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NAME AND ADDRESS DATE

CONSTRUCTION OF A HEAVY DUTY MILITARY AIRFIELD ON PERMAFROST

By

Owen N. O'Leary

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Civil Engineering

The University of New Mexico

1958

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 13, 1958
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Thesis committee

Eugene Zwoyer
CHAIRMAN

W. C. Wagner

Roy Foot

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ACKNOWLEDGMENTS

The author wishes to thank The Library of Congress, The Arctic Institute of North America, The Corps of Engineers of the U. S. Army, The National Geographic Society, The U. S. Air Force, and The U. S. Navy for their combined assistance and the furnishing of aids without which this report would not have been completed.

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INTRODUCTION

An examination of the map of the northern hemisphere will show that the two great population areas of opposing ideologies are located across the Arctic regions from each other. This fact has been recognized by the U. S. military authorities since the early 1940's, and an effort has been made to locate military forces in these regions to act as a possible deterrent to any aggressive actions. The nature and geography of this region generally preclude any military forces except a combat airfield. The most outstanding and possible only example of a major military airfield located entirely on permafrost material in these regions is the U. S. Airbase at Thule, Greenland. A discussion of the Thule Airbase may be found later in this thesis.

The economics of construction do not play a very important part in locating and constructing an airfield on permafrost. An argument could be initiated that the necessity of location of the airfield for the defense of the country far out-weighs any considerations of economics. This thesis, however, will consider the required economics commensurate with the construction and establishment of a major airfield on permafrost. A somewhat related economic factor involved in the airfield construction would be the emergency service available to the commercial airlines which are at present flying polar routes. This service could be weather information, landing strip for emergencies, and air rescue services.

The discussion of the many problems that would be encountered during the design and construction of the permafrost airfield could be broached with the statement that as in the case of most heavy construction projects, man must realize that rather than fight the natural laws, he should learn to cooperate and use them to his advantage. Construction of the airfield in the Arctic and sub-Arctic regions requires designs and methods that vary quite a bit from those used in the temperate regions. The construction of the airfield is especially difficult when the region is underlain with permafrost as in this design. The active zone located over the permafrost suffers more from the seasonal effects of freezing and thawing than areas underlain by material that is not permanently frozen. The U. S. Army, Corps of Engineers in experiments have found that stresses developed in freezing ground may reach 30,000 psi, and it is difficult to handle these stresses with structural design alone. Stated in another way, the peculiarities of the region must be recognized and accepted with conventional designs, construction methods, and materials modified accordingly.

Permafrost or permanently frozen subsurface material may be found in northern North America, Antarctica, and northern Asia. The northern half of Russia from the cold Arctic wastes to the northern Mongolian steppes plus considerable areas in Alaska and northern Canada are all locations where permafrost is found. The area within Russia is much larger than the entire United States, while altogether approximately 20% of the world's land area is underlain with various depths of permafrost. See Figure 1 for the global locations of the permafrost

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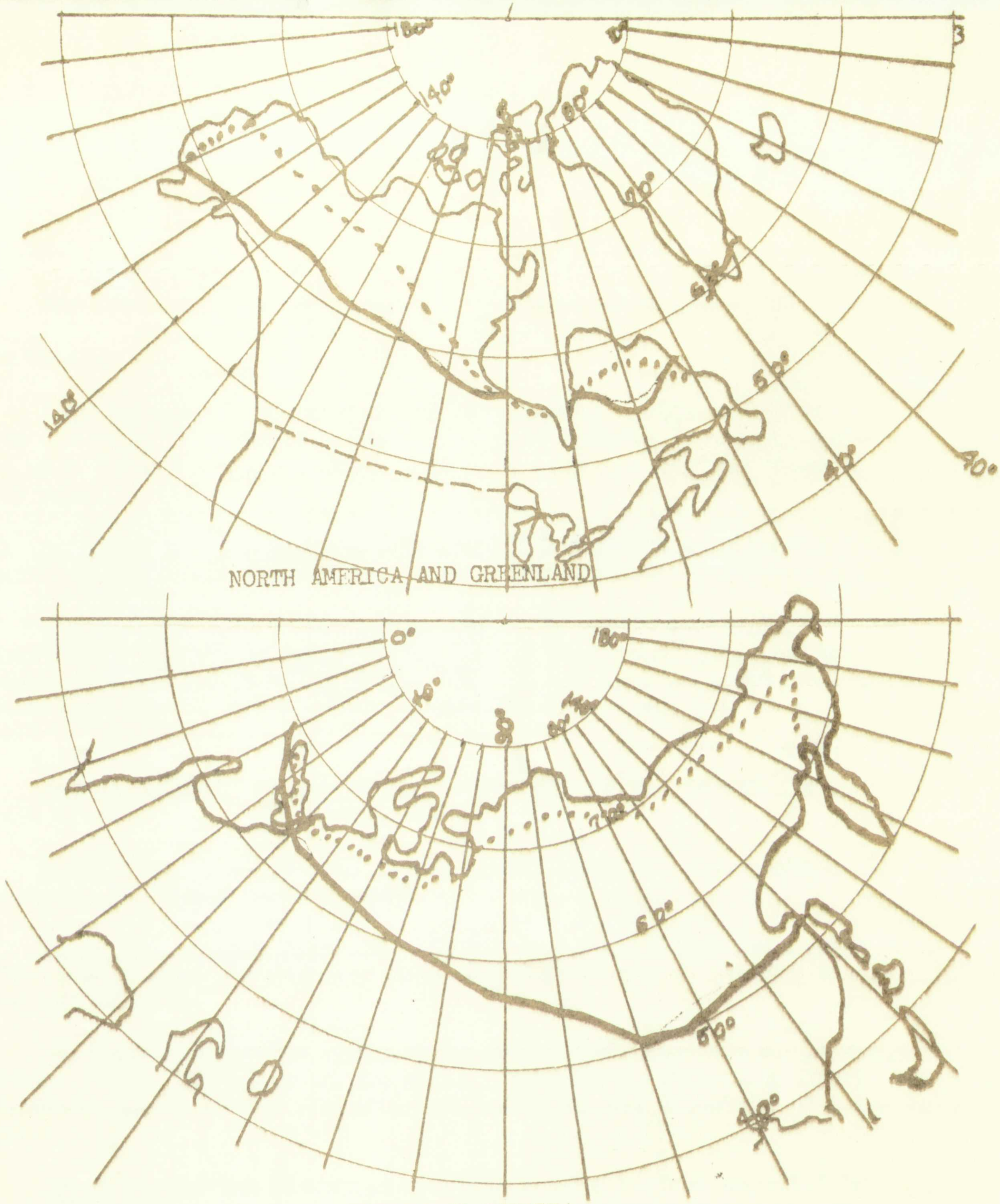

NORTHERN EURASIA

——— Approximate southerly limit of continuous permafrost

• • • • • Approximate limit of trees

Fig. 1.—Distribution of permafrost

regions.

The following are definitions of terms which are used throughout this thesis:

Active Zone--That layer of surface material which is located above the permafrost table. The active part of this term is associated with the fact that almost all of this zone freezes and thaws every year.

Aggradation of Permafrost--Growth of permafrost as a result of natural or artificial means--opposite of degradation.

Arctic--The area on the globe where the mean temperature for the warmest summer month is below 65°F., or the mean temperature of the warmest four months is below 50°F. This is the area of varying width located immediately south of the Arctic Area and there may be a forest in this area.

Degradation of Permafrost--Deterioration of the permafrost as a result of natural or artificial means.

Permafrost Province--The entire Arctic and Antarctic regions where permafrost is likely to be present.

Frost Susceptible Soil--Soil in which a significant ice segregation occurs when the required amount of moisture and freezing conditions are present.

Ice Segregation--The build-up of ice as definite lenses, layers, patches, veins, and masses in the soils. Some have advanced a theory that these bodies of ice are oriented normal to the direction of heat loss.

Frost Heave--The elevation or raising of a surface material because of the displacement due to the formation of ice in the underlying soil.

Ice Content--The ratio of the weight of the ice to the dry weight of the soil. This is expressed as a percentage.

Per Cent Heave--The ratio, expressed as a percentage, of the amount of heave to the depth of the frozen soil prior to the freezing which caused the heaving.

Permafrost--(permanently frozen ground)--The subsurface layer of earth, other surficial deposit, or even bedrock located at varying

depths which has been in a continuously frozen state for a long period of time. The term 'long period of time' means at least 100 years.

Frost Zone--The topmost layer of the active zone which thaws in the summer and freezes in the winter. Frost zones occur in the temperate regions as well as in the Arctic and sub-Arctic.

Water Content--The ratio, expressed as a percentage, of the weight of the water to the weight of dry soil in the sample analyzed. The weight of the water in frozen ground includes the weight of ice and unfrozen water.

Other pertinent terms used in this thesis will be defined as they are encountered in the discussion.

Permafrost, depending upon the weather and local conditions can exist in the following forms or a combination of the forms:

(a) A monolithic layer or strata.

(b) A broken layer with unfrozen spots or islands and strips. This permafrost layer that contains strips or 'swaths' of unfrozen material is known as 'layered permafrost.'

(c) Spots or islands within unfrozen material.

Note: Spots or islands of ice that are eliptical in cross section are known as ice lenses and there are a great number of them throughout the permafrost province.

Permafrost should be expected in areas where the mean annual temperature stays below freezing and the following weather characteristics are present:

(a) Dry, short, and fairly cool summers.

(b) Long, cold winters.

(c) Very little precipitation during all the seasons.

Figure 2 shows typical sections through permafrost.

The thickness of continuous permafrost varies from a thickness of two or three feet to nearly 1000 feet. Naturally, the thickness

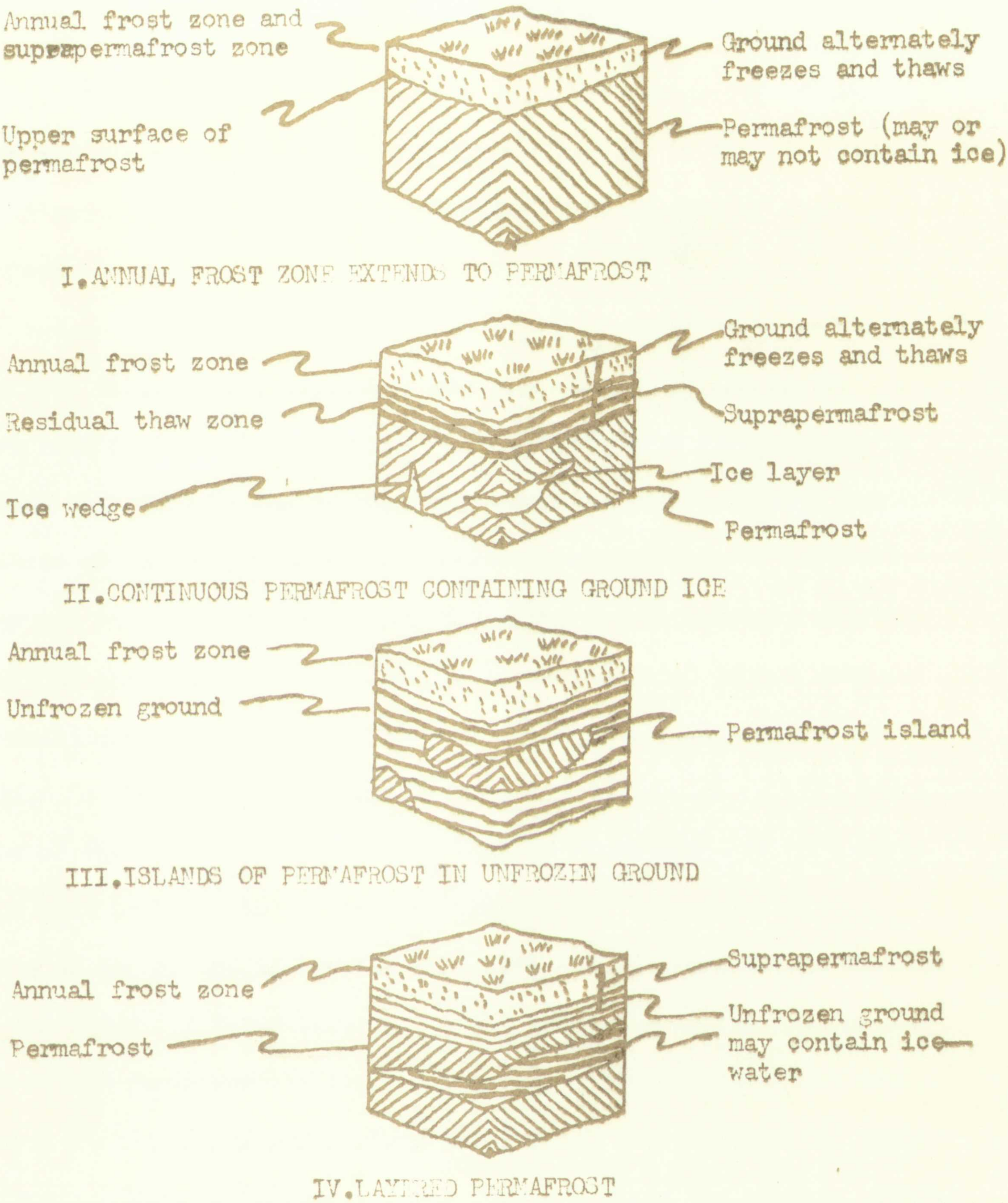

Fig. 2.—Typical sections through ground containing permafrost

generally increases as you get farther from the boundaries of the permafrost province. The town of Amderma, Russia, is the location of the maximum known thickness of permafrost, with a depth of over 1300 feet.

The upper surface of the permafrost layer which is called the permafrost table and is separated from the ground surface by the active zone is irregular in shape and position. The irregularity in position and shape is due to the differences in heat transmission qualities of the active zone. The active zone may also be affected by any one or a combination of the following: soil density, moisture content of the soil, type of soil, or any movement of ground water. The conditions at the ground surface play an important part in the distance to the permafrost table. Trees and underbrush usually serve as one of the best insulators while smaller vegetation and snow serve as the next best insulators against thawing and freezing. If the surface of the ground is exposed to direct sunlight and winds, it will have the effect of increasing the thickness of the active zone or the depth to the permafrost table. The smaller depth of the active zone, the more stable the ground surface will be and consequently the easier construction will be in such a case. Table I gives the average active zone depth at certain global locations.

Construction activities will usually affect the distance to the permafrost table by the process of removing snow, vegetation, tundra, or other insulating material from the surface of the ground which causes the active zone to freeze deeper and attain lower temperatures in the

generally increases as you go northward [illegible] permafrost province. The area of [illegible] the maximum known thickness of permafrost [illegible] 1300 feet.

The upper surface of the permafrost [illegible] permafrost table and is separated from the ground surface by the active zone [illegible] position and shape is due to the differences in [illegible] qualities of the active zone. The active zone depth [illegible] by any one or a combination of the following: moisture content of the soil, type of soil, amount of vegetation, the conditions at the ground surface [illegible] distance to the permafrost table [illegible] as one of the best insulators while [illegible] as the next best insulator [illegible] surface of the ground is [illegible] have the effect of increasing the [illegible] depth to the permafrost table. The greater the [illegible] the more stable the ground surface will remain [illegible] construction will [illegible] zone depth at certain [illegible] locations.

Construction [illegible] permafrost table [illegible] or other insulating material [illegible] the active zone [illegible]

TABLE 1

AVERAGE DEPTH OF ACTIVE ZONE AT LOCATIONS
IN ALASKA AND RUSSIA

Location	Latitude	Surface Material	Type of Soil	Depth of Active Zone (feet)
Alaska	71°18'	Moss	Loamy sand	2
Fairbanks	64°50'	Moss	Silt	3—6
Kotzebue	66°52'	Moss	Peat, sand, gravel	3—3.5
Nome	64°30'	Moss & peat	Loam, sandy loam	3—4
Wales	65°37'	Cleared	Sand	4
Northway	62°58'	Moss & peat	Fine silty sand	3—5
Russia	S. of 55°		Sandy	9
			Clayey	5.5—7.5
			Peaty	2—3
	62°		Sandy	6—7.5
			Clayey	4—6
			Peaty	1.5
	N. of 70°		Sandy	3—5
			Clayey	2—3
			Peaty	1

winter. This removal of the insulating material will also cause the active zone to be deeper by thawing faster and increasing the temperatures of the soil. Heated buildings used for personnel or equipment may prevent the active zone from freezing in the winter if the structures are built directly upon the ground. Any structure or item of construction which is built upon the ground will cause the depth to the permafrost to be changed if the heat transmission qualities are different from those furnished by the original natural ground cover.

