sample calculations that for a large ice cap, Nye's theory is satisfactory; for a small ice cap (or the order of 30 km in width) it is important to include the longitudinal stress.

383. Weertman, J., "Rate of Growth or Shrinkage of Nonequilibrium Ice Sheets," August 1964, 16p. AD-449 421, 20 refs. 24-3294, USA-CRREL Research Report 145.

An analysis is made of the time required to build up an ice-age ice sheet and of the time required to destroy such an ice sheet. The calculations are based on the approximation that the theory of perfect plasticity is valid. It is concluded that the time required to build up an ice-age ice sheet is longer than the time required to eliminate it. If it is assumed that the accumulation rate of an ice-age ice sheet lies in the range of 0.2 to 0.6 meter/year, it is found that growth time of a large ice sheet is of the order of 15,000 to 30,000 years. Ablation rates of 1 to 2 meters/year lead to shrinkage times of the order of 2000 to 4000 years, provided ablation occurs over an appreciable area of the ice sheet.

384. Wegmann, E., Design and Construction of Dams, 1922, ed. 7, Wiley, New York 535pp.

P. 160. Quaker Bridge dam is designed to resist an ice thrust of 43,000 lbs per lineal foot. P. 194. Washusett dam will resist an ice pressure of 23.5 tons per lineal foot. P. 203-4. Cross River dam designed to resist ice pressure of 24,000 lbs per lineal foot, Croton Falls dam, of 30,000 lbs.

385. Weller, G., "Heat-Energy Transfer Through a Four-Layer System: Air, Snow, Sea Ice, Sea Water," Journal of Geophysical Research, Vol. 73, No. 4, 1968, pp. 1209-1220.

The heat-energy transfer through a four-layer system of air, snow, sea ice, and sea water is determined numerically, and the optical, thermal, and composition properties of the solid layer are discussed. The annual sea ice investigated was close to the Australian National Antarctic Research Expedition station of Mawson. The observation was made over a period of five months from the middle of June to the middle of November 1965. Net long-wave radiation losses through the surface of the sea ice are high to balance a large heat flux from the water below; they exceed 140 cal cm^{-2} day^{-1} in November. The disappearance of the snow cover over the ice in summer results in a crop of the albedo from 75 to 37% and allows a large amount of short-wave radiation to be absorbed by the ice. This results in changes in heat storage in the ice and a considerable increase of the conducted heat flux at the upper boundary as summer approaches. It is shown that consideration of the effects of absorbed radiation is essential in heat budget studies in transparent bodies of finite thickness. Idealized curvature characteristics of measured wind and temperature profiles are used over the sea ice to compute the eddy heat flux with neutral or near-neutral stability representing the average condition.

386. Wiegel, R. L., "Ship Mooring Literature Survey," Series 91 and 92, Issue 2, August 1955. University of California, Berkeley AD 74530.

Presented herein are summaries of over fifty papers on various phases of the general problem of mooring a ship subject to wave or surge action.

387. Wiegel, R. L., Dilley, R. A., Clough, R. W., Williams, J. R., "Model Study of Ship Mooring Forces," Final Report, Series 92, Issue 8, August 1956. University of California, Berkeley, AD 114763.

Presented herein is a discussion of the problem of wave-induced forces on ships moorings, together with the details of a study of four ship models, each with a different mooring system. The resulting mooring line and mooring fender forces are given. In addition, the correlations between prototype and model natural periods of surge and sway for an AFDL (Floating Drydock) are given.

388. Wijngaarden, H. van, "Investigations Concerning the Transport of Heat Through a Solid Sheet of Ice in Periods of Frost and Thaw," Int. Assoc. of Sc. Hydrol., General Assembly of Helsinki, 1960, Publ. No. 54, pp. 40-55.

