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ICE FORMATION ALONG THE ALASKA HIGHWAY

(In Abstract)[1]

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SYNOPSIS

Climatic, drainage and topographic conditions in subarctic regions as along the Alaska Highway cause ice formations that will invade the roadway surface in winter unless prevented. These formations are the result of water from seepage, springs, small streams, creeks and rivers emerging to the exposed surface where it spreads in thin film layers and freezes. Surface disturbances resulting from highway construction intensify this action.

It is impracticable to prevent icing entirely, and it is a difficult but performable task to keep the ice formations from invading the roadway where they are a hazard to and may stop traffic. During the winter of 1943–44 practices in ice control were developed and used to keep the road surface open to traffic throughout the winter.

Methods used and the various factors affecting ice formation are discussed. The influence of these factors on location, design, construction methods, and subsequent maintenance are pointed out.

The Alaska Highway extends from Dawson Creek, British Columbia, to Fairbanks, Alaska, a total length of 1,520 miles. Twelve hundred and twenty miles of the main highway is in Canada and 300 miles is in Alaska. Elevations range from 1,000 ft. above sea level at the Muskwa River near Fort Nelson to 4,251 ft. at the summit, 90 miles west of Fort Nelson. Most of the highway lies between elevations of 2,000 and 3,000 ft. It extends from about latitude 56° to 64° North and from about longitude 120° to 146° West. The area traversed is hilly or mountainous and for the most part is thickly timbered but the trees are generally too small to be of commercial value.

The highway was built during the period from March 1942 to November 1943. In 1942 seven regiments of U. S. Army Engineers, and 47 civilian contractors employing about 7,500 men working under the direction of the Public Roads Administration pushed through a pioneer road. Streams were bridged with temporary timber trestles not expected to withstand the spring break-up. The engineer troops were withdrawn from the highway before the beginning of the 1943 construction season with the exception of two companies that remained until July. Most of the permanent bridges required and an all-season gravel road suitable for heavy trucking were constructed during 1943 by 81 contractors employing about 14,000 civilian workers. These forces were directed by the Public Roads Administration.

[1] Reported more fully in *Public Roads*, January–February–March, 1945.

REGION OF THE HIGHWAY HAS A SEVERE WINTER CLIMATE

The climate of the region traversed by the highway is classed as the subarctic and is characterized by relatively short and wet summers and long, cold, and dry winters. Spring and fall are short, inconspicuous seasons. Table I gives a comparison of the climate along the highway with other better-known places.

Figure 1 shows normal mean monthly temperatures along the route of the highway based on records of 5 years or more and compares these data with that for the past two winters. It will be noted that the maximum mean temperature variations occurred during the winter months. This condition seems to be typical for subarctic climates. Temperatures are apt to fluctuate widely during the same winter and from one winter to the next.

TABLE I
CLIMATOLOGICAL DATA

Place	Temperatures			Mean Annual Precipitation (Water)
	Mean Annual	Maximum	Minimum	
	°F.	°F.	°F.	*Inches*
Along the Alaska Kighway:				
Fairbanks, Alaska	26	99	−66	11.8
Tanacross, Alaska			−76	
Whitehorse, Y. T.	27	84	−69	11.4
Fort Nelson, B. C.	30	98	−54	13.9
Fort St. John, B. C.	35	105	−65	15.7
Off the highway:				
Yellowstone Park, Wyo.	39	97	−66	20.4
Bismarck, N. Dak.	40	114	−45	16.3
Denver, Colo.	50	105	−29	14.1
New York City, N. Y.	52	102	−14	43.0
Los Angeles, Calif.	62	109	28	15.2
Miami, Fla.	74	96	27	55.7

PHENOMENA OF ICING

The type of ice formation described in this report is called icing and may be defined as the formation of ice in such a manner that its thickness and area are continually increased.

When thin films of water are exposed to very low temperatures such as are common along the Alaska Highway in the winter, a very rapid build-up of ice may occur. The mass which forms in icing action has the appearance of a heavy viscous liquid in motion. The formation of ice in relation to the supporting earth is much the same as that of a lava flow, although the methods of formation are entirely dissimilar (see Fig. 2). Small obstructions or restrictions in the channel cause the ice to dam up in its downstream progress.