Thermal Regime -- An equilibrium established by natural forces where ground surfaces underlain by permafrost tend to remain undisturbed by surface changes or seasonal temperature variations is known as the thermal regime. The natural law that causes this balance to remain in existence is that the heat will be attracted from a warm body to a colder body and thereby equalize the temperatures. The soil beneath the permafrost is warm and unfrozen and it is always trying to melt the permafrost. In the winter months the frozen ground of the active zone is colder than the permafrost which has acquired heat from the warmer ground below. Heat then passes from the permafrost to the active zone. The warming of the active zone in the summer stops the heat from leaving the permafrost, which completes the cycle and thus the permafrost's dimensions remain in balance with no degrading or aggrading. Cutting and removal of vegetation, excavating and filling of dirt, and changing of the flow of ground water by subdrainage will all disturb the thermal regime. The mean annual temperature at the ground surface will be raised by any installation placed upon the

winter. This removal [illegible] active zone to be deeper [illegible] tures of the soil. [illegible] may prevent [illegible] tures are built directly [illegible] construction which [illegible] permafrost to be [illegible] ent from those [illegible]

Thermal Regime [illegible] where ground surfaces [illegible] by surface changes [illegible] thermal regime [illegible] existence is [illegible] colder body and [illegible] the permafrost [illegible] the permafrost. In the [illegible] zone is colder than [illegible] warmer ground below. [illegible] active zone. [illegible] heat from nearby [illegible] the permafrost [illegible] something. [illegible] of dirt, and [illegible] all disturb the thermal [illegible] ground surface [illegible]

ground which destroys the thermal regime beneath the constructed item. Removal of vegetation and other surface matter has the effect of lowering the active zone temperatures in late winter and allowing thawing to start early in the summer and to penetrate deeper into the permafrost table. The lowering of the permafrost table usually increases the thickness of the permafrost layer as shown in Figures 3 and 4. These changes disturb the balance established by the natural forces which results in adjusting forces occurring in establishing a new equilibrium. Such adjustments are usually accomplished within three to five years, and during this time, reactions may appear at the ground surface as frost heaving, caving, frost boils, frost mounds, and surface icing. Naturally, any construction should be such that the equilibrium is kept or if a new balance is established, the potentially destructive reactions are controlled. Unusually mild winters will cause the frost zone depth to be less than the depth of the active zone, leaving a layer of unfrozen ground above the permafrost which also disturbs the equilibrium.

Ground water must also be considered in construction designs in permafrost regions. This is water found within the earth and relative to the permafrost layer, it may exist above, within, or below the layer depending upon such variables as geographic configuration, seasonal weather changes, climate, or geological features. The most important influence that might be exerted by the water is its ability to thaw the permafrost. Ground water is supplied from such sources as melted snow and ice, water, or water that travels upward from subsurface sources

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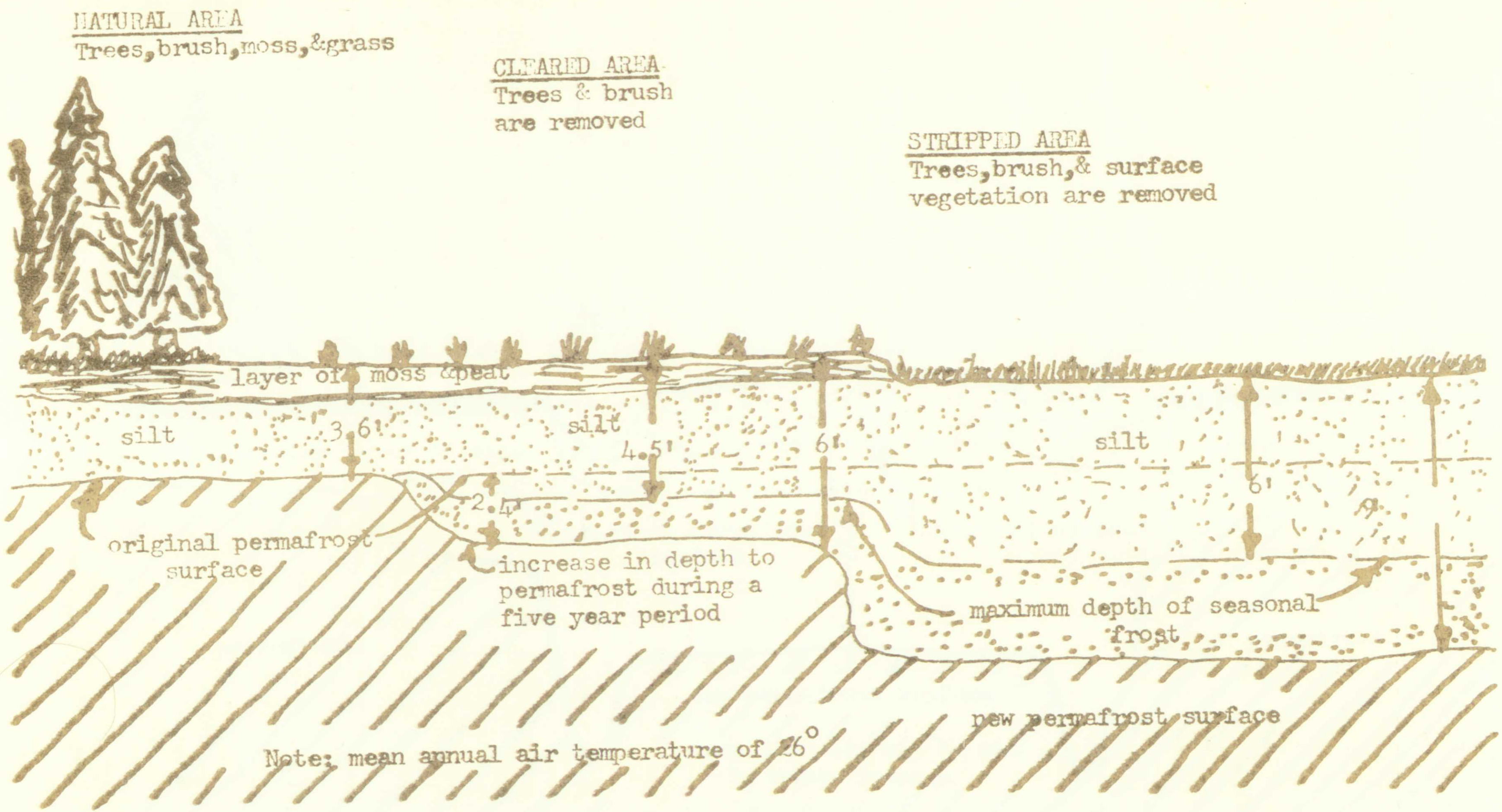

Fig. 3.-Measured degradation of permafrost in frost-susceptible soils below different surfaces in a subarctic region after a five year period

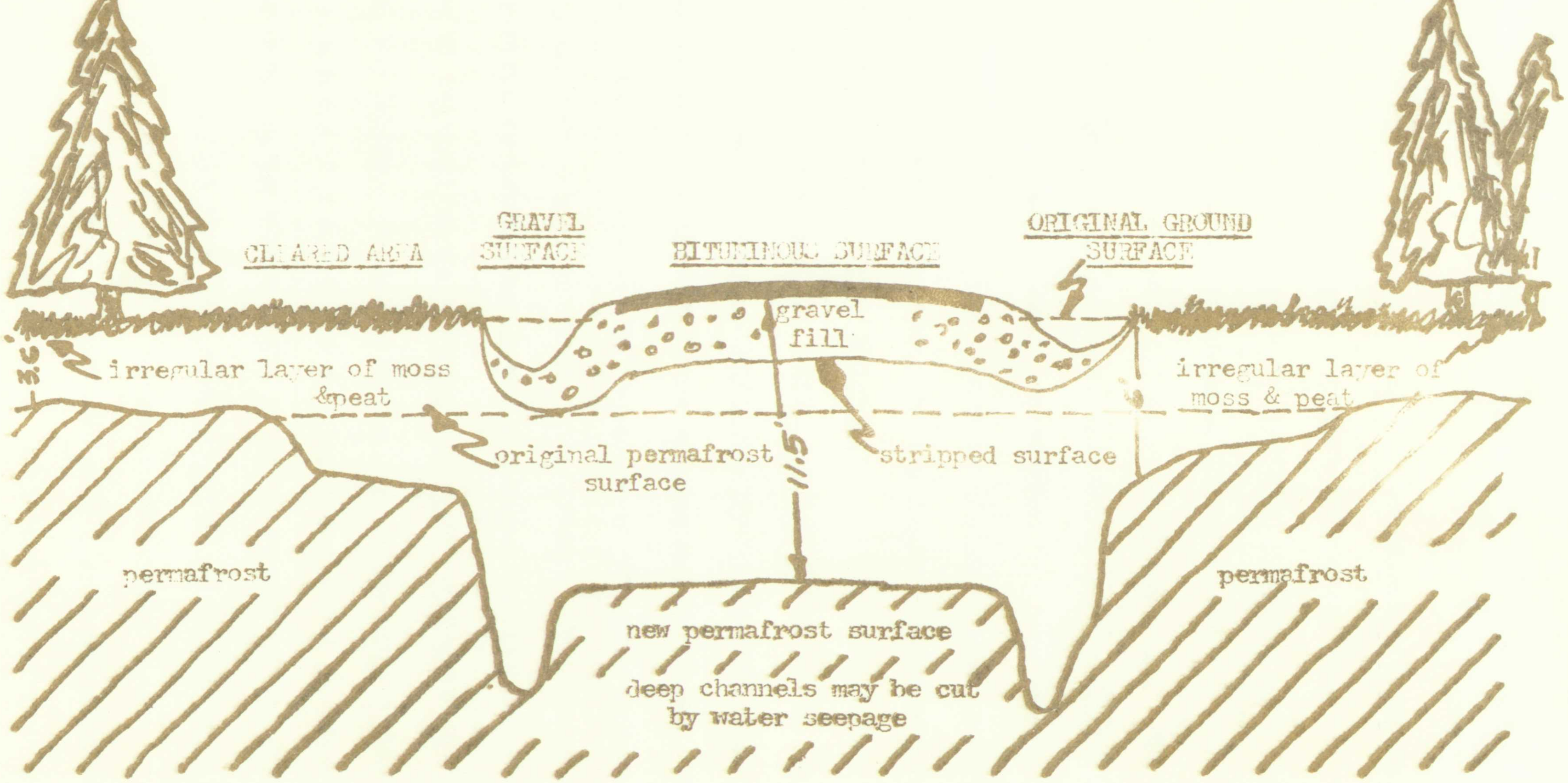

Fig. 4.—Maximum depth to permafrost below a road after five years in a subarctic region

that are above, within, or below the permafrost. The water found under permafrost usually occurs as a result of seepage from higher elevations. This water is generally under hydrostatic pressure when it is found at its normal location, which is under large valleys in water bearing soils such as sand, gravel, and water-carrying silt. The water under hydrostatic pressure is an excellent source of year-round water supply for an installation such as the airfield.

If the surface of the ground is saturated with ground water at the start of freezing weather, the top layer immediately freezes and acts as an impervious layer which puts the remaining water in the active zone under pressure. This pressure builds up as the depth of the frozen ground increases until finally a weakened area is found and the water is forced out where surface ice is formed. Normally the surface ice keeps building up until enough pressure exists to prevent more water from coming up through the ground. Ice lenses are formed when a plane of horizontal weakness appears and the water forces out a pocket in the soil where the water freezes and forms the eliptical-shaped ice lenses. Ground water in the active zone during the warm season behaves like any water in the ground above an impervious layer. If the water is in coarse soil, it moves faster in the direction of gravitational pull than the water would if contained in fine peaty soil such as that found in some areas of Alaska.

Ground water has an important effect upon any construction with which it might come into contact. If the object of construction such as pilings and foundations are not down in the permafrost, the water

will get around and under it, and while freezing it raises the object. The soil after thawing will allow the construction to settle to a depth lower than it originally was. This settlement is usually prevalent in fine-grain soils. Because water is an excellent medium for carrying heat, the ground water when it comes into contact with a piling or foundation that has been built into permafrost, may by moving downward, thaw and loosen the support furnished by the frozen ground and allow settlement to occur.

The second type of water that must be considered is surface water which includes lakes, streams, and any other water found in the upper portion of the active zone. The melting snow and ice add to the surface water and during the early thawing season, much water is found at the surface in the form of lakes and rivers. Naturally, the airfield should not be built where it will be endangered by any excessive amounts of surface water. Water flowing in rivers may freeze on the bottom of the stream as anchor ice and force water up through the surface ice to cause ice jams or buildups which cause trouble for nearby installations or may even damage structures when the ice moves out in the thawing season. This factor is further discussed in section II of this thesis.

An understanding of the actions that soils undergo during the freeze and thawing cycle is necessary in order to design an efficient airfield. Some of the actions which soils go through during the freezing and thawing cycles are cracking, settling, swelling, creeping, and sliding which are influenced by the following:

will get around [illegible] [illegible] [illegible] [illegible] [illegible]
The soil after thawing will [illegible] the ground water [illegible]
lower than [illegible] [illegible] [illegible] [illegible]
fine-grain soils. [illegible]
heat, the ground water [illegible]
foundation [illegible] [illegible] [illegible] ground [illegible]
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of this [illegible].

An understanding of the [illegible]
freeze and thaw [illegible]
airfield. [illegible]
freezing and thawing [illegible]
and sliding [illegible] by the [illegible].

(1) Type of soil.

(2) Density or compaction of soil

(3) Change in the air temperature and rate of change.

(4) Water content of soil.

(5) Thermal conductivity of soil.

(6) Slope of ground and slope of water table.

(7) Porosity of permafrost.

(8) Depth to permafrost table and slope of table.

(9) Surface cover of ground.

Figure 5 shows an aerial view of different soils. The shrinking and cracking occurs in all wet soils when the temperature drops below freezing. In any soils that might be impervious to water movements, the cracks will allow the water to move through the cracks where freezing will cause frost boils, ice lenses, heaves, ice crystallization, and surface icing. Settling or caving usually happens in soils that are in a capillary saturated condition when freezing occurs. The freezing separates the soil grains and thereby changes the density and the bearing capacities of the soil. After thawing starts, the soil changes to a soft mucky or muddy variety. Where an ice lense melts, the resulting cavity allows the soil to fall into the void which causes caving. Ice lenses and heaving will cause the soil to slide and creep when the thawing season starts. The soil will slide and creep toward the downhill direction of the slope at the ground surface. The hills or slopes that face the direct sunlight are the ones which will suffer the most sliding and creeping. Sliding and creeping of soils are

Interpretation of an aerial photograph used to show soil-permafrost characteristics. Area A is the gravelly flood plain of the stream. Areas B, C, and D are parts of a low terrace between the flood plain and the upland. Area B is frozen gravel, area C is frozen gravel with a deep peat and silt overburden—with polygons, and area D is a large depression which contains considerable ground ice and is very swampy.

Fig. 5.—Permafrost surface features

practical demonstrations of horizontal movements within the surface material. When the hydrostatic water pressure in areas of sloping ground builds up between the frozen permafrost table and the frozen active zone's crust, a frost heave or swelling occurs. Swelling is the greatest where ground water collects in one location and builds up into ice lenses when it freezes. Soils such as the loose silty variety and the fine sands where capillary water is pronounced, are likely to have quite a large amount of ice freezing in the soil. The fine-grain and layered soils will also have water freezing in large voids, and this freezing or crystallization of ice will attract other capillary water until the source of water is exhausted. The result is generally a large swelling at the ground surface. Figure 6 shows how swelling occurs and affects the ground surface.