Within the scope of investigations of factors having influence on the appearance and the disappearance of ice on the branches of the River Rhine in the Netherlands, it is important to pay attention to the heat-transport through a solid ice-sheet. Investigations were done to determine to what extent the heat transport through a solid ice-sheet was influenced in the time of frost and thaw by the presence of coal-dust on the surface of the ice-sheet.

389. Williams, G. P., "Frazil Ice, A Review of Its Properties with a Selected Bibliography," The Engineering Journal, Nov. 1959.

This report reviews the theory of frazil ice formation and the main factors which cause formations. The methods of forecasting frazil ice and the design and remedial considerations are also included. Although the frazil problems has been solved at many sites in Canada, this review summarizes investigations which would not generally be available to Canadian engineers.

390. Williams, G. P., "An Empirical Method of Estimating Total Heat Losses From Open-Water Surfaces," IAHR 8th Congress Montreal, 1959, Sem. I, pp. 10-SI-1-5.

This report presents some information on the heat losses from the surface of a tank of water, 10 ft in diameter, exposed to various atmospheric conditions. A comparison of experimental observations with various empirical formulae has been made.

391. Williams, G. P., "Some Observations on Super-Cooling and Frazil Ice Production," IAHR 8th Congress Montreal 1959, Sem. I, pp. 9-SI-1-3.

This report presents some laboratory investigations of the factors that determine the super-cooling of water during frazil ice formation.

392. Williams, G. P., "Thermal Regime of Lakes and Rivers with Reference to Air Bubbling Systems," Proceedings of the Symposium on Air Bubbling, Ottawa, May 11, 1961.

The thermal in lakes and rivers at a potential site for an air bubbling installation can be calculated with sufficient accuracy if water temperature profiles are measured, if the water depth is determined, and if the area of influcence of the air bubbling unit is known. The heat losses to be expected can probably be estimated with sufficient accuracy if air temperature can be predicted and the thickness of the ice to be melted is known. In many cases where the thermal reserve is adequate, a detailed knowledge of the heat available and the heat losses to be expected is not necessary. Where the thermal reserve is likely to be critical at a particular site, calculation of the expected hear balance during the operation of an air bubbling system should be made to determine whether the system will be successful.

393. Williams, G. P., "Freeze-Up and Break-Up of Fresh Water Lakes," Ice Pressures Against Structures, Proceedings of a Conference held at Laval University, Quebec, 10-11 November 1966, Compiled by L. W. Gold and G. P. Williams, March 1968, NRC No. 9851, Technical Memorandum No. 92, Ottawa.

In this paper, sheet ice formation, growth and melt of freshwater lakes is described. The problems connected with estimating the date of freeze-up, maximum ice thickness, and estimating the date of break-up of fresh water lake ice are discussed. It is shown that there are two approaches to these types of problems: (a) to develop formulae based on physical principles, or (b) to make an analysis of past records to give statistical limits within which maximum ice thickness or freeze-up or break-up can be expected to occur. The comparative usefulness of the two approaches is discussed.

394. Wilmot, J. G., "Investigation of Ice Pressure on Dams," First report on measurement of coefficient of linear expansion of artificial and natural ice. Ontario Hydro-Electric Power Commission, Research Division. Report No. 56-392, Aug. 1956, 41 pp.

The initial results of laboratory determinations of the coefficient of linear expansion and pertinent mechanical properties of ice designed to be used as parameters in an as-yet-undeveloped buckling equation to determine the end thrust applied by an ice sheet to dams and shores are reported, and

data are tabulated and graphed. The specimens tested included 2 samples of natural ice cut perpendicularly to the surface of an ice sheet and 1for artificial ice, the specimens being in the form of cylinders 10 in. in diam. and 4 in. thick. Ice temperatures were measured by embedded thermocouples and strains by means of bonded resistance strain gages embedded diametrically near the surface of the samples, with a temperature correction being applied to the gage output. The average coefficient of linear expansion of the first sample of natural ice subjected to 1 temperature from 32° to -33°F was 31.2×10^{-6} per degree F during temperature decrease and increase, while for the 2nd specimen, which was subjected to 2 temperature cycles, expansive drift averaging 57 μ in./in.-hr. precluded the use of the results. The cause of this drift was not determined. For artificial ice subjected to 4 consecutive temperature cycles from -30° to +30°F the coefficient increased from $24.8\text{-}29.0 \times 10^{-6}$/degree F during periods of temperature decrease, and remained practically constant at 33.7×10^{-6}/degree F during periods of temperature increase. Reference not in Engineering Societies Library and not verified.