Generally speaking, icing cannot be prevented entirely by any method that is reason-

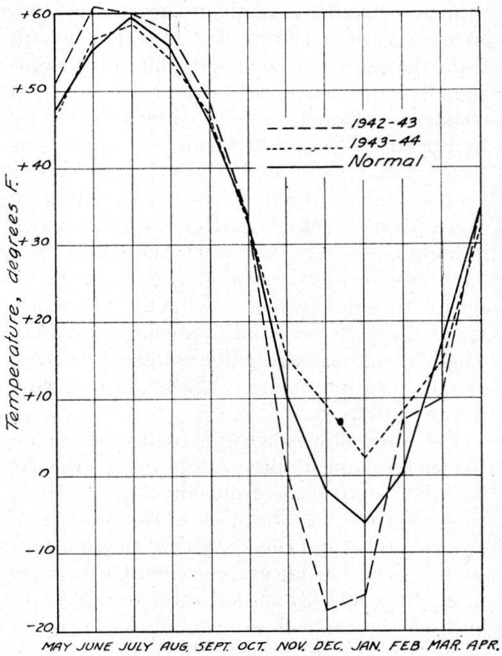

Figure 1. Mean Monthly Temperatures on the Alaska Highway Based on Records at Fort St. John, Fort Nelson, Watson Lake, Whitehorse, Northway, Tanacross, Big Delta, and Fairbanks.

Figure 2. Ice formation, by icing of a small stream, preceding the Culvert. The arrow indicates the culvert entrance.

able in cost but under certain conditions it may be controlled so as not to interfere with the use of the highway. It is important to know what causes the water to emerge on the surface in thin films, since once it emerges icing will result if the temperature is low enough. In the area of the Alaska Highway the temperatures are generally below freezing throughout the winter and the surface insulation in the form of snowfall is generally light.

Ice forms on the surface of water in normal drainage channels and the water continues to freeze downward from the surface, inward from the sides of the channel, and even occasionally upward from below. Ice may so constrict a channel that the water is forced by hydrostatic pressure to break out on the surface. Constriction to flow of subsurface water occurs similarly if not sufficiently insulated by earth cover, vegetable matter, moss and snow.

Icing can occur only when the latent heat contained in surface emerging water is transferred to some colder medium. There are three methods of heat transfer—radiation, convection, and conduction—and all of them are important in icing. These are discussed in the full report.

The water flow which eventually emerges on the surface and results in icing on or near the highway, may come from any one or all of three sources: (1) Surface water flowing in rivers, creeks, and small streams, the source or sources of each being at a considerable distance from the icing; (2) spring water from fissures and porous strata flowing to the surface at a definite place on or near the highway, and; (3) percolating water or seepage from muskeg swamps, talus slopes, alluvial fans, seams between strata of ledge rock, and sloping ground with a heavy vegetal cover.

The term "seepage" is used here in a limited sense to describe water surfacing on or near the highway that does not have a single discernible surfacing place. The term "muskeg swamp," as used in the region of the Alaska Highway, refers to any basin which does not readily drain and which is filled with saturated muck, fine silty soil, decayed vegetation, and has a heavy ground cover of moss, grasses, and low-growing bushes. There are frequently scattered growths of stunted trees on these areas. These swamps frequently occur on hillsides between ridges, where, in spite of the slope, the muck and vegetation retain a high concentration of water. Frequently, the subsoil in these swamps is permanently frozen.

ICING PROBLEMS AT RIVER CROSSINGS SOLVED

During the winter of 1942–43 the most serious icing conditions, from the standpoint of travel, developed at some of the rivers and larger streams which were crossed at low level on temporary timber trestles. It was evident at that time that the permanent bridges should be placed above any possible ice formation, and the designs for the permanent structures were prepared accordingly.

During the 1943–44 winter, after the permanent crossings had been constructed, no trouble was experienced at any of these locations.

ICINGS CLASSIFIED

Icings along the Alaska Highway may be divided into two classes.

Natural Icings.—These would develop normally regardless of road construction. They occur as follows:

(1) In glacial rivers and creeks and in streams on alluvial fans, where the nature of the channel is such that little protection from freezing is afforded the flow. Relatively steep gradients are a factor, since channels under the ice become constricted by continued freezing, and water is subjected to considerable hydrostatic head, often breaking through the ice cover and spreading out on the surface. Icing is always worse in a wide, shallow, gravelly channel with a steep gradient than in a deep, narrow, low-velocity stream having a heavy overhanging growth of vegetation along the banks.