Underground pockets of water in the active zone will also cause swelling when the water's volume expands by approximately 9% during the freezing process. Ice that builds up into a large ice lense causes frost heaving which is usually the largest example of swelling in the ground surface. These larger pockets of ice are usually found in soils such as the loose silty variety and fine sands. Coarse gravels and sands plus consolidated clay soils are normally not affected by this condition. Ice crystallization, another cause of swelling, generally occurs in fine-grain layered soils and happens when water freezing in large pockets attracts water from capillaries. These ice pockets will continue building up until the supply of capillary water is exhausted.

practical concern [illegible]

material. When [illegible]

ground builds up [illegible]

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variety and [illegible]

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The fine-grain [illegible]

large voids, [illegible]

other capillary [illegible]

result is generally [illegible]

shows how swelling [illegible]

Underground percolated water [illegible]

swelling when the [illegible]

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causes frost [illegible]

in the ground [illegible]

in soils such as the [illegible]

gravels and sands [illegible]

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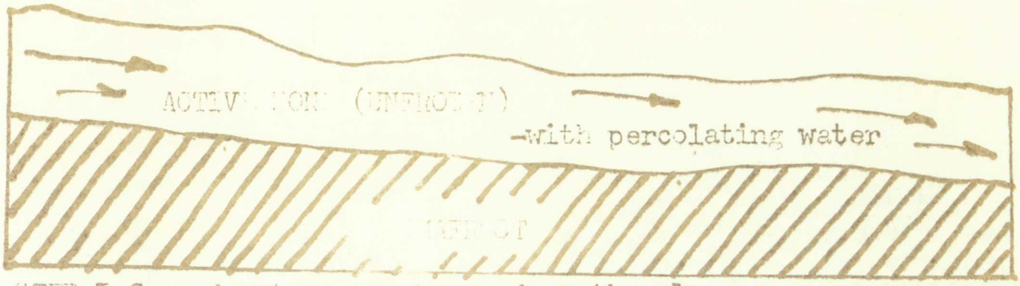
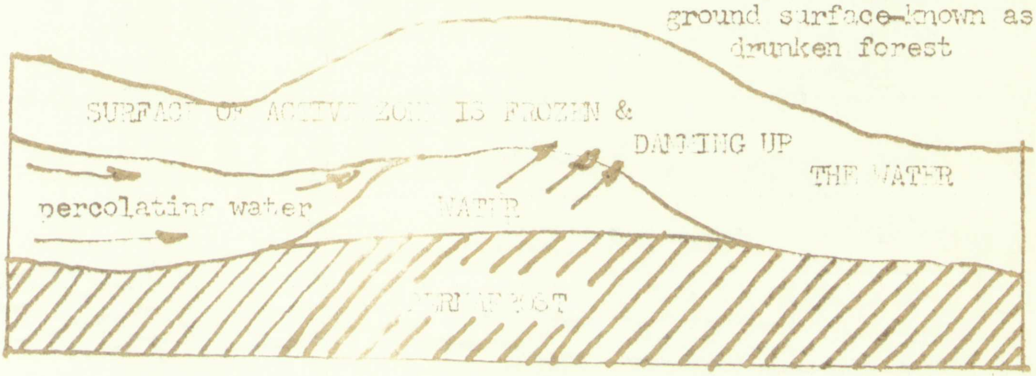
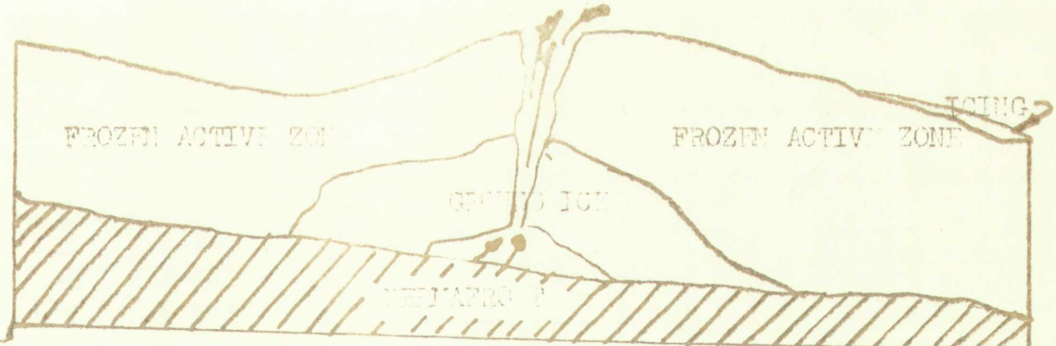


STEP I. Ground water percolates down the slope

Note: Any trees will be tilted at right angles to the ground surface-known as drunken forest



STEP II. Ground surface forced up by hydrostatic pressure



STEP III. Ground is broken and water is forced out-caused by hydrostatic pressure and ice crystallization

Steps showing formation of frost heave, frost blisters, or swelling

Fig. [illegible].-Frost heave surface features in profile

Another force produced by freezing water that must be considered in construction on permafrost is that known as the adfreezing force. This force comes into existence when the moisture within the soil freezes and fastens onto any construction installation such as a piling or a foundation wall. If the installation does not penetrate the permafrost table, the adfreezing force will usually get beneath and force upward to cause the structure to be pushed out of the ground. When the installation has penetrated the permafrost, the force holding the structure down in the ground is greater than the force which is trying to push it out when the active zone is freezing. Stated simply, the adfreezing force in the permafrost layer is greater than the adfreezing force in the active zone.

One of the most important facets to be considered in designing the airfield is the bearing capacity of the frozen ground. The bearing capacity varies with the moisture content of the soil, and in the case of dry-frozen soil, the value is at least equal to the capacity of the soil when thawed. The freezing and thawing cycles will reduce the load-carrying capacity of fine-grained soils by separating the grains as previously explained. Soils with high moisture content have a bearing capacity that is equal to and often exceeds that furnished by ice. Just as the strength of ice decreases at a fast rate when the temperature rises to the melting point, so does the strength of wet-frozen soil when it is subjected to the same temperatures.

Another force [illegible]

in construction of foundations [illegible]

This force comes from [illegible]

freezes and [illegible]

or a foundation wall. [illegible]

permafrost table, the [illegible]

force upward [illegible]

When the installation has [illegible]

the structure [illegible]

trying to push [illegible]

the adfreezing force [illegible]

adfreezing forces [illegible]

One of the more [illegible]

the airfield is the [illegible]

capacity varies [illegible]

of dry-frozen soil, [illegible]

soil when thawed. [illegible]

load-carrying capacity [illegible]

as previously [illegible]

bearing [illegible]

ice. Just as the strength of [illegible]

temperature [illegible]

frozen soil [illegible]

PART I. BASIC AIRFIELD

A. <u>Make Up of Airfield</u>

The airfield due to its location in a remote section of the world, will be a multipurpose military type. That is, it can be used as a refueling field, a base for air-rescue units, an emergency field for commercial and military airplanes, a combat field for tactical or strategic bombers, a field for dispersing planes during times of an emergency, or a service field from which surveys and studies may be made. This multipurpose quality of the airfield will require that the site include the runways and their environs, drainage facilities, plus various types of service facilities.

The dimensions of the main runway will include a length of 10,000 feet and a width of 300 feet. The length of the runway will be supplemented by a 2000 feet addition at each end while 150 feet shoulders will be constructed on each side for the entire length. An emergency runway, 3000 feet long and 150 feet wide, will be constructed parallel to the main runway and on one of the shoulders. The shoulders will be constructed from excavated permafrost while the runway extension, like the runway, will be of the flexible pavement type, however the quality of the extension pavement will not be equal to that of the runway. The dimensions of the runway were chosen so as to be large enough to accomodate the largest transports such as the C-124, C-131, C-130, and the largest jet bombers such as the B-47, B-52, and the B-58. Military information is not available as to whether the runway

4. Make Up of Airfields

The airfield [illegible] world, will be a multipurpose airfield [illegible] as a refueling [illegible], a base [illegible] emergency [illegible] for commercial and military [illegible] strategic bombers, a field for [illegible] emergency, or a [illegible] made. This [illegible] site include [illegible] various types of [illegible].

The [illegible] 10,000 feet and a width of [illegible] be supplemented by a [illegible] shoulders will be [illegible] emergency runway, [illegible] parallel to the main [illegible] will be constructed [illegible] Like the runway, will [illegible] quality of the [illegible] runway. The dimensions of the runway [illegible] enough to accommodate [illegible]-130, and the largest [illegible] B-58. Military information [illegible]

length will be sufficient under maximum gross weight take-offs, but it may be assumed that if the length was marginal during such a take-off, ATO units (assist take-off--rocket propellants) would be utilized to help perform the operation.

The airfield site will require a minimum land area of four square miles plus any additional land that may be required for water, sewerage, and radar facilities. Right-of-way for an all-weather road to the harbor facility, twenty-five miles away, will be still another requirement for land near the site.

The actual make-up of the airfield site will include besides the main runway and emergency airstrip, the necessary taxiways, revetments, hardstands, aprons, buildings, and service facilities. Each end of the runway will be connected by taxiways to the revetments, aprons, and hangars. Provisions for a large bulb-shaped warm-up apron will be made at each end of the runway. Quite naturally the runway centerline will be parallel with the direction of the prevailing winds.

The buildings will include two large size hangars, four barracks, a power building for heating and generating, a mess hall or personnel building, a vehicle maintenance building, a building for housing service equipment, a fire station, and other buildings required for an airbase of this size and nature. The buildings will be positioned on the site so as to add to the efficiency of the location as much as possible.

The service facilities will include among other installations a water system; a complete drainage system for the runways, taxiways, and other like areas; a sewerage system; service tunnels for water,

length will be sufficient [illegible] eight [illegible]

it may be assumed [illegible]

off, ATO units [illegible]

to help perform the operations. [illegible]

The airfield [illegible]

square miles [illegible]

coverage, and radar [illegible]

to the harbor facility [illegible]

requirement for land [illegible]

The actual make-up [illegible]

the main runway and [illegible]

ments, hardstands, aprons, buildings, [illegible]

of the runway will be [illegible]

and hangars. [illegible]

made at each end of the [illegible]

will be parallel with the [illegible]

The buildings [illegible]

a power building for [illegible]

building, a vehicle [illegible]

equipment, a fire station, [illegible]

of this size [illegible]

so as to add to the [illegible]

The service [illegible] will [illegible]

a water system; [illegible]

and other like [illegible]

electric, and fuel lines; a lighting system; a wind direction indicating system; a small weather forecasting unit; and other required service equipment.

The map, Figure 14, at the end of this thesis shows the relative position of all components of the airfield to each other.

B. Selection of Airfield Site

All potential areas with their particular topography, drainage, type of soil, materials for the fill and surfacing, wind direction, and other local conditions, present a different problem in the consideration for the final site for the airfield. The most important basic consideration for this airfield site, however, will be the location of it so as not to impair the prime mission of the base--that is its combat and service effectiveness.

Just as in locating an equalivalent airfield in temperate zones, the terrain of any potential site and surrounding land in the Arctic and sub-Arctic should undergo careful consideration. The area should lend itself readily to development without an excessive amount of excavation being required. Cuts should definitely be avoided if possible, and any side slopes in fill composed of fine-grained materials should be kept to a 4 to 1 ratio or less.[1] This material would be found only on the shoulders. The suitability of the site could be said to be dependent upon two somewhat opposing facets. That is, the terrain features should be such that the land sloped enough to provide a natural drainage system, but this sloping should not be so excessive as to require very much grading and consequently cause a lot of erosive action. A site that may lie in a deep river valley should be thoroughly checked to ascertain how much and how often flooding will occur. Flooding which occurs along such a stream location in the permafrost

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[1]U. S. Army, Construction Manual, Part XV, October 1954, pp 2.

B. Selection of [illegible]

All potential [illegible]

type of soil, moderate [illegible]

and other local conditions, [illegible]

sideration for the time [illegible]

basic considerations [illegible]

location of [illegible]

is its combat and [illegible]

Just as in [illegible]

the terrain of any potential [illegible]

and sub-Arctic should [illegible]

lend itself readily to [illegible]

excavation being required. [illegible]

possible, and any [illegible]

should be kept to [illegible]

found only on the [illegible]

said to be dependent [illegible]

terrain features should [illegible]

a natural drainage system, [illegible]

as to require very much [illegible]

action. A [illegible]

checked to ascertain [illegible]

flooding which [illegible]

[illegible]

regions will generally be more pronounced and more destruction will result than on the same terrain conditions in the warmer regions. If it is not possible to remove the choice of the airfield site from the areas of possible flooding, dikes can be constructed to divert the water and ice flow. A cross section of the materials used in the dike should show the active zone plus two feet of the permafrost excavated and replaced with sand and gravel. The interior of the dike should be constructed from sand and gravel while the outer material should be impervious material previously removed from an excavation.

The landing area is the most important element of the airfield, and in general, the field should have a fairly smooth and well-drained landing area that is sufficiently strong enough to permit combat and service operations during normal and some abnormal weather conditions. The landing area should be nearly level with no dips, depressions, or other obstacles that would cause the flying operations to be of a hazardous nature.

The location should have adequate natural drainage channels, or in topographical terms, a near perfect area would be a level area of the proper length with the terrain gently sloping away in several directions. Another location that might be suitable would be one which was on the side of a very gentle slope in a valley. A location with the appropriate slope would have the advantage of having rapid enough dispersal of surface water which would reduce the danger of any standing water softening the ground. The appropriate sloping at the airfield site would also assist in planning the drainage system and it might

regions will generally be [illegible]

result them on the [illegible]

If it is not possible to remove the material [illegible] from

the areas of possible flooding, [illegible]

water and ice free. [illegible]

should show the surface [illegible]

and replaced with [illegible] gravel. [illegible]

constructed from sand [illegible]

impervious material [illegible]

The landing area [illegible] aircraft,

and in general, the [illegible]

landing area [illegible]

service [illegible]

The landing [illegible]

other obstacles [illegible]

hazardous nature.

The landing [illegible]

in topographical [illegible]

the proper length [illegible]

directions. [illegible]

was on the side of a very gentle slope [illegible]

the appropriate [illegible]

dispersal of surface [illegible]

water collecting [illegible]

site would also [illegible]

even remove the necessity of any subsurface drainage.

There should be no obstruction over fifty feet tall within one half mile of each end of the runway extension and for one hundred yards on each side of a line extended through the centerline of the runway. An attempt should be made to locate the strips so they parallel any range of nearby mountains and the landing or takeoff leg of the approach flight should not be directly into or over mountains because of the obstructions and the up and downdraft wind conditions found over mountains. Mountains tend also to have moisture-laden air pile up on their upper reaches and cause clouds to form which usually bring storms and definitely limit visibility at any nearby airfield.

Another major consideration for the selection of an airfield site is the availability of construction materials. Previous heavy construction projects performed by the U. S. military forces in the permafrost have shown that much sand and gravel can be found along stream locations which is suitable as a base course or foundation material for the runway and other airplane service-ways. The sand and gravel can be supplemented by local rocks of maximum size of up to two feet. All rocks that might be too large for the fill requirements may be crushed at the pit location. Good engineering dictates that any large amount of smooth and rounded rocks should be run through the crusher to give the rocks angular surfaces and thereby better bearing qualities for the fill materials. It can be stated that the availability of good engineering materials within a reasonable hauling distance of the construction site is a factor which must be weighed

even remove the [illegible]

There should be no obstructions over [illegible] half mile of each end of the [illegible] on each side of [illegible] An attempt should be made [illegible] range of nearby mountains [illegible] Flight should not be [illegible] obstructions and [illegible] mountains. [illegible] their upper [illegible] and definitely [illegible]

Another major consideration [illegible] site is the availability of [illegible] construction purposes [illegible] permafrost have [illegible] stream locations [illegible] material for the runway [illegible] gravel can be [illegible] feet. All rocks [illegible] be crushed at the [illegible] large amount of [illegible] crusher to [illegible] qualities [illegible] ability of [illegible] tance of the [illegible]

carefully with the other aforementioned factors. Figure 7 shows a typical cross section of the material in the runway and other airplane handling surfaces.

The accessability of the site is a factor that exerts a fairly definite influence upon the choice of one among many potential sites. A particular site may be an excellent location when considering the weather, topography, and other factors, but the site would not prove to be suitable if it could not be reached from the docking facility or if the supply of construction material was located in such a fashion as to be practically out of reach of the airfield location. The docking facilities should not be over twenty-five miles from the airfield and the construction materials' locale should be within three miles of the construction site.

Aerial photographs and maps should be checked to determine the potential locations when considering all the influencing factors discussed in this section. The following section will discuss further how such devices as aerial photos and maps may be used to assist in making a decision as to the final location.

Lastly, a very important factor not to be overlooked is the availability of a water supply for an airbase not only during the construction but during the operation of the base. Not only should the supply of water be within a close proximity of the airbase, but it should be capable of an efficient development. This development may involve a system of retention such as a dam or dike which would increase the capacity of the water basin. Another aspect of the

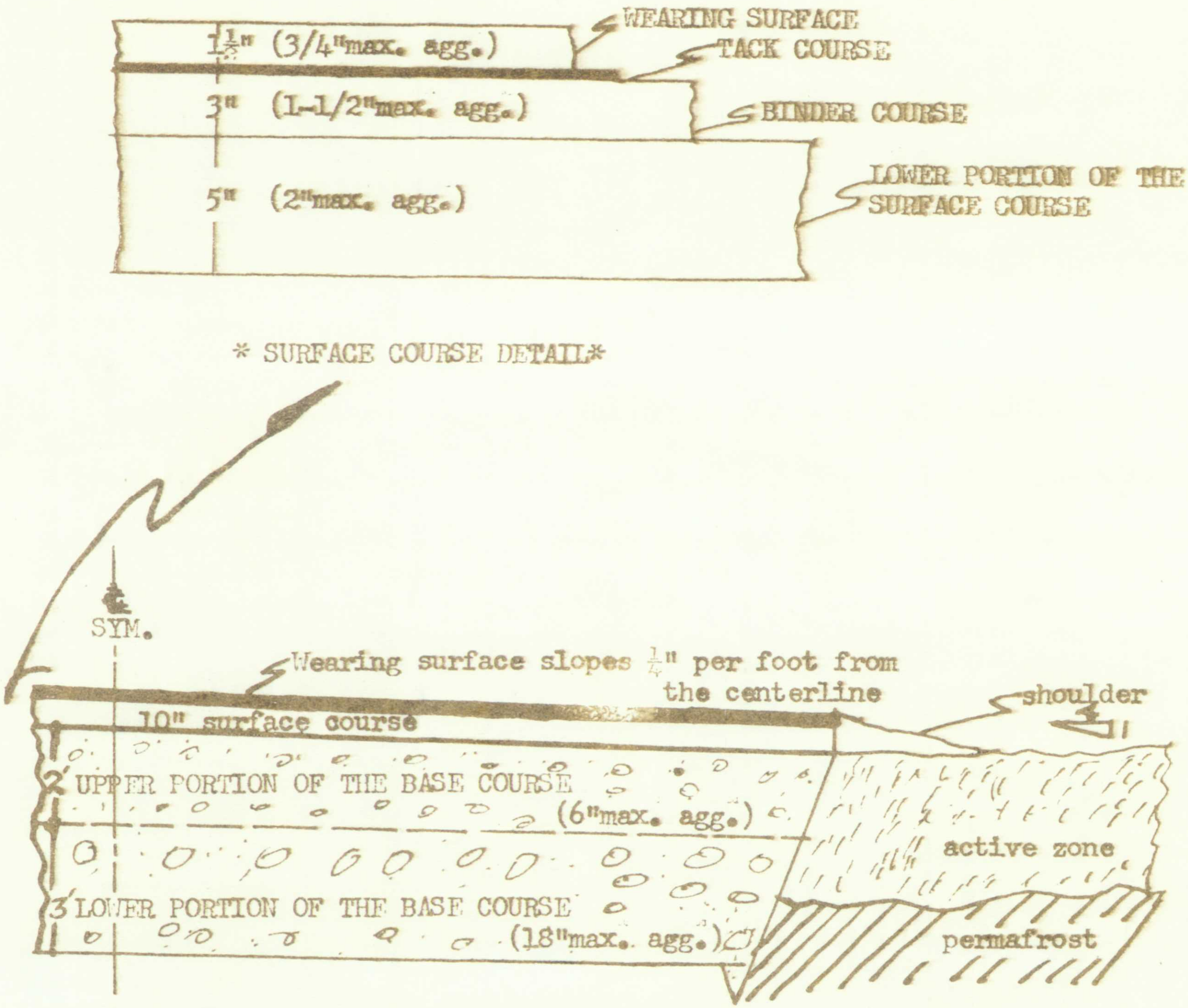


Fig.7.-Typical cross section of runway and other airplane handling surfaces

development will be a means of transporting the water from the source to the airbase - such transportation may be in the form of heated (for freezing weather) tank trucks or conduits. The airbase, as in the case of habitated places, cannot exist with a water supply that is non-existent.