395. Wilson, George E., "Season Extension for America's Fourth Coast," The Seaway Review, Vol. 1, No. 4, 1970, 5-9.

This is a summary of various projects being conducted by govern ment and private industry into extending the shipping season on the Great Lakes and St. Lawrence Seaway with the hope of eventually being able to extend it to year-round operation. There is also mention of laws passed by the U.S. government dealing with the Seaway. Finally there is mention of the economics benefit that can come from an extended shipping season.

396. Wilson, George E., "The Seaway Development Corporation," The Seaway Review, Vol. 2, No. 2, 1971, 20-22.

This paper give a report on what the Seaway Corporation and the U.S. Government are doing to help extend the shipping season on the Great Lakes and St. Lawrence Seaway.

397. Wilson, J. T., Zumberge, J. H., and Marshall, E. W., (1954) "A Study of Ice on an Inland Lake," USA SIPRE Report 5, 78p. AD-043 143 refs. Michigan University. Research Institute 24-3004.

The final report is given on laboratory and field studies on ice of both small and large lakes in the Great Lakes area during 1950-53. The 3 main topics discussed are: development of a genetic classification of lake ice; studies of the crystallinity of lake ice from the descriptive and genetic viewpoints; and the thermal push of an ice cover. The 2 main types of ice cover occurring in the area are classified as sheet and agglomeritic ice. Four ice textures were identified: granular, columnar, porphyritic, and tabular. Ice push on Wamplers Lake (SE Mich.) amounted to about 2 ft each winter, averaging 2 in each cycle.

398. Wortley, C. Allen, "Lake Superior Marinas Resist Ice and Snow," Civil Engineering, ASCE, February 1972.

Consulting engineers faced special problems designing two yachting marinas for the Apostle Islands area in southwestern Lake Superior. Subzero weather during the winter months required special piling that would not be wrenched out of the lake by ice. Sleeved piles were used and a dock de-icing system was installed. Materials specified were rugged but attractive and were chosen to blend into the rustic setting. The projects both helped boat owners and created jobs in a high-unemployment area.

399. Yamaoka, Isao., "Estimation of Incipient Ice Cover Formation Date of Reservoirs in Hokkaido by Use of a Time Series of Daily Accumulated Air Temperature," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

As a first step towards understanding the annual variation in date of incipient ice cover formation in relatively large reservoirs in Hokkaido, the author presents an estimation method of annual date above mentioned by use of a discrete time series of daily accumulated air temperature Da and the linearly correlated relation of surface water temperature Tw to Da. The relation $Ts = \alpha Da + \beta$, was derived in an elementary manner based on the convection boundary condition of heat transfer problems. The constant was obtained as 0.031 (hr^{-1}) by using five years data in 1964-1968 observed in two reservoirs in the middle part of Hakkaido. The constant D represents the quantity Ah/mcp where h is the heat transfer coefficient.

400. Yang, L. C. and Good, W. B., "Crystallization Rate of Supercooled Water in Cylindrical Tubes," Journ. of Geoph. Res., 71, 1966, nr. 10, May, pp. 2465-2469.

The rate of crystallization of supercooled water in cylindrical tubes is determined. It is found that the rate depends on the tube diameter, on the degree of supercooling, and on the thermal conductivity of the wall, but in no simple way. The various ice structures observed during the experiment are reported, along with their possible correlation with the observed growth rates.