(2) Where seepage and subsurface water flows from springs that reach the surface near the base of a hill or mountainside. Wherever water emerges in small quantity it is sure to freeze. The additional exposure at the roadway with the resulting greater depth of frost penetration may be a factor in forcing the flow to the surface. However, it has been noted that ice frequently forms where water emerges at locations remote from any influence of the highway construction.

(3) At light surface flows down steep watercourses. Here the flow is spread out thinly to give maximum exposure to the atmosphere and loss of heat by radiation.

Artificial Icings.—These are caused or promoted by the road construction. They occur as follows:

(1) At seeps and springs intercepted by highway excavation. Springs are more apt to be found at considerable depths and therefore are likely to continue active all winter. Seepage

flows most often appear in the lower part of or immediately under a heavy vegetal ground cover. With prolonged periods of cold weather and only a light snow cover, these seepage flows may freeze up before they reach the roadway and become inactive.

(2) At crossings of small streams where the additional exposure created by the construction promotes the formation of ice. These are narrow, deep, low-velocity streams with heavy vegetation on banks which normally do not ice without being disturbed or altered—at least not at the point crossed by the highway.

Culverts and bridges are invariably placed under or in fill materials of high heat conductivity, and snow covering on the road surface is removed by maintenance forces, affording opportunity for heat loss greater than in the original channel. The normal, protected channels are necessarily disturbed within the limits of the construction operations and may even be unnecessarily obliterated or obstructed in these operations. Icing may be started by freezing in a culvert or under bridges or at a disruption or obstruction of the normal drainage channel.

(3) At highway fills where subsurface flows are forced to the surface by a damming action. This may result from additional compaction but more often removal of protective cover in construction and maintenance of the highway permits frost to penetrate much more readily and thus create a "frost dam." Considerable icing occurred where very light fills were placed.

CONDITIONS UNDER WHICH MAJOR ICINGS OCCUR ANALYZED

In the study of icing conditions along the Alaska Highway during the winter of 1943–44 the highway was divided into two sections, since one man could not travel and inspect icings on the entire highway with sufficient frequency, even though the highway could be traveled without difficulty throughout the winter. One section extended 913 miles from Dawson Creek to Whitehorse. The other section included the 509 miles to Big Delta, approximately 100 miles from Fairbanks.

At 92 places between Dawson Creek and Whitehorse the icing was active enough to constitute a considerable maintenance problem and was classified as major. There were 34 such places between Whitehorse and Big Delta. In addition, there were 57 places between Dawson Creek and Whitehorse and 38 between Whitehorse and Big Delta where minor icing activity occurred. Observations of all these icing points were made on various inspection trips during the winter. Information on icing activity and maintenance methods used were obtained by detailed inspection and by discussion with the maintenance men and from written reports prepared by them and by officials. In the spring after the snow and ice had largely disappeared a close inspection was made of the drainage conditions and other features at each of the major icing points.

Practically none of the icings observed could be attributed wholly to a single circumstance or condition. More than half occurred where natural conditions would have produced some icing had they been left undisturbed but the amount of icing was greatly increased as a result of disturbance in construction of the highway.

Natural and Artificial Conditions.—At 65 per cent of the icings the natural slope of the drainage channel was conducive to icing and 49 per cent of the icings formed where subsurface flow emerged naturally near the foot of a hill or mountain. Increased exposure of water to freezing by removal of ground cover or alteration of channels in construction of the highway contributed to over 90 per cent of the icings.

The original natural drainage channels at the roadway were classified as follows: 13 per cent good, 37 per cent fair, 31 per cent poor, and 19 per cent were not classified, of the constructed drainage channels at the roadway, 2 per cent were classed as good, 27 per cent fair, 46 per cent poor, and 25 per cent were not classified.

Source of Water.—Flow of water to points of icing sometimes came from more than one source. Percentages of icings by water sources were as follows:

	per cent
Creek	6
Small stream or branch	54
Spring	14
Seepage	44

Icing occurs in a natural channel when it is wide and shallow, has little protection by vegetal growth, and a fairly steep gradient or a sudden change in gradient. Near the foots of hills and mountains subsurface flows tend to be forced to the surface and icings are likely to occur at such places.

At practically every icing the greater exposure resulting from construction of the highway has been a factor.