C. Exploration of Site

It naturally follows that after preliminary exploration and analysis have assisted in locating a site, a more thorough exploration will be required to utilize and ascertain the potentialities of the site. An axiom could be that a site is only as good as the thoroughness with which it is explored and investigated during the early construction stages.

The permafrost layer, because it is the foundation on which all heavy construction in this region rests, should be investigated first and with the utmost care. The permafrost should be investigated and observed not only during the exploratory stage of construction but even during the operation of the field.

Generally, the character of the permafrost depends upon the soil texture. Permafrost that is made up of fine-grained soils such as silts and clays, will often contain several types of ice formations such as lenses, wedges, layers, bulbs, mounds, and other forms. If the permafrost contains gravels and clear sands with very little moisture in the soil, there will be a minimum of ice formations in in the ground. Some of the permafrost that contains ground ice may cause certain physical configurations to appear on the surface of the ground, making the explorations simpler. The two, more common of these disturbances are frost mounds and fissure polygons. The description of frost mounds may be found in the first section of this thesis.

--Note: A condition where trees are tilted at odd angles due to the

4. Exploration of Site

It naturally follows that [illegible] analysis have assisted in locating [illegible] will be required to [illegible] site. An area could be [illegible] with which it is explored and [illegible] stages.

The permafrost layer, [illegible] heavy construction. In this [illegible] and with the [illegible] observed not only during [illegible] during the open [illegible]

Generally, the [illegible] soil texture. [illegible] as silts and clays, [illegible] such as Jensen, [illegible] the permafrost [illegible] moisture in the [illegible] in the ground. [illegible] cause certain [illegible] ground, making the [illegible] these disturbances are [illegible] description of frost [illegible] sheets.

--Note: A [illegible]

upheaval of the ground is known as a "drunken forest" and is a sure indicator of a frost mound. Generally the fissure polygons cause two types of surface reactions, (a) dome-shaped with a depressed perimeter, and (b) dish-shaped with a raised perimeter or dike. Disturbances do not always occur at the surface over ground ice, making the ice harder to locate.

After the entire ground surface of the site has been thoroughly examined for any adverse permafrost conditions, the runway location and other airplane handling locations should be explored to the permafrost layer. The best method of exploring beneath the surface is to make suitable test borings. The number of borings to be made varies with the type of soil found at the locations - the fine-grained or frost-susceptible materials will require more borings than the non-frost-susceptible cohesionless materials such as crushed rocks, gravels, sands, cinders, and other like-materials.

First borings will be made along the runway's centerline at a spacing of 100 feet. If any core samples indicate a questionable area, additional borings should be made in the immediate vicinity in order that a more complete log may be made of the cross-section along the centerline. All borings should penetrate to at least ten feet into the permafrost. Borings should be made along each edge of the runway on a staggered location with the centerline borings for the entire length.

In addition, borings should be made to determine the depth of the permafrost and its quality at each end of the runway and at each

upheaval of the ground [illegible] indicator of a frost mound. [illegible] types of surface [illegible]: (a) dome-shaped [illegible] and (b) dish-shaped [illegible] not always [illegible] to locate.

After the [illegible] of the [illegible] examined for any [illegible] other airplane handling [illegible] layer. The best [illegible] suitable test boring [illegible] the type of soil [illegible] susceptible materials will [illegible] susceptible [illegible] sands, cinders, and other [illegible].

First borings will be [illegible] spacing of 100 feet. [illegible] additional borings [illegible] that a more complete [illegible] centerline. All borings [illegible] the permafrost. [illegible] on a staggered [illegible] length.

In addition, [illegible] the permafrost and its [illegible]

edge near the midway point. The emergency strip and other airplane handling locations should be checked along their centerlines and edges at every 100 feet in a manner similar to that performed along the runway. An accurate log should be made of all the surface material information gathered during the borings, and this log should be supplemented by core samples which will be taken during the airfield operation. Road locations on the airfield should be core-tested at the same time as the airplane handling locations. More borings should be made where cuts and fills are required along the route of the road to increase the information at these critical points.

Locations for buildings, parking areas for vehicles and equipment, pads for water and fuel tanks, and lines for services (water, sewage, fuel, and steam), must all be core-tested to determine the make-up of the material directly below the location. The number of cores taken at each building location should be determined in the field, however locations of buildings that have a floor line which is on the same elevation as the ground surface, will require enough borings to indicate the actual sub-surface material profile.

An analysis must be performed on each core removed from the ground, and the following information should be recorded in a log: date, location of boring, types and depths of materials, depth to permafrost, permafrost thickness, water and ice content of the permafrost, temperature at different depths, depth of frost zone, sieve analysis of the materials which make up the active zone and the permafrost, and any other pertinent data. Because the time required to

edge near the [illegible] point. [illegible]
handling locations should be [illegible]
at every 100 feet [illegible]
way. [illegible]
mation gathered during the [illegible]
by core samples [illegible]
Road locations on the airfield [illegible]
as the airplane landing location. [illegible]
cuts and fills are [illegible] along the route [illegible]
the information at these [illegible]

Locations for [illegible]
ment, pads for [illegible]
storage, fuel, and [illegible]
up of the [illegible]
taken at each [illegible]
however locations of fill [illegible]
same elevation as the [illegible]
indicate the [illegible]

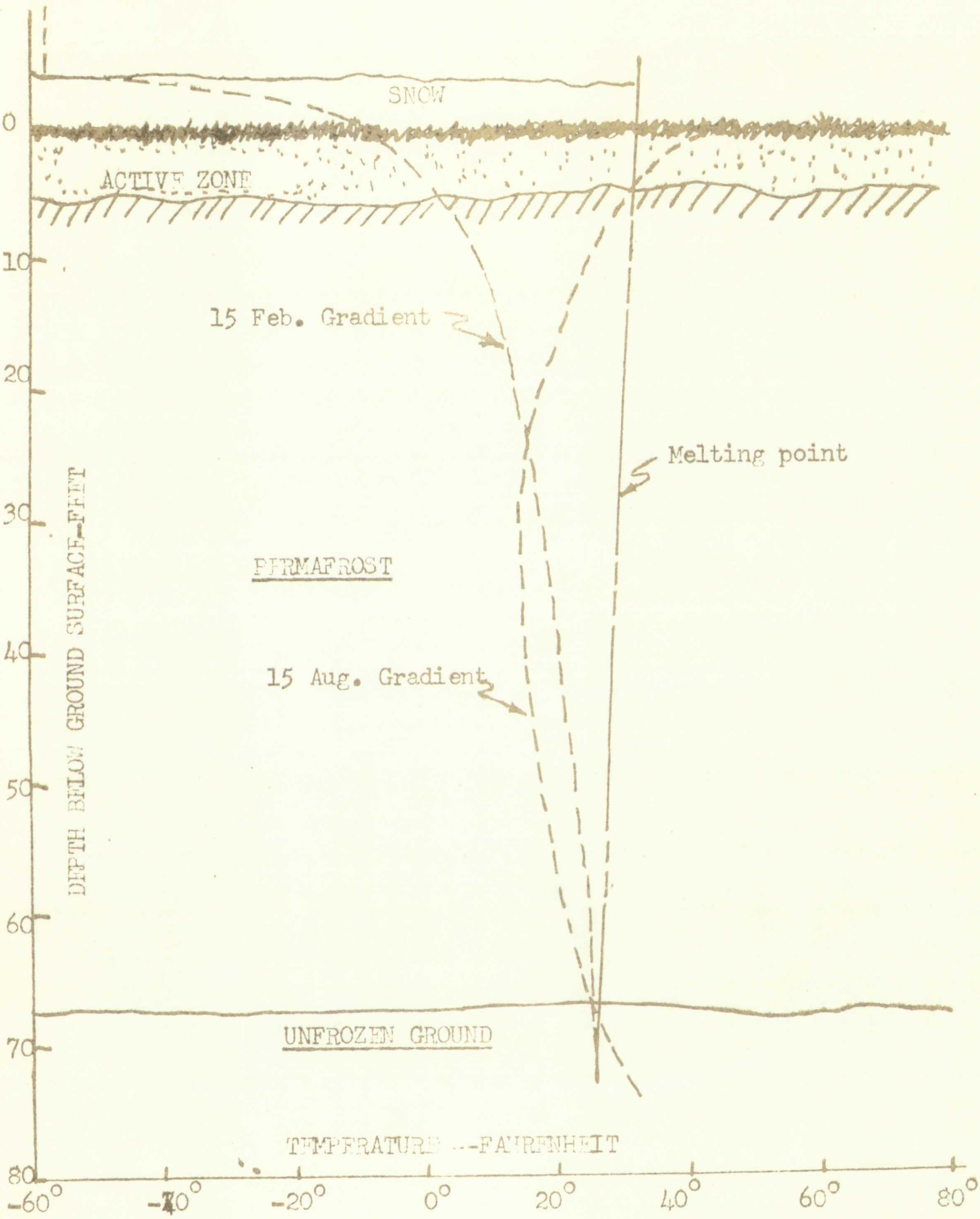
An analysis [illegible]
ground, and [illegible]
date, location of [illegible]
permafrost, permafrost thickness, [illegible]
frost, temperature of [illegible]
analysis of the [illegible]
frost, and any other pertinent [illegible]

construct the complete airfield will continue through two consecutive summers, borings should be made throughout the winter prior to the start of construction. Supplemental borings should be made during the construction. Figure 8 is a hypothetical graph of the internal temperatures at various depths in the ground at Point Barrow, Alaska.

While borings are being made at the site, other cores should be taken at potential material locations in order that an efficient source be available to meet the construction requirements. As previously stated, these potential sites for the sand and gravel will usually be found along stream beds, while the rocks may be found near the foot of a slope.

A contour analysis of the entire airfield site is equally as important as the subsurface investigation, and it should be conducted at a time when the ground is free from excessive amounts of snow and ice. This surface profile will be required in order to effectively plan the location of the strip, sewer lines, and water lines. Three foot contour lines will be satisfactory for marking the profile of the ground on a map, unless there is an abrupt change in the elevation at a certain location.

Lastly, the following information is furnished to demonstrate how much the surface conditions can forecast the quality of the subsurface materials. This information was observed during American and Russian construction projects in the permafrost regions. The following features are general clues to drainage, material, and permafrost conditions:



A hypothetical graph to show internal temperatures of permafrost (the 2 dates were chosen as being the typical warmest and coldest days at Point Barrow, Alaska)

Fig.3.-Ground temperatures

1 Vegetation and foliage

(a) Aspens are generally on dry, south-facing, unfrozen slopes.

(b) Willows are usually found near large streams on coarse material with the permafrost about two and one-half feet or more below the surface. Bushy or low creeping willows will be found in tundra where the depth to the permafrost is one to two feet.

(c) Irregularly titled trees (drunken forests) normally are located on frost mounds. These tilted or inclined trees may also be found along streams and cave-in lakes - surface action due to a body of water melting in the permafrost.

(d) Thick moss and hummocky tundra quite often will be located on a water-bearing zone over a high permafrost layer where there is very poor drainage.

(e) Pine and fir trees normally are good indicators of well-drained granular soils where the permafrost exists at a depth of six feet or more.

(f) Cotton grass (Alaska cotton) is generally found in poorly drained ground while alder bushes usually grow where the soil moisture is abundant.

(g) In the sub-Arctic, Jackpine will generally be found growing on well-drained gravel ridges which are excellent sources of sand and gravel for fill and wearing surfaces.

2 Surface Reactions

(a) Water found in the form of springs or icing are definite indicators of the presence of ground water.

(b) An area where the soil is flowing or creeping is indicative of slipping planes in the ground and in these regions such evidence usually occurs on permafrost.

(c) Large polygonal soil structures are produced in areas of fine-grained soils and silts where the action of freezing and thawing in the ground water has produced the broad cracks.

(d) Outcroppings of rock, sand, and gravel on hills that are adjacent to lowlands form a good drain for surface water and indicate that chances for ground water in the lowlands are good.

(e) Flood plains near rivers and other bodies of water usually have large layers of unfrozen material containing ground water all of which make them unsuited for construction. Flooding is the most dangerous condition in these locations.

(f) Because of exposure to the sun, southern ground slopes ordinarily have thicker active layers than do northern slopes and, are therefore more apt to contain large quantities of unconfined ground water.

(g) Naturally, where surface conditions are uniform, unconfined ground water above permafrost will usually flow in the direction of the surface slope.

(h) The depth of the water table is usually influenced by the profile of the ground surface. Flat, low areas are not as well drained or free from surface ice formations as ridges. Springs and other forms of water seepage most commonly occur at or near a break in a slope, such as the foot of a hill or mountain; gullywalls; and edges of valley bottoms.

3 Geological Features

(a) Coarse soils have a thicker active layer and consequently water is transmitted more readily. Fine-grained soils have a high permafrost table and the movement of water is somewhat opposed.

(b) Water usually will be found along the contact plane between soil and rock; this water will occur as springs when the plane is exposed in a cut, outcropping or bluff.

These are general identifying conditions to assist in field explorations, however many more individual ones will be observed that are peculiar to the site under analysis.

Exploration of the site will not terminate with the construction of the field but will continue during the operation. Borings will be

carried on at selected spots with air photo mosaic maps being made to ascertain any forthcoming changes at the field or in the territory adjacent to the site. Such information will not only assist in determining the field's condition, but will furnish an excellent source of information for planning any stage or future construction.

Tables 2, 3, and 4 are examples of results of investigations of the structural properties of soils by the Russian Government.