401. Yen, Yin-Chao, and Galea, Francis, "Onset of Convection in a Water Layer Formed Continuously by Melting Ice," The Physics of Fluids, Vol. 12, No. 3, March, 1969, 509-516.

The onset of convection, in a water layer continuously formed by melting ice from above, has been obtained by the experimental determination of the water layer depth d at which the mode of heat transfer changes from conduction to convection. This was accomplished both by determining the time at which the

temperature profile of the water layer started to deviate from linear distribution and by locating the inflection point in the curve relating water-ice interface position and time. Experimental values of d (either for melting from above or below) were found with a mean deviation of 14.1% from those by theoretical analysis of a similar problem. From the present and previous investigations (Phys. Fluids 11, 1263, (1968)), it can be concluded that the critical Rayleigh number for a horizontal layer of fluid with a density inversion is not a single value as for a normal fluid with a monotonic density-temperature relationship, but varies with boundary temperatures.

402. Yen, Y. C., "An Analytical and Experimental Study of a Melting Problem with Natural Convection," July 1967, 8p. AD-659 780 4 refs. 24-3374. USA-CRREL Research Report 234.

The correlation by O'Toole and Silverston (1959) of natural convection heat transfer for fluids confined between two parallel horizontal plates has been extended to the case involving phase change. The new correlation, which is applicable for melting from below in a water-ice system, is described with special focus on theoretical considerations, estimation of heat flux, and the experimental and analytical results. In all experiments, bubble-free, homogeneous ice samples were prepared beforehand to assure reliable and reproducible results. In general, the results from theory and experiment are in close agreement.

403. Yen, Y. C. and Tien, C., "An Analytical Investigation of a Modified Stefan Problem," March 1966, 15p. AD-633 489 6 refs. 24-3332. USA-CRREL Research Report 185.

Approximate solutions of temperature distribution and melting rate of ice have been obtained for the case where the mode of heat transfer is natural convection due to the thermal instability caused by the heated lower surface. Extensive numerical solutions were obtained for the ice-water system corresponding to various thermal conditions in terms of the temperature of the heat source, the melting point of ice, initial ice temperature, latent heat of fusion, and heat capacity of ice.

404. Yen, Y. C., Tien, C., Sander, G., "Experimental Study of a Melting Problem With Natural Convection," International Heat Transfer Conference, 3rd, Aug. 7-12, 1966 Chicago. Proceedings, Vol. 4, N.Y. American Institute of Chemical Engineers, 1966 p. 159-166. In English with German and Russian summaries. 13 refs. 25-2699. Miscellaneous Publication 516.

An experimental technique has been successfully developed to study the effect of natural convection (thermal instability) on the melting rate of ice. Reproducible results were obtained by using homogeneous, bubble-free ice samples for the melting process. The problem of volume change due to phase transition or separation of the ice-water interface encountered when melting from below was solved by continuously adding water at the

same temperature as the constant temperature bath which supplied heat for melting. Under certain temperature conditions irregularities in the interface, a result of convective motion, became very apparent and could be observed by visual means. By periodically measuring the amount of water added and varying the initial temperature of the ice sample and that of the heat source extensive results were obtained.

405. Yen, Y. C., Odar, F., Bracy, L. R., "Impact of Spheres on Ice," American Society of Civil Engineers. Journal of Engineering Mechanics Division. Oct. 1970, p. 641-652 25-2241.

An oscilloscopic method for determining the coefficient of restitution, e, by impact of spheres on ice was developed. Teflon, acrylic, nylon, and steel spheres having 1/4 in., 1/2 in., 3/4 in., and 1 in. diam. were used. The experiments were conducted at -1C, -10C and -20C, respectively. With the exception of Teflon spheres, the coefficient of restitution is found to decrease with the diameter of the sphere and increase as the temperature is lowered. All the data can be well represented by an exponential expression in terms of impact velocity V(i) in a form of e equals A exp (-B V(i) with correlation coefficients in the range of 0.91 to 0.99. The occurrence and extent of ice cracking were found to depend on the sphere material, diameter, temperature, and impact velocity.