Streams from about 1 to 4 ft. wide and from 3 to 12 in. deep and seeps are the principal sources of water causing major icing. In most cases the small streams originate in springs or seep from muskeg areas or from under a heavy mat of ground cover. Seepage most often emerged near the tops of cut slopes. A heavy protective layer of moss and vegetal debris and sometimes snow prevented the water from freezing before reaching the highway. This cover not only protected the water from freezing in winter but in summer it prevented lowering of the level of permafrost.

Road Location.—Terms descriptive of road location are applicable at points of icing as follows. At some locations two terms are applicable.

	per cent
Across flats and at a considerable distance from a hill or mountainside	21
Rolling, irregular grade	34
Sidehill cut and fill	30
At or near foot of hill or mountainside	33
Miscellaneous	27

The cross slopes at the major icing locations are grouped as follows:

	per cent
Nearly flat	20
Light, up to 15 deg	45
Heavy, over 15 deg	35

These data on road location and on cross slope at icings indicate that there is less of a tendency toward icing where the highway is located on relatively flat ground. Conversely, a fairly steep watercourse gradient is conducive to icing.

Subgrade Soil.—Considering the length of the entire highway, 43 per cent was located on soils classed as better than A–3–4. These better subgrades were mainly A–2, A–2–3, A–2–4, A–2–7, A–2–3–4, rock and gravel. The subgrades worse than A–3–4, found on 57 per cent of the highway, were classified as A–4–7, A–5–7, A–7, A–4–6, A–2–4–6, A–4, A–6–7, A–8, and A–4–6–7.

The distribution of points of icing as to character of soil was as follows. A few places had two types of soil and were placed in two classifications.

	per cent
Sand, sand and gravel, rock	45
Silt with some sand or gravel	23
Silt with little or no sand or gravel	9
Clay with some sand or gravel	11
Clay with little or no sand or gravel	9
Silt and organic soil, A-5, A-8	11

These data indicate a tendency for ice to form where the subgrade material is of the more porous or granular type. Obviously such soil is better able to carry subsurface water and is most commonly deposited along stream courses.

Type of Culvert.—On the entire highway 66 per cent of the culverts were made of wood and 34 per cent were metal. The points of icing were distributed as follows:

	per cent
Wood culvert	46
Metal culvert	40
Both wood and metal culverts	13
No culvert	1

It has been suggested that wooden culverts, because of their better insulating properties, might have less tendency than metal to cause freezing in the winter. Observations do not indicate that either material is superior to the other in this respect.

Ground Cover.—Practically the entire region of the Alaska Highway below the timber line is covered with a thick mat of moss and vegetal debris. With regard to thickness of ground cover the points of icing were distributed as follows:

	per cent
Heavy, over 12 in.	72
Medium, 6 to 12 in.	25
Light, 6 in. or less	2
None	1

Months of Icing Activity.—During the winter of 1943–44 major icings were active as follows:

	per cent
November	31
December	62
January	76
February	75
March	54

PERMAFROST A FACTOR IN PROMOTING ICING

Permafrost is permanently frozen ground, or ground in which the temperature remains below freezing throughout the year. If the ground contains enough moisture, the soil particles will be bound together in a hard, impermeable mass. If little moisture is present, the materials may be loose even though the temperature remains below freezing. Along the Alaska Highway all permafrost observed had a high ice content.

There was a decided tendency for icing to occur on areas of permanent frost because it kept subsurface water flows in position for frost dams at the highway to make the water emerge to the surface.

ICING MOST ACTIVE IN JANUARY AND FEBRUARY

Formation of ice was most active in January and February. Figure 1 shows that the minimum mean temperature was reached in January, but there was little recession in icing activity until about a month after the mean minimum temperatures had been passed.

DEEP SNOW PREVENTS ICING

Over most of the highway icings occurred at fairly regular intervals wherever the depth of snow cover was less than 15 in., and water flows were of a character conducive to icing; but did not occur when the snow cover exceeded this amount.

ELEVATION AFFECTS BOTH TEMPERATURE AND EXTENT OF ICING

The maximum mean winter temperature during the winter of 1943–44 occurred at elevations of about 2,300 ft. Mean temperatures were appreciably lower at elevations both above and below this level.

The greatest frequency of active icing was at elevations above 2100 ft.

That the greatest frequency of active icing was found at elevations above 2,100 ft. may be explained by the following conditions:

(1) At the higher elevations the topography is more rugged and the water flows intercepted by the highway, although smaller, are more numerous.