TABLE 2--Continued

Investigator	Soil Type	Percent finer than			
		1.0 mm	.25 mm	.05 mm	.005 mm
Tsytovich, N. A. & Sumgin, M. I. 1937 (All specimens disturbed)	Frozen sand	100		0	
	Frozen dust-like	100		88.3	5.8
	Frozen sand&gravel	15			
	Frozen sand	56			
	Frozen dust-like				4
	Frozen silt-like	99.5			7
	Frozen clayey sand	95			10
	Frozen clayey type				45
	Frozen sandy clay	97			23
	Frozen clay&gravel	88			17
	Frozen dust-like				26
	Frozen dust-silt				22
Knomichevseaia, L.S. 1940	Permafrozen silt	100	59	2.	
	Permafrozen silt	100	76	34	2.3
	Permafrozen silt	100	76	34	2.3
	Permafrozen clay	100	98.7	94.7	21
	Permafrozen clay	100	98.7	94.7	21
	Permafrozen clay	100	99	97.8	14.6
	Permafrozen clay	100	92.5	86.1	10.5
	Permafrozen clay	97.7	77.2	27.2	12.4
	Frozen silty sand	100	99.6	64.2	9.1
	Frozen silty sand	100	99.6	64.2	9.1
	Frozen clayey sand	100	95.2	88.2	9.0
	Frozen silty sand	85.4	71	43.8	7.7
	Frozen silty sand	100	99.2	39.6	9.1
	Frozen clayey sand	100	96.4	65	9.1
	Frozen clayey sand	100	46.6	15.8	3.9
	Frozen clayey sand	100	96	51.2	5.4
	Frozen clayey sand	99	74.8	10.1	9.4
	Permafrozen sand	76.2	71.3	61.7	9.4
	Permafrozen sand	72.8	66.7	48.2	6.6
	Frozen clayey sand	100		34	
	Frozen gravel&sand	100		41	
	Frozen gravel&rock	21.4	14.9	9.1	1.9
	Frozen clay&rock	54.4	44.5	25.3	7.5

TABLE 2—Continued

Specific gravity	Average water content	Temperature of specimens (°F)	Average compressive strength (psi)	Remarks
	11.6	24.8	392	2cm cubes
		26.6	836	20cm cubes
	9.8	24.8	308	2cm cubes
	15.0	29.4	383	
	17.6	30.5—28.9	478	
	38.0	31.3	313	From tests to
	20.0	30.0	398	
	31.5	31.4—29.3	250	determine
	42.4	31.4—28.9	210	
	31.6	30.9—28.6	300	effect of
	23.0	28.8	313	
	52.0	28.4	412	soil gradation
2.81	24.4	29.8—9.1	1940	5cm cubes
2.80	26.8	28.6—23.0	1712	5cm cubes
2.80	24.0	30.9—24.8	1048	
2.81	32.8	28.6—10.8	586	5cm cubes
2.80	34.8	24.4—24.1	522	10cm cubes
2.43	91.8	29.6—16.0	703	5cm cubes
	188.0	29.8—28.2	662	6cm cubes
2.87	28.9	14.4	1855	7cm cubes
2.80	24.5	23.0	920	7cm cubes
2.80	41.5	12.2	1382	7cm cubes
			1025	4.5cm cubes
2.80	52.2	26.2	504	9cm cubes
2.88	25.6	25.9	890	5cm cubes
2.71	18.1	26.2	1540	8.5cm cubes
2.80	41.5	26.2	834	8.5cm cubes
2.80	42.7	21.2	1530	4cm cubes
2.80	30.2	21.2	1055	8cm cubes
2.80	23.6	27.5	794	7cm cubes
2.79	195.0	23.0	850	6cm cubes
	39.8	24.8—6.8	660	7cm cubes
	6.2	30.4—29.8	327	10cm cubes
2.83	16.9	24.8—23.0	670	
2.67	13.1	24.8—23.0	516	

TABLE 4

SHEAR STRENGTH OF FROZEN SOILS

Investigator	Soil Type	Average water content	Temperature of specimens (°F)	Average shear strength (psi)
Sheikov, M.L., Prof. 1931	Clayey soil	41.5	31.6—16.1	222
	Clayey sand	18.1	31.3—15.2	305
	Dust—silt	28.3	28.8	142
	Clay	34.0	28.8—28.2	104
	Clayey soil	29.0	28.6	128
	Sandy clay	29.4	30.4—28.2	124
	Sandy clay	29.0	29.6—27.0	126
	Clay&sand	19.0	29.1	154
	Sandy clay	49.0	30.0	213
	Dust—silt	55.0	30.9	111
	Dust—silt	26.0	29.1	142
	Sand	27.0	30.7—30.6	164
	Gravel	23.0	28.8	156
Laboratory of L.I.I.K.S. 1935-36	Clayey sand (disturbed)	19.0	24.8	357
Tsytovich, N.A. 1937	Sand	17.6	31.1—12.2	301
	Dust-like ground	28.0	31.1—14.9	249
	Sand	17.1	27.3	347
	Clay	53.6	31.1—14.0	135
Meister & Mel'Nikov 1939	Silty-dust soil	30.3	27.0— 0.6	164
	Silty-dust soil	40.6	26.2— 9.3	92

A Summary of Tables 2, 3, and 4

The following conditions were used to determine the structural properties of the frozen soils:

1. Loads were applied parallel to the direction of freezing in determining the compressive and tensile strength and perpendicular to the direction of freezing in computing the shear strength.
2. Uniaxial loads were applied for the tension compression tests while biaxial loadings were applied for the shear tests.
3. The clays and peats were tested in an undisturbed condition from the field with all other soils being remolded into the samples and tested. Test personnel considered samples representative enough of undisturbed field conditions to the extent that the natural frozen soil conditions were produced.

An analysis of the test data in the tables would indicate the following:

1. Generally, clean and cohesionless materials have the highest strengths when frozen and clays have the lowest.

2. The temporary strength of silt made up of non-clay minerals is approximately the same as that of the clay soils at temperatures near 32° F., however the strength increases very rapidly with a decrease in temperature.

3. The temporary strength of frozen soils increases when the temperature drops below freezing.

4. Clean uniformly graded sand has greater temporary strength when frozen than well-graded sands and gravels.

The temporary compressive strength of soils increases from four to nine times with decrease in temperature from freezing (31.5° F.) to -10° F. - the increase rate is the greatest in the first few degrees

below freezing. Temporary compressive strength values ranged from 1350 to 3230 psi at -10° F. and 170 to 760 psi at freezing (31.5° F.). Loading was applied at a rate of 400 psi/min.

At temperatures slightly below 32° F., changes in the rate of stress increase in the range from 200 to 1000 psi/min have very little effect upon the temporary compressive strength of the frozen soils.

Frozen soils and ice loaded in compression at temperatures from 26° to 30° F. each had continuous plastic deformation while being subjected to constant stresses that were less than 10% of the temporary compressive strengths at equivalent conditions. Ice had the least plastic deformation of all frozen materials tested while clayey and peaty soils had more plastic deformation susceptibility than the more course-grained materials.

At temperatures a few degrees below freezing the temporary tensile strengths in the specimens ranged from 36 to 178 psi and the temporary shear strengths varied from 72 to 189 psi.

Tables 2, 3, and 4 and the summary of the information contained in the tables is submitted as evidence of field and laboratory data that has been gathered during the last twenty years by the American and Russian Governments as listed in U. S. Corps of Engineers, SIPRE Report No. 8, June 1952. These data will greatly assist any field investigations into the strength of certain materials within a definite location.

below freezing. Temporary [illegible] ranged from
1350 to 3230 psi at -10° F. and 172 to [illegible] psi at freezing [illegible].
Loading was applied at a rate of [illegible].

At temperatures slightly below 32° F., changes in the rate of
stress increase in the range from 20 to [illegible] psi/min have [illegible]
effect upon the temporary compressive strength of the frozen soils.

Frozen soils and ice [illegible] deformation at temperatures
from 26° to 30° F. each bar [illegible] deformation while being
subjected to constant pressures that [illegible] than [illegible]% of the temporary
compressive strength at [illegible]. Ice had the least
plastic deformation of all [illegible] soils; clayey and
peaty soils had more plastic deformation susceptibility than the more
course-grained materials.

At temperatures a few degrees below freezing the temporary
tensile strengths in the specimens ranged from 16 to [illegible] psi and the
temporary shear strengths varied from [illegible] to [illegible] psi.

Tables 2, 3, and 4 and the summary of the information contained
in the tables is submitted as evidence of field and laboratory data
that has been gathered during the last twenty years by the American
and Russian Governments as listed in [illegible] S. Corps of Engineers [illegible]
Report No. 8, June 1952. [illegible] greatly [illegible]
investigations into the strengths of [illegible]
definite location.

D. Design and Construction of Runways

Any discussion of the design and construction of runways on permafrost possibly should be opened with a discussion covering the design and construction of Thule Air Base and the problems encountered during the construction.

Thule is located in north-western Greenland approximately 900 miles from the North Geographic Pole. As added information it might be stated that the United States received permission from Denmark to construct, operate, and maintain the big base under the NATO Treaty.

The importance of constructing the base can best be stressed by quoting from a speech made in 1951 by the U. S. Air Force General, Chief of the North-East Command:

> The air routes through the Arctic provide the shortest distances for air travel between major economic and industrial centers of Europe and the United States. A defense in this part of the world - and a strong one - is a requirement that cannot be ignored, for the following reasons:
>
> 1. This area lies on the direct sea and air routes between the north-eastern parts of the U. S. and the NATO nations in Europe. Personnel and material shuttle to and fro along this line of supply.
>
> 2. This area contains that portion of the western hemisphere which lies closest to Europe.
>
> 3. This area covers the air routes which a potential enemy could use to the greatest advantage in striking at Canada and the U. S. A.
>
> 4. This area provides an unexcelled vantage point from which to study mass air movement and forecast weather for military operations in the North Atlantic and in Western Europe.

D. Design and Construction of [illegible]

Any discussion of design and construction [illegible] permafrost, probably should be [illegible] the design and construction of [illegible] during the construction [illegible].

[illegible] 900 miles from [illegible] might be [illegible] Denmark to construct [illegible] NATO treaty.

The importance of [illegible] by quoting [illegible] Chief of [illegible]:

> The air route [illegible] airport [illegible] [illegible] for the NATO [illegible].
>
> 1. [illegible] and the [illegible] suitable [illegible].
>
> 2. This area [illegible] western hemisphere [illegible].
>
> 3. This area [illegible] [illegible] the U.S.
>
> 4. The [illegible] point [illegible] used [illegible] for military operations in the North Atlantic and in Western Europe.

The Air Force first acquainted the Corps of Engineers with the Thule project late in 1950. Instructions stated that the completed airfield with supporting facilities must be in operation by 1 October, 1951. A small inspection and reconnaissance team flew to the Danish weather station airstrip at Thule in January, 1951, to conduct the initial survey prior to starting construction. The advance construction team arrived in May, 1951, to set up beach facilities and living quarters for the main construction teams. The airbase was used by an airplane for the first time on 11 September, 1951, pointing out the fact that a permafrost airbase may be prepared within a short period of time given enough equipment, personnel, and information regarding the site. Usually (as at Thule) major construction must be performed during the summer months when the weather is fine and the harbors are free of ice - the most important factors which determine how much time is required for construction of the airbase.

No effective outside construction work could be carried out from November through April due to the -45° F. temperatures and 125 MPH winds. The first large construction team arrived by sea off Thule on 9 July, 1951, with more than 300,000 tons of cargo being unloaded during the two months the harbor was ice-free.[1] The expression "the land of the midnight sun" is appropriate for this area because from the first part of May to the 20 of August there is continual daylight, while

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[1]Major A. C. Cooper, "Arctic Air Base", Royal Engineers, (London), Dec. 1955.

The first major construction performed was the providing of docking facilities for the enormous quantities of cargo that would have to be handled as quickly as possible. The main structural configuration of the dock was furnished by four barges each measuring fifty by 250 feet which had been towed from the Gulf of Mexico. Each of the barges contained tubes which were fitted with caissons when the barges were positioned in the docking area. The caissons were lowered to the ocean bottom and after the barges were raised on the caissons, the caissons were then cut off at the deck level and filled with concrete. The barges were used as decking material. A stone causeway measuring fifty by 1000 feet was used to supplement the pre-fabricated dock to make a combined dock of 100 by 1000 feet. The docking facilities handled approximately 500,000 tons of cargo during the years 1951 through 1953.

It was decided that the thermal regime balance beneath the constructed installations at the base was to be maintained by using the following methods: insulation, ventilation, and a combination of ventilation and insulation. However, it was found at the site that the majority of the buildings should be constructed using the combination method - which proved to be the most practical.

Beneath the majority of the buildings such as offices, storerooms, housing, warehouses, etc., a pad of non-frost-acting soil (well graded sand and gravel) was used to take the place of the active zone. Mudsills made of twelve by twelve inch wooden timbers eighteen inches long of which six inches was buried in the insulating pad, were used

The first major [illegible] the provision of docking facilities for the enormous amount of cargo that would have to be handled as quickly as possible. The main structural configuration of the dock was furnished by four barges each roughly fifty by 250 feet which had been towed from the Gulf of Mexico. Each of the barges contained [illegible] which were filled with caissons when the barges were positioned in the docking area. The caissons were lowered to the ocean bottom and after the barges were raised on the caissons, the caissons were then cut off at the deck level and filled with concrete. The barges were [illegible]. A [illegible], measuring fifty by 1000 feet was used to supplement the pre-fabricated units to make a combined dock of 100 by 1000 feet. The docking facilities handled approximately 900,000 tons of cargo during the years 1951 through 1953.

It was decided that the thermal regime beneath each [illegible] constructed installation at the base was to be maintained by using the following methods: insulation, ventilation, and a combination of ventilation and insulation. However, it was found at the site that the majority of the buildings could be constructed using the ventilation method - which proved to be the most economical.

Beneath the majority of the buildings such as offices, storerooms, housing, warehouses, etc., a pad of non-frost-susceptible soil (well graded sand and gravel) was used to take the place of the active zone. Backfill made of twelve by twelve inch wooden timbers [illegible] long of which six inches were buried in the gravel pad, were then

as a foundation. The mudsills were placed at eight foot intervals. Two and one-half inch thick shims or insulators were attached to the top of nine inch high dwarf columns which were in turn placed on the top of the mudsills. Six by twelve inch timber stringers resting on the shims were used to support the insulated flooring. The result of this type of construction is that there is at least two feet nine inches distance between the ground surface and the floor. The dwarf columns which are poor conductors of heat, form the only contact between the ground and the building. In such a position the exposed portions of the columns are completely surrounded by cold air. These construction methods are conductive to continuing of the thermal balance in the ground.

Buildings for boilers, generators, and other heavy stationary equipment were built on reinforced concrete slabs two feet eight inches thick which were supported on piles driven seven to eight feet into the permafrost. The active zone was removed and replaced with the usual pad of non-frost-acting material. The concrete flooring was supported on the piling such that there existed a foot airspace between the floor and the ground surface. Buildings such as hangars, garages, and fire stations whose operations required that the floor line be near ground level, used a variation of the above construction. Enough of the active zone was removed to allow a three foot thick non-frost-acting pad topped with the required thickness of reinforced concrete slab.[1]

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[1]Cooper, <u>op. cit.</u>, p. 342.

as a foundation. The pedestals were [illegible] rock intervals. Two and one-half inch piling, driven by [illegible] on the top of nine inch high steel columns which [illegible] were placed on the top of the pedestals. [illegible] inch high [illegible] resting on the piling were used to support the insulated floor. The [illegible] of this type of construction is that there is at least two feet nine inches distance between the ground surface and the floor. The steel columns which are poor conductors of heat, form the only contact between the ground and the building. In such a position the exposed portions of the columns are completely surrounded by cold air. These construction methods are conducive to maintaining of the thermal balance in the ground.

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[1]Cooper, op. cit., [illegible]

The pad beneath the hangars had twelve inch diameter corrugated metal pipes located on three foot centers for the full length of the building in the direction of the prevailing winds. The cold air enters the pipes at the up-wind ends and passes through the pipe to be discharged at the opposite ends. These pipes act as under-floor ventilators and thereby keep the pad's temperature close to that of the outside air.

A special type of pre-fabricated building called the Clements panel construction was used to construct all surfaces of the general purpose buildings such as barracks, offices, power plants, warehouses, etc.[1] The panels were prefabricated with three and one-half inches of Fiberglas insulation between two sheets of aluminum-clad one-quarter inch plywood.[2] These type of buildings were in reality built on the reverse principle of the conventional walk-in refrigerator.

The main air-strip which was 10,000 feet by 300 feet wide was quite naturally the major construction requirement at the airfield. One major part of the construction was the active layer which was mostly quakey soil required removed from beneath the locations of the runways, taxiways, hardstands, and aprons.[3] The bottom three feet of the fill consisted of rocks up to two feet in size while the

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[1]Ibid., p. 343.

[2]Sturgis, Samuel D., "Arctic Engineering---Gets Test at Thule", Civil Engineer, (Sept., 1953), p. 587.

[3]Smith, Vincent B., "Construction Details Bared on Thule Air Base Project", Engineering News Record, (2 Oct., 1952), p. 22.

The [illegible] the hangars and [illegible] of [illegible] metal pipes located [illegible] the [illegible] outside building [illegible] of the [illegible] the pipes at the [illegible] ends and [illegible] changed at the [illegible]. These pipes [illegible] inlets and [illegible] the [illegible] temperature [illegible] that of the outside air.

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The main [illegible] 10,000 feet [illegible] quite [illegible] one major part of the construction [illegible] mostly [illegible] the runways, [illegible] foot of the [illegible]

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[1]Ibid., p. [illegible]

[2][illegible], "[illegible]," Civil Engineering, [illegible]

[3]Smith, [illegible], "[illegible] Base Projects," [illegible] News-Record, [illegible]

top two feet had maximum size rocks of eight inches. The lower six inches of the surface course was made up of rocks with a maximum size of two and one-half inches. The two and one-half inch binder course was a hot-mix asphaltic concrete with maximum size aggregate of one and one-half inches. The wearing surface had a maximum size aggregate of three-quarter inch in the one and one-half inches of hot-mix asphaltic concrete. The binder course material was made from aggregate produced from local stream gravel, and crushed screened diorite rock was used in the wearing surface.[1]

Excavation at the airbase required the moving of over two million cubic yards of material, while over ten million cubic yards of non-frost acting material was used as fill. The permafrost that had to be removed during excavation was blasted with powder and used as fill on the 200 foot shoulders.

Over 1000 vehicles of all types were used to carry out the task of construction of the base so quickly. Water used for construction and operation of the base was obtained from three purification units set up on the beach plus Crescent Lake, six miles distance.[2] An earth dam was built at the lake to increase the water-retention capacity of the natural facility. After the water was chlorinated and filtered it was transported by a fleet of heated tank trucks.

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[1]Sturgis, *op. cit.*, p. 588.

[2]*Ibid.*

top two feet had [illegible]. Three and [illegible] inches of the surface course [illegible] with a surface [illegible] of two and one-half inches. [illegible] was a [illegible] concrete [illegible] and one-half inches. The [illegible] of three-quarter inch [illegible] tile concrete. The [illegible] produced from local [illegible] gravel, [illegible] was used in the [illegible].