406. Yen, Y. C. et al, "Laminar Heat Transfer Over a Melting Plate - The Modified Leveque Problem," January 1964, 10p. plus appends. USA-CRREL Research Report 125.

Heat transfer in a system consisting of a fluid flowing over a melting plate composed of the same material as the fluid was investigated. The test model is similar to the heat transfer phenomenon occurring when an iceberg drifts in warm sea water. The flow of a liquid, initially at a uniform temperature, over a flat plate composed of the solid phase of the flowing liquid at constant temperature was assumed. For simplification of subsequent analysis the flow was stipulated as the Leveque type. The temperature distribution in the flowing fluid is determined; melting at the interface is shown to result in a decrease in the Nusselt number; consideration is given to the practical application of the results; and a simple numerical calculation of the melting rate of ice is given.

407. Yen, Y. C., "Natural Convection in Ice Melting from Below," December 1966, 13p. USA-CRREL Research Report 211.

An experimental technique has been successfully developed to study the effect of natural convection (thermal instability) on the melting rate of ice. Reproducible results were obtained by using homogeneous, bubble-free ice samples for the melting process. The problem of volume change due to phase transition

or separation of the ice-water interface encountered when melting from below was solved by continuously adding water at the same temperature as the constant temperature bath which supplied the heat for melting. Under certain temperature conditions irregularities in the interface, a result of convective motion, became very apparent and could be observed visually. By periodically measuring the amount of water added and varying the initial temperature of the ice sample and that of the heat source, extensive results were obtained demonstrating the effects of these temperatures on the melting rate which could be expressed in terms of dimensionless parameters. The results from this experimental investigation are compared with those obtained from an analytical solution of the same problem.

408. Yen, Y. C., "Thermal Instability in a Layer of Water Formed by Melting Ice From Below," March 1969, 12p. AD-686 283, 10 refs. 24-3395, USA-CRREL Research Report 263.

The transition in the mode of heat transfer from conduction to convection in a layer of water formed continuously by melting ice from below has been determined experimentally. This was accomplished by locating the inflection point on the curve relating the water-ice interface (or melting front) and time. Thus, the critical Rayleigh number at which convective heat transfer started can be correlated empirically as a function of warm plate temperature between 7.72 and 25.50C. The initial ice temperature was varied from -4.8 to -22.00C, and its effect was found to be insignificant. Homogeneous, bubble-free ice was prepared and used in all the experiments.

409. Zajac, A. (1958) "Thermal Motion in Ice and Heavy Ice," Journal of Chemical Physics, Vol. 29, p. 1324.

Changes with temperature of x-ray intensities of the 001 reflections in ice and heavy ice are investigated. From these the amplitudes of thermal motion of oxygen and hydrogen atoms are determined separately. This can be accomplished since only hydrogen atoms contribute to the 004 reflection. The thermal amplitudes of the oxygen atoms, which represent molecular amplitudes, can be expressed in terms of a constant Debye characteristic temperature; 224°K for ordinary ice and 237°K for heavy ice. The amplitudes of thermal vibration of the hydrogen and deuterium atoms as derived from absolute intensities of 004 at various temperatures, cannot be expressed in terms of a characteristic temperature. They consist of superimposed stretching, bending and librational motions. In addition to these a rotational motion of low zero point energy seems to be present.

410. Zhydkykh, M. I., "Calculation of Flow Velocity in the Operative Zone of Pneumatic Installations Used for Ice-Fighting," IAHR Ice Symposium, Reykjavik, Iceland, 1970.

In this work are given analytical dependences for calculating the velocities of circulating flows originating in the basins with stagnant waters due to the working pneumatic installations.

SUBJECT INDEX