(2) Water flows having steep gradients are more subject to icing and at the higher elevations the watercourses are naturally steeper.

(3) Temperatures during the winter, while averaging higher than at the lower elevations, are apt to fluctuate more widely.

That the greatest frequency of active icing occurred at elevations above 2,100 ft. while the lowest mean temperatures were found below that elevation is not in agreement with the general observation that icing activity varies inversely with temperature, the period of greatest icing activity lagging somewhat behind the lowest mean temperatures. It is possible to rationalize these two conditions by considering that icing, to a very large extent, depends upon the flow of water and also upon the temperature. Other things being equal, for maximum icing there must be a maximum flow of water coupled with low temperature. However, when the temperature consistently remains very low, the flow of water is inevitably decreased which in turn decreases the icing. This decrease in flow is bound to lag considerably behind decrease in temperature whereas an increase in icing activity takes place immediately after the temperature drops.

VARIOUS METHODS USED TO PREVENT OR ALLEVIATE ICING

It is impracticable to prevent icing entirely, but there are steps that may be taken in locating, designing, and constructing a highway to reduce or even eliminate the necessity for control of the icing during the winter. Certain locations are most apt to be subject to icing and these locations should be avoided if possible. Generally it will be impossible to avoid all such locations and where they cannot be avoided certain procedures should be adopted to reduce the winter maintenance. This work can be done during initial construction but may also be done by maintenance forces after the location of the most active icing points has been determined by experience. Only a careful study at each icing point will indicate the best methods to use. Records of past activity at any particular location will help to determine how much preventive work is justified.

Procedures in use on the Alaska Highway or suggested by observations on the highway are:

1. Improvement of drainage channels and structures.
2. Installation of numerous and large drainage structures.
3. Raising the roadway grade.

4. Construction of dikes to confine the flow within certain channels.
5. Construction of subsurface drains.
6. Construction of basins for formation and storage of ice, either at the roadway or some distance upstream.
7. Construction of diversion dikes and ditches.
8. Stripping areas across watercourses and seepage areas to induce icing away from the highway when winter starts.
9. Construction of dikes to act as storage dams for ice formation.
10. Location of highway wherever possible on higher ground across flats and at considerable distance from a hill or mountain side—avoid side-hill cuts wherever there is or may be subsurface water.

CONTROL MAINTENANCE NECESSARY IN ADDITION TO PREVENTIVE MEASURES

Where all reasonable ice-preventive measures have been taken in the location, design, construction, and summer maintenance of the highway it may still happen that, as the winter progresses, ice may threaten to invade the road surface. Some method of direct control must then be applied. The primary purpose will be to keep ice from forming on the road surface where it would interfere with the normal use of the highway. Three general methods were followed in control of the icing on the Alaska Highway during the winter of 1943–44:

(1) Heating the flowing water by artificial means to prevent its freezing. This was done in locations near the highway.

(2) Periodic removal of the ice formed, usually by mechanical means, but sometimes by melting the ice using artificial heat.

(3) Periodic construction or opening up of drainage channels to carry the flow which would otherwise result in icing. This was more easily accomplished by use of a steam jet to thaw channels. This method appears to be the most efficient but under certain conditions it may be necessary to resort to other methods.

EFFECT OF VIBRATIONS ON THE BEARING PROPERTIES OF SOILS

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SYNOPSIS

The paper reports facts of practical and theoretical importance established to date during a study of the effect of vibrations on airport pavement performance which is being carried out for the Technical Development Division of the Civil Aeronautics Administration by the Soil Mechanics Laboratory of Princeton University. A brief summary is given of the limited amount of published work previously performed elsewhere concerning the effect of sustained vibrations on soils. Special features presented by the vibrating system plane-tire-pavement are briefly discussed. The vibration studies in progress at Princeton are outlined.

The findings are explained by which it was demonstrated that controlled strain load tests or CBR tests cannot be applied to the study of vibration effects. The results of a completed series of small-scale controlled stress 2-in. and 5-in. diameter plunger tests on a well graded sand are reported. These tests were performed at frequencies below the established resonance range of the vibrating systems. Diagrams are given showing the relationship between observed plunger penetrations and the time of vibration; also the relationship between the relative density, the saturation conditions of the sand and the observed plunger penetrations under static and dynamic loading. Comparisons are made between the observed effects of a dynamic vibratory force and an equivalent static force showing the greater relative magnitude of the former. For equal densities and