Excavation at [illegible] amounted to over two million cubic yards of material, [illegible] of non-frost [illegible] material [illegible] used as fill. [illegible] had to be [illegible] as fill on the [illegible].

Over 1000 vehicles [illegible] peak of construction of the [illegible]. [illegible] struction and operation of [illegible] fication units set up [illegible] distance.[2] An earth dam was built [illegible] retention capacity of the [illegible] chlorinated and [illegible] tank trucks.

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[1]Brandt, op. cit., p. [illegible]

[2]Ibid.

The vehicles were supplemented with two primary crusher units and four combination primary-secondary units with an average daily production rate of over 3000 cubic yards. Three continuous batching hot asphalt plants produced 1000 tons of binder course and 1000 tons of wearing surface each day. All mechanical equipment was maintained and serviced right on the construction site by mobile service units. Major repairs were made at buildings set aside for such purposes at the center of the construction project.

The 7000 feet of usable temporary runway was completed by September 1951, however the runway was not paved until 1952 at which time it was extended to a length of 10,000 feet.

One source of information and knowledge the Corps of Engineers had regarding airfield permafrost construction, was that acquired from "Operation Nanook" in which a small landing strip had been constructed glacial moraine north of Thule Village in 1945. This operation demonstrated that an active layer must be removed and replaced with sand and gravel.[1] During this removal, as in the case of most active layer-removals, about one and one-half feet of the permafrost was removed to provide a level footing for the fill. The effectiveness of using stream gravel and native rocks in both crushed and natural state for the fill and the base course was also demonstrated during the construction of the earlier airbase.

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[1]Besing, R., "Operation Nanook Airfield Construction", Engineering Aviation Battalion Report No. 1, M-32774-R, (1946), p. 12.

The vehicles [illegible] and

four combination [illegible]. In

production runs of over 2000 [illegible]

hot asphalt plants produced [illegible] tons of [illegible]

of wearing surfaces on [illegible]. [illegible] and equipment were [illegible]

and serviced right up [illegible].

Major repairs were made at [illegible]

the center of the construction area.

The 7000 feet of [illegible] temporary runway was [illegible] by September 1951, however the runway was not paved until 1952 at which time it was extended to a length of 10,000 feet.

One source of information and knowledge was [illegible] Engineers had regarding subgrade permafrost construction, [illegible] gained from "Operation Snowman" in which a small [illegible] was constructed [illegible] glacial moraine north of [illegible] in 1950. This operation demonstrated that an [illegible] could be removed and replaced with sand and gravel.[1] During this [illegible] of work active layer-removal, about one and one-half feet of the permafrost was removed to provide a level [illegible]. The effectiveness of using stream gravel [illegible] in both [illegible] and natural state for the fill and base course was also demonstrated during the construction of the earlier runway.

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[1]Healy, R., "[illegible]," Engineering Aviation Battalion Report No. 1, [illegible], p. [illegible].

Any construction attempted in the Arctic or sub-Arctic will have to take into consideration how the efficiency of a man while performing outside tasks will vary with the temperatures. The following table represents the findings of several observations by American military forces during various construction projects in these cold regions.

TABLE 5

Temperature (°F.)	Percentage of Efficiency
70	100
20	75
0	50
-23	25
-40	14 Point where Arctic natives become inactive.
-50	10 Point where man can no longer work outside---energy needed to survive.
-80	0

The two main types of construction undertaken in the permafrost regions are passive and active. The passive construction type involves very little if any disturbance of the active zone or the permafrost layer, while the active construction type pertains to any removal or disturbance of the active zone and upper surfaces of the permafrost layer.[1] Simply stated, aggressive construction methods are termed just that. The degree of aggressiveness may vary on a large heavy construction project.

The design of the runways and other construction features at

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[1]Black, Robert L., "Permafrost", Applied Sedimentation, (1950), p. 260.

the airfield site is based upon the use of an active type of construction.

Success or failure of any construction attempted at the site will definitely depend upon the amount and type of construction equipment or special transportation which is moved into the area. Primary importance is given to heavy construction equipment, such as D-7, D-8, D-9, or equivalent size track-type tractors, self-loading graders and scrapers, large rooters or scarifiers, four to five cubic yard dump trucks, 1 cubic yard or larger shovels, and heavy duty escalator-type loaders. The equipment that is next in importance during the early construction stages is the soil stabilization equipment, such as sheepsfoot rollers, scrapers, steel-tired rollers, and wobble-wheeled rollers. Pneumatic compressors, air-operated equipment, steam generating equipment, steam jets, and drilling equipment are also required. Double-ended sleds, extra wide tracks, and other special traction devices should be among the first construction equipment transported to the site. The efficiency of all motorized equipment will be increased if winches are mounted to each unit. In addition, provisions should be made to have fire-fighting equipment available or adapt existing construction equipment to serve such a need. All equipment should be winterized and waterproofed with sufficient replacement parts furnished for a nearly continuous operation. Gasoline, oil, or similar type engine heaters are required for starting motorized equipment when the temperature falls below 0° F.

Special types of equipment and items used for this type of

the airfield site is [illegible] of [illegible].

Success or failure of any construction [illegible] will definitely depend upon the amount and type of construction equipment or special transportation which [illegible]. Particular importance is given to heavy construction equipment, such as D-8, D-9, or equivalent size track-type tractors, self-loading [illegible] scrapers, large [illegible] graders, [illegible] dump trucks, 1 cubic yard or larger shovels, and [illegible] loaders. The equipment that is needed to [illegible] construction stages is the soil stabilization equipment, [illegible] sheepsfoot rollers, [illegible] rollers. [illegible] compressors, [illegible] ating equipment, steam jenny, and drilling equipment [illegible]. Double-ended [illegible], extra wide [illegible] devices should be among the first [illegible] to the site. The efficiency of all [illegible] equipment will be increased if [illegible]. Provisions should be made to have [illegible] existing construction equipment [illegible] should be standardized and [illegible] parts furnished for [illegible] or similar type [illegible] equipment [illegible].

Special [illegible]

construction should include the following: winter tractor-train freighting equipment (this equipment should include heavy duty double-ended sleds which proved highly successful during "Operation Deep-freeze" in the Antarctic), three portable steam generators complete with points and hose for thawing frozen materials, and all necessary blasting supplies and equipment.

The construction items and equipment as well as personnel equipment and clothing should all be of the quality that will operate efficiently under the hardships and rigors of construction in these regions. If faulty equipment is not observed until it arrives at the site, the supply of spare parts will soon be depleted with a resultant loss to equipment and efficiency.

Plans for moving to the construction site should be formulated only after careful study of the terrain with the benefit of the advice and experience of natives of the regions. A pioneer construction party should construct a temporary road from the docking facility to the site where a pioneer or temporary landing strip should be built. This temporary strip will be used to handle the supplies, personnel, and equipment that will be air transported during the main construction phase. The pioneer construction party should start to move overland with the temporary road during late fall as it is generally more practicable to move overland and set up the construction area during the time when any bodies of water will be frozen.

The major construction phases at the airfield site should be planned so as to take the best advantage of weather conditions in the

construction should [illegible]
freighting equipment ([illegible]) [illegible]
ended sleds which proved highly successful [illegible]
freeze" in the [illegible]. These [illegible]
with points and hose for [illegible]
blasting supplies and equipment.

The construction items and equipment [illegible]
equipment and clothing should [illegible] operate
efficiently under the exacting [illegible]
regions. [illegible]
site, the supply of spare parts [illegible]
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Plans for moving [illegible] construction [illegible] should be formulated
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and experience of [illegible]
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to the site where a [illegible] temporary landing strip should be [illegible].
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with the temporary [illegible]
practicable to move [illegible]
the time when any bodies of water [illegible].

The major construction equipment [illegible] should be
planned so as to [illegible] in the

the region. The following information pertains to the types of work which may be accomplished in a particular season and are the results of observations made by the U. S. military forces while constructing and operating bases in permafrost regions:

(a) Work that could be most efficiently accomplished during the winter season.

1. Construction of temporary compacted snow and earth road to airfield site.

2. Overland tractor-train operations for moving supplies and convoys of construction equipment over temporary road.

3. When temporary road reaches airfield site, construction of compacted snow airstrip should commence so air supply lifts may start as soon as possible.

4. Erection or temporary portable buildings for personnel and equipment.

5. Establishment of radio and other like forms of communications.

6. Gathering of data on the weather conditions, such as snow, wind, fog, ice, and temperatures.

7. Checking of all equipment at construction site for more continuous uninterrupted usage during coming spring and summer season.

8. Stockpiling all types of supplies brought in by air lifts or tractor trains - especially heating and engine fuels.

9. Stockpiling of any native materials that will be used during the construction period. Such materials will include rocks, gravels, sand, and timber (if available).

10. Transporting of water handling equipment to nearby fresh water source.

(b) Work that could be most efficiently accomplished during the warm season.

1. Locating and establishment of source for gravels, crushed stones, and stone that are to be used for fill and other construction materials at the airfield.
2. Construction of roads between material sources and construction.
3. Removal of snow and vegetation over areas where construction will be performed.
4. Start of major construction phase as the site.
5. Development of permanent water supply with necessary distribution system to the airbase.
6. Start of excavation of active zone and upper portion of permafrost layer beneath runway and other surface handling locations.
7. Start of construction of storm and sanitary drainage system.
8. Preparation of insulation pads where required at building locations.
9. Establishment of facilities for reducing native timber to useable lumber (in areas where suitable timber is available).
10. Start of construction of foundations for all buildings at the site.
11. Collecting and stockpiling any necessary construction materials that will be used during the approaching winter months.
12. Construction and location of windbreaks for combating blowing snows on all roads, runway, airplane handling surfaces, some buildings, and any other facilities that might require such protection.
13. Stockpiling of heating and engine fuel, food, and equipment that will be needed for the winter season.

The listed operations for construction of the airfield do not have to strictly follow the order as given, but such operations should generally adhere to the order as stated. All operations must be

considered with the construction of the main runway as the governing factor. The order of construction of all other installations must be planned such that maximum service can be provided airplanes as each particular useable length of the main runway is completed. Because of the military importance of the location of the airfield, it is imperative that its useful operation commence as soon as possible even if on a limited capacity at the early stages.

The active zone beneath the runway and other airplane-handling surfaces should be entirely removed except where the subsurface soil profile shows non-frost susceptible materials to be present. In addition to average five feet depth of the active zone, approximately eighteen inches of the permafrost table should be removed. This removal of the upper surface of the permafrost will provide a more sure foundation by eliminating irregularities as well as active zone impurities in the surface of the permafrost.

The removal of frozen portions of the active zone plus the upper surface of the permafrost will each have to be expedited by the use of blasting powder, heavy duty rooters or scarifiers, heavy duty scrapers, pneumatic equipment, and power shovels. The best removal methods will be ascertained at the site, however it is assumed that the blasting powder will be used as the primary equipment for fracturing the frozen materials while the other equipment will be used to break some of the material into smaller pieces so that it may be easier to handle. Self loading graders, power shovels, and trucks will be used to remove the materials. The cross section of the amount

considered with the [illegible] of the [illegible] factor. The order of [illegible] planned such that [illegible] particular usable length of [illegible] of the military importance [illegible] imperative that [illegible] even if on a limited [illegible].

The active [illegible] surfaces should be [illegible] profile shows non-frost [illegible] addition to average five-foot [illegible] eighteen inches of the [illegible] removal of the upper portions of the [illegible] sure foundation by [illegible] impurities in the [illegible].

The removal of [illegible] upper surface of the permafrost will [illegible] use of blasting powder, heavy [illegible] scrapers, pneumatic equipment, and [illegible] methods will be ascertained [illegible] the blasting powder will be used [illegible] during the frozen [illegible] to break some of the [illegible] easier to handle. [illegible] will be used to [illegible]

of material to be removed is shown in Figure 7 in an earlier part of this thesis.

Material that is removed from these locations should be disposed of in such a manner that drainage or other features of the site will not be jeopardized. A possible location for this material might be in some vicinity where a wind break was required. Any location chosen to accommodate the material for wind break purposes, should be investigated very thoroughly so the melting or other change in the material will not interfere with any operations at the base.

The material should be removed to the full depth for a useable length of the runway and then replaced with non-frost susceptible material rather than removing the full depth for the entire length. If this method is not followed, there will be some danger of thawing the permafrost and causing an unnecessary amount of water to make the construction task more difficult. This does not mean to state that the melting ability of the thawing season should not be taken advantage of by uncovering the frozen material ahead of the location that has already been back-filled with the stones and gravels. The thawing may be used to assist in the blasting and removal operations by hauling fill materials while the above-freezing temperatures are doing their work.

A study should be made at the site to determine the most efficient use of equipment for removal of the unwanted material and hauling in of the fill material. The access roads from the locations of the material sources should enter the main construction area at

of material to be [illegible]

this thesis.

Material that is removed [illegible]

posed of in such a manner [illegible]

will not be jeopardized. A [illegible]

be in some vicinity [illegible]

chosen to accommodate the [illegible]

be investigated very thoroughly [illegible]

the material will not interfere [illegible]

The material should be removed [illegible]

length of the runway and [illegible]

material rather than removing the full [illegible]

If this method is not followed, there will [illegible]

the permafrost and stabilized [illegible]

the construction task very difficult. [illegible]

that the melting ability of the [illegible]

advantage of by uncovering the [illegible]

that has already been pre-thawed [illegible]

thawing may be used by [illegible]

by hauling fill material while the [illegible]

doing their work.

A study should be made [illegible]

efficient use of equipment [illegible]

hauling in of the fill material [illegible]

of the material removed should [illegible]

central locations to enable traffic to move in a fluid manner.

Due to the fact that an average depth of at least six and one-half feet of material will be removed to eliminate the frost susceptibility and that the permafrost of suitable thickness is as resistant as bedrock to loads, the depth of the fill material will be adequate enough to furnish the required structural quality of an adequate foundation. Plainly stated, if all the frost susceptible material is replaced with well graded rock and gravel, and the location is well drained, such fill material will most certainly furnish an excellent base course.

When the fill or base course is placed upon the permafrost, special care must be undertaken to provide drainage laterals for excess water that is forced out of the permafrost and surrounding materials. Trenches will be dug into the permafrost at each side of the runway and other similar surfaces for their entire length. These trenches will be backfilled with aggregate up to three inches in size, and connected to subdrains in the drainage system to lead the water away from the construction site. By thus reducing the subgrade moisture content, better compaction will be possible and the subsequent settlement of the base course will be reduced.

Excavation of the active zone and upper layer of the permafrost beneath the runway location, should be performed in 4000 feet sections. Immediately after the excavation has reached its full depth along a 4000 foot portion of the runway section, the construction of the base course should be started. This method of construction is

utilized in order that a shorter prepared length of the runway be placed in service and emergency use while the remaining portion is under construction.

The lower three feet of the base course should be made up of crushed quarry material that is angular in shape and has a maximum dimension of eighteen inches. This lower level should be placed in two equal thickness lifts with each being traffic compacted by the equipment as the base course work progresses. Bull dozers and graders should be used to place the base course material after it is hauled in by trucks, trailers and scrapers. There should be enough smaller particles in the material of the lower level to remove the possibility of having any of the large rocks becoming islands. Such isolated material would move when construction traffic passed over them and thereby cause a cavity that would result in unsuitable bearing qualities in the base course. While construction of the base course is progressing, some of the lower portion of the base course will settle into the melted upper surface of the permafrost and cause the fine material to ooze up into the base.

The remaining two and one-half feet of the base course should be constructed of the same type of crushed quarry material as the lower level, however the maximum size of the aggregate should be six inches. This portion of the base course should be constructed in six inch lifts with compaction being supplied by the construction traffic and sheepsfoot rollers. The amount of four inch or larger aggregate should not exceed 50% by volume of the upper portion of the base course.

utilized in order that [illegible] proposed lengths of the highway be placed in service and emergency [illegible] while the remaining portion is under construction.

The lower three inches of the base course [illegible] made up of crushed quarry material, each [illegible] and [illegible] direction of [illegible]. This layer [illegible] be placed in two equal thicknesses [illegible] with [illegible] the equipment on the base course [illegible]. [illegible] and graders should be used to place the base course material after it is hauled in by trucks, tractors and scrapers. [illegible] smaller particles in the interstices of the larger [illegible] to ensure [illegible] possibility of having any of the large rocks [illegible]. [illegible] isolated material would [illegible] them and thereby [illegible] bearing qualities in the base course. While construction of the base course is [illegible], some of the lower portion of the base course will settle into the [illegible] and cause the fine material to [illegible].

The remaining [illegible] and one-half inches of the base course should be constructed of the same type of crushed quarry material as the lower level, however the maximum size of the aggregate should be six inches. This portion of the base course should be constructed in [illegible] inch lifts with compaction being [illegible] and sheepsfoot rollers. The [illegible] should not exceed [illegible] by volume of the upper portion of the base course.

The disposal of the 2,000,000 plus cubic yards excavated from beneath the locations of all airplane surfaces should be planned with as much care as that which is expended in placing the base course materials. As previously stated some of the material can be used as wind breaks for buildings and other structures. The excavated material usually contains a great amount of frozen water, and consequently when it thaws there may be some movement in the material. This movement can be lessened or controlled by constructing trenches that are one foot deep by one foot wide located ten feet on centers in the ground surface beneath the disposal piles.

This material should not be disposed of on the sides of slopes that are steeper than three on one. The slopes on the material disposal piles should not exceed four on one due to movement mentioned above and also because all this material is of the frost susceptible type and would be affected by freeze-thaw cycles. This material should not be used for any roads, foundations, or any other construction purposes at the airfield site.

Some settlement will occur in the over 2,000,000 cubic yards of base course used along the airplane handling surfaces, which will necessitate construction of temporary surface courses until subgrade conditions become stable. While these temporary surfaces are in use, extensive and continuous maintenance must be conducted to keep them in useable condition. The temporary wearing surface will be laid down upon the five inch lower portion of the surface course and this temporary one and one-half inch surface will become a part of the

The disposal of the 2,000,000 cubic yards of unclassified fill beneath the locations of all airplane surfaces should be placed with as much care as that which is expended in placing the base course materials. As previously stated some of the material is satisfactory for wind breaks for buildings and other structures. This material usually contains a great amount of frozen water, and consequently when it thaws there may be some movement in the material. This movement can be lessened or controlled by constructing trenches that are one foot deep by one foot wide located ten feet on centers in the ground surface beneath the disposal piles.

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Some settlement will occur in the over 2,000,000 cubic yards of base course used along the airplane landing surfaces, which will necessitate construction of temporary surface courses until subgrade conditions become stable. While these temporary surfaces are in use, extensive and continuous maintenance must be performed to keep them in useable condition. The temporary landing surface should be laid down upon the five inch lower portion of the surface course and this temporary one and one-half inch surface will become a part of the

three inch binder course as shown on Figure 7.

The five inch layer of aggregate which makes up the lower portion of the surface course should contain two inch maximum size material and a sieve analysis which falls within the following limits of Table 6.

TABLE 6

Passing	Percentage by weight
2 inch sieve	100
1 1/2 inch sieve	70-95
1 inch sieve	60-85
3/4 inch sieve	50-75
3/8 inch sieve	40-70
No. 4 sieve	25-55
No. 10 sieve	20-45
No. 40 sieve	10-30
No. 200 sieve	5-15

The sieve analysis of the lower portion of the surface course is very similar to the materials required for granular stabilized roads.

The materials which make up the upper portion of the surface course should be placed in two lifts of approximately two and one-half inches of thickness each, with the material being spread by a screed device and compacted by the hauling vehicles and wobble wheel rollers. At least four passes should be made over each lift to secure an efficient surface course.

The one and one-half inch temporary surface which makes up half of the binder course will be laid upon the five inch surface course and this dense-graded mix should contain one and one-half inch maximum size aggregate and fall within the following sieve analysis

three inch binder course as shown in [illegible].

The five inch [illegible]

portion of the surface course should [illegible]

material and a sieve analysis [illegible]

of Table 6.

TABLE [illegible]

Passing	Percentage by weight
2 inch sieve	[illegible]
1 1/2 inch sieve	[illegible]
1 inch sieve	[illegible]
3/4 inch sieve	[illegible]
3/8 inch sieve	[illegible]
No. 4 sieve	[illegible]
No. 10 sieve	[illegible]
No. 40 sieve	[illegible]
No. 200 sieve	[illegible]

The sieve analysis of the lower portion of [illegible]

is very similar to the [illegible]

The materials which make up the upper portion of [illegible]

course should be placed in [illegible]

inches of thickness each, with the material being [illegible]

device and compacted by [illegible]

At least four passes should be made [illegible]

efficient surface course.

The one and one-half inch [illegible]

half of the binder course will be [illegible]

course and this [illegible]

maximum size aggregate [illegible]

limits of Table 7.

TABLE 7

Passing	Percentage by Weight
1 1/2 inch sieve	100
1 inch sieve	60-75
3/4 inch sieve	55-65
3/8 inch sieve	50-60
No. 4 sieve	45-55
No. 10 sieve	35-50
No. 40 sieve	20-40
No. 200 sieve	5-15

Grades MC-2 and MC-3 liquid asphalt will be used in the hot plant mix at the ratio of approximately 8% by weight. These liquid asphalts of the medium cure variety are especially suited for extreme climatic conditions and the asphalt percentage is higher than normally used in a more temperate zone, in order to provide a more durable surface course.

When the temporary wearing surface has been constructed on both the emergency strip and the main runway as well as the remainder of the airplane handling surfaces, the work on these surfaces should be suspended until the next spring and summer. This suspension will allow the subgrade and base course to become stabilized and will give more time and energies to construction of the building units at the site. A seal or waterproofing coat of MC-3 at the rate of one-tenth of a gallon per square yard of surface area should be applied in order to protect all the surfaces until construction is completed the following summer.

Asphalt or flexible pavement should be used in lieu of concrete or rigid pavement in the surface course. The rigid pavement would normally resist applied loads more successfully than the asphalt pavement, however with the high type of foundation qualities furnished by the permafrost and the base course, the difference is practically non-existent. In addition, the flexible pavement may be placed at much lower temperatures than the concrete and thereby increase the number of days when pavement may be laid. The low temperature application is a very important factor in the construction of the runway and other airplane handling surfaces.

Time and motion studies conducted by the U. S. Air Force have revealed that jet airplanes require the times mentioned for the following phase of operation: three and one-half minutes for warming-up while parking, thirty seconds spent taking off the runway, fourteen minutes spent on the maintenance apron-made up of two cycles of seven minutes each (five and one-half minutes at 40% throttle and one and one-half minutes at full throttle).[1] Flexible pavements suffer more damage than the concrete pavements from the hot jet blasts. Within the design of flexible pavements, open graded asphaltic concrete mixes will furnish more resistance to the high temperatures and blast forces than the dense graded mixes.[2]

The flexible pavement should not have a thickness of greater

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[1]Kilrain, W. A., "Jets Pose Airport Design Problems", American Aviation, (25 May, 1953), p. 37.

[2]Ibid., p. 38.

Asphalt or flexible pavement would be used in limited patches or rigid pavement in the extreme margin. The rigid pavement would normally render applied loads more efficiently than the asphalt pavement, however with the [illegible] type of construction, [illegible] by the [illegible] and the base course. The [illegible] non-existent. In addition, the flexible pavement may be obtained at much lower [illegible] than [illegible] number of days than [illegible] application in a very limited [illegible] of the runway and other airplane handling surfaces.

Tire and surface studies [illegible] for the U. S. Air Force have revealed that jet airplanes require the [illegible] for the following phases of operation: [illegible] while parking, [illegible] minutes spent on the [illegible] of seven minutes each (five and one-half minutes of [illegible] and one-half minutes at full [illegible]).[1] [illegible] damage than the concrete pavement [illegible] the design of flexible pavement, [illegible] mixes will [illegible] forces than the dense graded mixes.[2]

The flexible pavement should [illegible]

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[1]Kilming, W. A., "[illegible]," Aviation (27 Feb. 1953), p. 57.

[2]Ibid., p. 31.

than five inches, otherwise the pavement will be more susceptible to freezing and thawing all their destructive forces. The pavement material should be of the hot plant mix type, with transportation furnished by fast moving vehicles that have covered bodies to keep the mix as warm as possible while in transit.

After the base course and subgrade has been allowed to become stabilized (approximately one year after the temporary surface has been placed), about one-half inch of the surface is removed so as to affect a more desireable bond with the remainder of the binder course. The three inch binder course will have the same mix design as that used for the temporary wearing surface. All airplane handling surfaces should be surfaced with a binder course before the wearing surface course is applied to any surface. This method should be used to enable the asphalt mixing plant to turn out one continuous design rather than discontinuing operations to change the design from the binder course to the wearing course. The end of the lane of pavement should be given a chisel configuration or "feathered" when the paving application crew leaves to place pavement at another location. This shape should be carried throughout the pavement operation at any terminal edges to curtail spalling-off or other failures in the pavement. However when a pavement is placed against an edge that is "feathered", this edge should be cut so as to furnish a good clean vertical butt joint for strength reasons.

A minimum of three days should be allowed before the MC-3 tack course is applied to any surface of the binder course. The

than five inches, otherwise the pavement will [illegible] freezing and thawing and their destructive [illegible]. The [illegible] material should be of the hot plant mix type [illegible] furnished by truck having vehicles that [illegible] the mix as warm as possible while in transit.

After the base course and subgrade has been allowed [illegible] stabilized (approximately one year after the temporary surface has been placed), about one-half inch of the surface is removed so as to [illegible] a more desirable bond with the remainder of [illegible] course. [illegible] three inch binder course will [illegible] design [illegible] for the temporary wearing surface. All [illegible] should be surfaced with a binder course before the [illegible] course is applied to any surface. This method would [illegible] enable the asphalt mixing plant to [illegible] rather than discontinuing operations to [illegible] binder course to the wearing course. The [illegible] ment should be given a rounded configuration [illegible] when the paving application crew leaves the place [illegible] This shape should be carried throughout the pavement [illegible] any terminal edges to [illegible] pavement. However when a pavement is placed [illegible] "feathered", this edge should be cut [illegible] vertical butt joint for strength reasons.

A minimum of three days should be [illegible] tack course is applied to any surface of the binder course. [illegible]

quantity of MC-3 necessary for this course should be one-tenth of a gallon per square yard of surface area, and such application should preceed the machine that is applying the wearing surface by at least two hours, otherwise the soft bituminous material will be carried off by vehicles' tires. It is not good practice, however, to apply the tack coat over any area that will not receive an application of the wearing surface within twenty-four hours.

The one and one-half inch thickness of wearing surface should contain three quarter inch maximum size aggregate, 9% MC-3 liquid asphalt by weight, and fall within the sieve analysis limits as shown in Table 8.

TABLE 8

Passing	Percentage by Weight
3/4 inch sieve	100
3/8 inch sieve	60-85
No. 4 sieve	50-65
No. 10 sieve	35-50
No. 40 sieve	15-30
No. 200 sieve	5-15

The wearing surface like the binder course should be rolled with a steel-tired roller for at least four passes to obtain a maximum amount of compaction.

The specifications for both the binder and wearing surface as listed in this thesis are generally what the final mixes should be, however, various inspections will be performed on the materials and the mixes to determine if the design is suitable. Sample cubes of the

mixes should be made up in the field laboratory to determine such items as the theoretical maximum density, percent of voids in the paving, apparent specific gravity, percent of bituminous materials, sieve analysis, and any other design data. Any deviation in the mixes found from the laboratory data may be corrected as such mixes are normally corrected when under engineering controls.

The wearing surfaces should be at least six inches above the surrounding terrain in order to provide an adequate surface drainage system. The upper surface of the wearing courses should be protected from moisture penetration by an application of MC-3 liquid asphalt at the rate of one-twentieth of a gallon per square yard of surface area. The wearing surfaces should be crowned one-quarter inch per foot downward from the centerline to provide a run-off for any surface moisture.

Military airplanes have recently started putting smaller tires with higher pressures of up to 350 psi on combat airplanes, which places a more severe loading condition on the airstrips. As a direct result of this change in airplane design the handling surfaces have had to become more heavy duty in nature as the design in this thesis. The increase in tire pressures was made to decrease heating of the tires as well as decreasing the tire size.

Heavy duty airplane handling surfaces such as this design must have a log kept of their material peculiarities, if any, during the construction, so that any marginal areas may be observed during airfield operation and any required maintenance may be made early

mixes should be made up in the [illegible] to determine such items as the distribution, [illegible], proportion of [illegible] paving, asphalt specific gravity, [illegible] sieve analysis, and any other design [illegible] found from the laboratory [illegible] may be [illegible] are normally [illegible] concrete.

The [illegible] should be [illegible] above the surrounding terrain in order to provide an adequate surface drainage system. The upper surface of the [illegible] should be protected from moisture penetration by an application of [illegible] at the rate of one-tenth of a gallon per square yard of surface area. The [illegible] should [illegible] per foot downward from the [illegible] to provide a [illegible] for any surface moisture.

Military airplanes have recently [illegible] smaller tires with higher pressures of [illegible] psi [illegible] aircraft, which places a more severe loading condition on the [illegible]. As a direct result of this change in airplane design [illegible] surfaces have had to become more heavy duty in nature [illegible] in this thesis. The increase in tire pressure [illegible] heating of the tires [illegible].

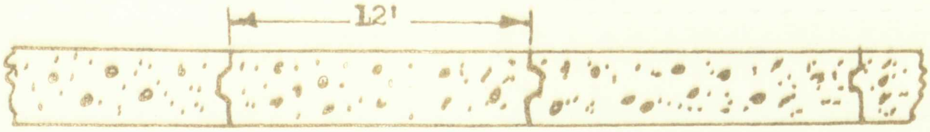
Heavy duty [illegible] must have a [illegible] during the construction, so that [illegible] airfield [illegible]

enough to avert unnecessary deterioration. In certain areas on the handling surfaces where the blasts and heat from the jets are constantly destroying the flexible pavement, rigid pavement may be substituted. Such conditions might exist at warm-up aprons or at run-up locations on the airplane maintenance hardstands. A typical rigid pavement design is shown in Figure 9.

A factor that should be also considered is that the Air Force might use the strip on an overload condition to handle either heavier or more airplanes for a temporary period during an emergency.

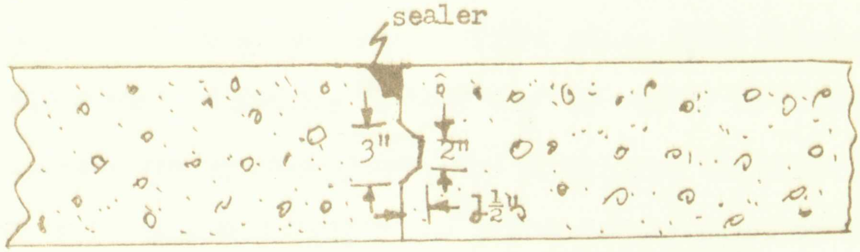
enough to avert [illegible] on the
handling surfaces where [illegible] from the [illegible] con-
stantly destroying the flexible pavement, which must not be per-
mitted. Such conditions might exist [illegible] or at various
locations on the airplane [illegible]. A typical [illegible]
pavement design is shown in Figure [illegible].

A factor that should be also considered is that [illegible]
might use the [illegible] a nearby [illegible]
or more airplanes for a [illegible] period [illegible].

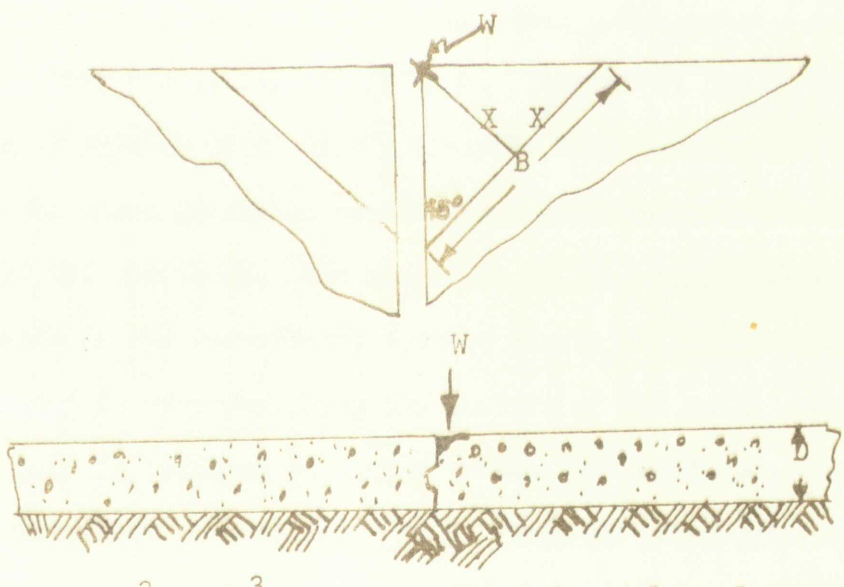


UNIFORM THICKNESS PAVEMENT DESIGN

Design of a rigid plain concrete pavement used at hardstands, warm-up aprons, hangar ramps, turn-outs (at the ends of the runway), and aprons.



KEYED LONGITUDINAL CONSTRUCTION JOINTS



$$I = \frac{BD^3}{12} = \frac{2XD^3}{12}$$

S = flexural modulus of concr. 700psi

$$Mom = WX = \frac{SI}{C} = \frac{S\frac{2XD^3}{12}}{\frac{D}{2}} = \frac{SXD^2}{3}$$

Fig. 9.-Basic rigid pavement design

E. Design and Construction of Service Facilities

Pilings form a very vital part of the foundations for many of the buildings at the construction site. However, it should be readily understood that it is improbable and almost impossible to drive piles into the frozen material of the permafrost. The most practical method of combating this difficulty is to use a steam jet to thaw a hole large and deep enough to accommodate a driven pile. This steam method of thawing the ground is similar to that used by miners in cold water thawing for placer mining operations - the miners put the water onto the location to be thawed and after the colder temperatures of the soil had replaced the warmer temperatures of the water, the water was replaced with fresh warmer water and the process was repeated.

The steam issues from a one inch steam point under a pressure of forty to fifty pounds per square inch. This steam jet is connected to sections of driving pipe while a flexible hose furnishes the connection to the steam generator connection. Protection shields are provided for the operators. The steam jet is gradually driven to the required depth in the permafrost, and the length of time needed to thaw the ground is dependent upon the texture of the soil. Approximately one hour is required to thaw a twelve inch hole about ten feet deep into permafrost that is composed of sandy or silty material. Three hours is the time required to melt a hole ten feet deep for the same size pile into a clayey permafrost.

The difference between the thawing times in the two materials is that in the sandy soils the heat penetrates the spaces between the

the particles by the process of the water's circulation and filtering actions. The process is slower in more impermeable or clayey soils due to the fact that the heat transfer or thawing is a function of the natural conduction process which is slower. When each hole is thawed to the desired depth, the piles are driven butt down to refusal. Good engineering practices dictate that the piles should be checked by additional driving two days after they were initially driven.

Experience gained from previous construction on permafrost indicates that the ground begins to refreeze very quickly after a thawing. Usually within ten days of the start of thawing operations, the temperatures in the materials around the piles have dropped to below freezing.[1] No loads should be placed upon the piles for at least two weeks as this is the time usually required for the piles to become firmly attached to permafrost by the ad-freezing process. The Russian military forces usually conducted the pile driving operation in the autumn and allowed the piles to stand all winter before any construction work is started on them.

The piles when driven into permafrost utilize the adfreezing strength of the frozen material to the pile. A value of approximately 10,000 pounds per square foot of pile surface area will be exerted on the wooden and steel piles when driven into clay soils or ice. Permafrost that is made up of gravel material will furnish a value of 6000 pounds per square foot of pile surface area while clay soils will

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[1]D'Appolonia, E., "Permanently Frozen Ground and Foundation Design", The Engineering Journal (Jan., 1946), p. 10.

the particles or the process of natural consolidation and alteration actions. The process is [illegible] due to the fact that the [illegible] the natural [illegible] process [illegible] is shown. [illegible] thawed to the [illegible] Good engineering practice dictates that [illegible] by additional driving [illegible]

Experience gained from previous construction on permafrost indicates that the ground begins to [illegible] thawing. Usually within ten days of the start of [illegible] the temperatures in the [illegible] around the piles have dropped to below freezing.[1] No loads should be placed on the piles for at least two weeks as this is the time usually required for the piles to become firmly attached to permafrost. [illegible] The Russians [illegible] in the autumn and allowed the piles to [illegible] construction work [illegible] them.

The piling when driven [illegible] strength of the [illegible] 10,000 pounds per square foot [illegible] the wooden and steel [illegible] Frost [illegible] 6000 pounds per square foot of pile surface [illegible]

[1] [illegible] "Permafrost [illegible] Design", The Engineering Journal, [illegible]

have a value of approximately 15,000 pounds per square foot. The total force supplied by the piling to any structure constructed above it can be increased by using, in the case of wooden piles, very rough posts; and in the case of steel piles, ones that have deformed surfaces.

One of the remaining features pertaining to the pilings is that if hollow steel piles are used, refrigerants may be pumped into coils within the piles' cores if there is any indication of the permafrost material thawing around the surface of the piles. After the piles have been driven into place, collars which are equal in height to the depth of the active zone are placed around the piles. These collars should have an internal diameter that is four inches larger than the external diameter of the piles. This method of using loose collars has been found to be very satisfactory in cancelling out any forces delivered by the active zone in the form of heaving or adfreezing.[1]

The load capacity of a pile in permafrost is greater than the same pile in equal depth of identical material in an unfrozen state. The pile in permafrost delivers its load to the soil in the two conventional ways:

(a) by friction with the soil, and
(b) by point bearing.

The frictional load delivered to the soil is greatly increased by the adfreezing and ice crystallization forces between the permafrost and the pile. The friction forces between the soil and the pile may

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[1]West, C. P., Arctic Air Institute Problems - Air University (March, 1949), p. 11.

have a value of approximately [illegible] kips per square foot. When the total forces supplied by the piling [illegible] be increased by [illegible] and in the case of steel piles, [illegible].

One of the [illegible] is that if hollow steel piles are used, [illegible] within the piles [illegible] material [illegible] around the surface of the piles. After the piles have been driven into place, casings which are equal in height to the depth of the active zone are placed around the piles. These [illegible] should have an internal diameter that is [illegible] larger than the external diameter of the piles. This method of [illegible] has been found to be very [illegible] by the active zone [illegible].

The load capacity of [illegible] same pile in [illegible]. The pile in [illegible] conventional means:

(a) by [illegible] and
(b) by [illegible].

The [illegible] by the [illegible] and the pile. The [illegible] the soil and the pile [illegible]

[illegible], C. E., [illegible] (March, 19[illegible]), p. 1[illegible].

be less due to the steam jet method, but the adfreezing and ice crystallization forces will be so great that any deficit of friction forces need not be considered.

One item not to be overlooked is that the hollow steel piles when first placed may tend to float out of the hole due to water in the bottom. This may be counteracted by placing weights on each pile until the water finally freezes.

The principle installations at the airbase which fall into the classification of service facilities are the various buildings such as hangars, housing, hospital, chapel, dining and recreation units, administration buildings, garages, control towers, fire stations, equipment buildings, generator and heavy equipment buildings, boiler houses, and other service buildings. The remaining service facilities will include the following: radar equipment including ground-control-approach equipment, radio transmission equipment including towers, weather station, wind direction indicating equipment, runway lighting equipment, water supply system with storage tanks, sewerage system, fuel dumps, bomb and ammo dumps, above and below ground service trenches, roads, fencing, and other incidental but vital service facilities.

The general locations of the buildings are as shown on the map accompanying this thesis and any general location of a building is determined by its relationship to other buildings at the site. At a military installation such as this, the location is further controlled by service, dispersion and administrative factors, however the precise location will be determined by the following natural factors:

be less due to [illegible], and the [illegible] of the crystallization [illegible] [illegible] forces need not be considered.

The [illegible] to be [illegible] when first placed [illegible] the bottom. This [illegible] until the water finally [illegible].

The principle [illegible] classification of [illegible] hangars, housing, [illegible] administrative buildings, [illegible] equipment buildings, [illegible] houses, and other service buildings. [illegible] will include the [illegible] approach equipment, [illegible] weather station, [illegible] equipment, water supply [illegible] fuel dumps, [illegible] roads, fencing, and other [illegible].

The general [illegible] accompanying [illegible] determined by [illegible] military [illegible] by service, [illegible] location will be [illegible].

(a) Condition of active zone and permafrost

If there are any large layers or lenses of ice in the active zone, the source of the moisture should be checked to see that there will be no large movement of water during the thawing season. Even the non-frost susceptible foundation material will be somewhat affected by such movement. Any large areas of ice in the permafrost could be adversely affected by piling that might be driven into them. The piling when first driven into the permafrost might thaw the ice body and cause the piling to lose some of its foundation qualities.

(b) Winds

Because the winds in the permafrost regions tend to blow at very high speeds (winds in the Antarctic have been measured at speeds of over 200 mph.), the locations of the different service facilities must not be chosen without considerations being given the winds and their directions.

Facilities such as service buildings, dining facilities, and latrines must always be located near the housing for personnel. Snow tunnels may be constructed between the buildings when enough snow becomes available.[1]

All buildings should be located with their longest axis parallel to the prevailing winds' direction.

If shelters such as banks, hills, or other geographic features are available, the buildings' locations may be changed to serve the best advantage.

The possibility of an excessive amount of snow build-up or drifts must also be considered before a choice of facility location is made. Buildings should not be "shelved" on a hillside or should not be constructed on a steep hillside because both of these locations are apt to have steep drifts and consequently cause avalanches or snow slides which are quite destructive. Steep hillsides that face the hot sun are also poor choices for locations because they are usually the scene of snow slides during the spring months.

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[1]Karatun, F., Defenses Under Winter Conditions, Moscow, SSR (1940), p. 30.

(c) Surface and underground drainage

Any facility site chosen must be free of all evidence of ground movement and surface ice.

(d) Exposure

Housing should face the sun whenever possible, and the use of gentle sunny slopes should be made available to utilize the radiant heat as well as the sunlight.

(e) Dispersion

Proper dispersion must be taken of the locations of buildings and building groups to lessen the explosion and fire hazards.

Construction of facilities will alter the thermal regime of the ground as has been previously explained in this thesis. Therefore positive actions will be undertaken to protect the permafrost and its bearing capacities. The three general types of foundations are as shown in Figure 10. The specific type of foundation chosen for each building will depend upon the following factors:

(a) Area of building and type of loading.
(b) Whether building is heated or unheated.
(c) Ground water movement.
(d) Type of building that will come into contact with ground surface.

Buildings such as hangars, garages, and fire houses that have to be constructed with their floor lines just slightly above the surface of the ground, must be placed on a pad of non-frost susceptible fill material used to replace the active zone.

Boiler houses, power houses, and other buildings that contain heavy equipment must be constructed on reinforced concrete slabs that rest on pilings which have been driven a minimum of ten feet into the permafrost. The heavy equipment buildings must be underlain with a

(c) [illegible]

Any facility above [illegible] ground [illegible].

(d) [illegible]

[illegible] the [illegible].

(e) [illegible]

Proper [illegible] and building [illegible].

Construction of [illegible] small portions of the

ground as has been [illegible]. [illegible]

positive actions will be [illegible] and the

bearing capacities. The three general types of [illegible] are

shown in Figure [illegible]. The [illegible] type of [illegible] chosen for each

building will depend upon the [illegible]:

(a) [illegible]
(b) Whether [illegible]
(c) [illegible]
(d) Type of [illegible] surface.

Buildings such as [illegible] have

to be constructed with [illegible] above the sur-

face of the ground, [illegible]

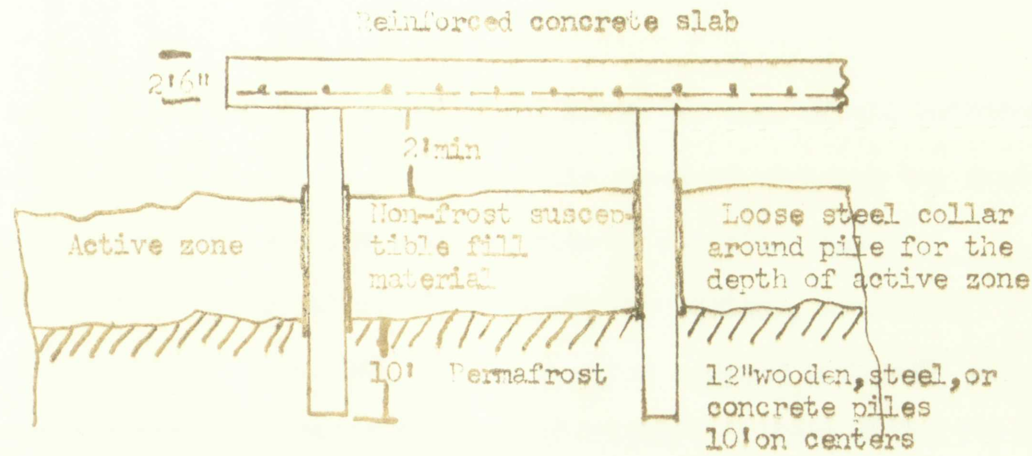
fill material used to [illegible].

[illegible]

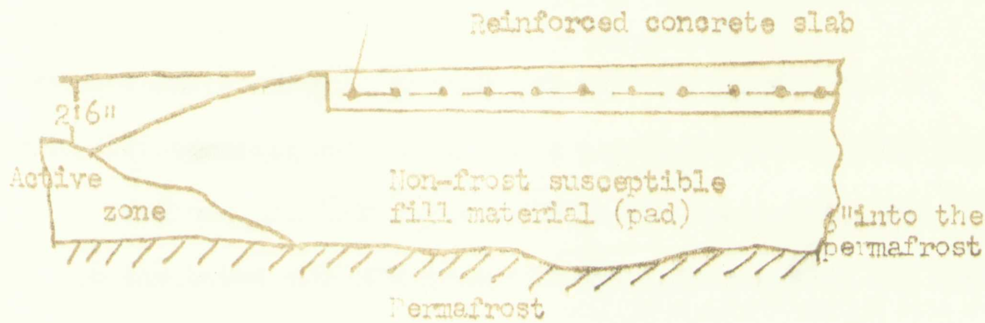
heavy equipment [illegible]

rest on pilings which were [illegible] the

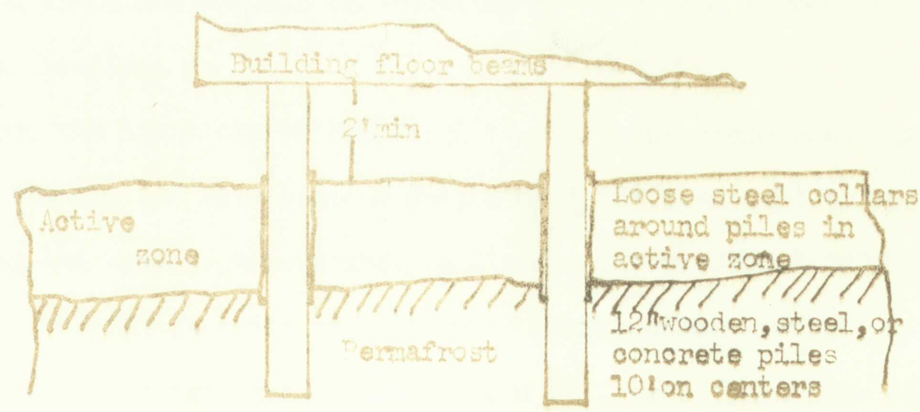
permafrost. [illegible]



DETAILS FOR POWER HOUSE,BOILER HOUSE,AND
HEAVY EQUIPMENT BUILDINGS



DETAILS FOR HANGARS,FIRE HOUSES,GARAGES,ETC



DETAILS FOR HOUSING,OFFICES,EQUIPMENT AND
PERSONNEL BUILDINGS

Fig.10.-Foundation details for buildings on permafrost

pad of non-frost susceptible material and as in the case of all buildings constructed on pilings, there must be an air space of at least two feet between the ground surface and the underside of the flooring.

Barracks, dining halls, administration buildings, latrines, buildings containing light equipment, plus other similar buildings will all be constructed on piles that have been driven a minimum of ten feet into the permafrost. The passive method or rather non-removal of the active zone was employed beneath these buildings to secure a permanent foundation.

Water storage tanks at the airbase will be constructed on reinforced concrete slabs and piles with a non-frost susceptible pad in a fashion like the buildings housing the heavy equipment. The tanks will be insulated with six inches of spun glass around all surfaces with the bottom raised about ten inches above the concrete slab. The space between the bottom of the tank and the top of the slab will be enclosed and a heater will be installed in this area to keep the water from freezing.

When the locations of buildings requiring the non-frost susceptible material pad have been chosen, a definite plan must be worked out to make the most of the weather conditions for construction purposes. These types of buildings are usually under construction shortly after the necessary personnel buildings have been finished. This plan of construction operations should be accomplished approximately in the following order and style:

(a) A sufficient supply of three-quarter inch maximum

graded angular material must be stockpiled within a close proximity of the areas where these materials will be required. If this is not done at this time, the movement of such material over the service roads will tend to magnify the traffic problems, and any road failures would hold up the construction of the foundation.

(b) Enough area must be laid out beyond the outer boundaries of each building to allow for at least a three on one slope at the edge of the excavation. Removal of the active zone plus approximately one and one-half feet of the top of the permafrost layer should be performed as at the airplane handling surface locations - that is by exposure to the sun's rays, with explosives, or a combination of the two methods. By the thawing operation, an average of three inches of the frozen subsoil may be removed daily.[1] Daily thawing will remove enough material until the required depth is reached.

(c) The stockpiled material should be placed in six inch lifts immediately after the excavation is completed in order to protect the frozen permafrost from deterioration due to the warm temperatures. The six inch lifts of material should be compacted with wobble-wheeled rollers with enough material being placed until the elevation of the material has an elevation of approximately two feet six inches above the natural ground surface. Where the compacted material is used under a building that has pilings and an air space, the elevation of the top of the material should not be more than three inches above the surrounding surface material.

(d) Excavations should be made in the compacted material to accommodate the piers, footings, and foundation slabs.

It should be stated at this point that any service lines such as sewerage, steam, and water should come into the building in an above ground utilidor rather than one that is of the underground variety. Any service lines which passes through the compacted angular material would give off heat that in turn would thaw the permafrost and cause a drop in its bearing qualities. See Figure 11 of this thesis for a view of above and below ground utilidors.

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[1]U. S. Army, Construction Bulletin, TB 5-255-3 (Aug., 1950), p. 41.

THEORY DESCRIPTION:

FAST FREEZE OCCURS AT "A" BENEATH THE TRENCH WHICH CAUSES GROUND WATER TO BREAK THROUGH THE GROUND SURFACE UPHILL AND FORM SURFACE ICE BEHIND THE DIKE

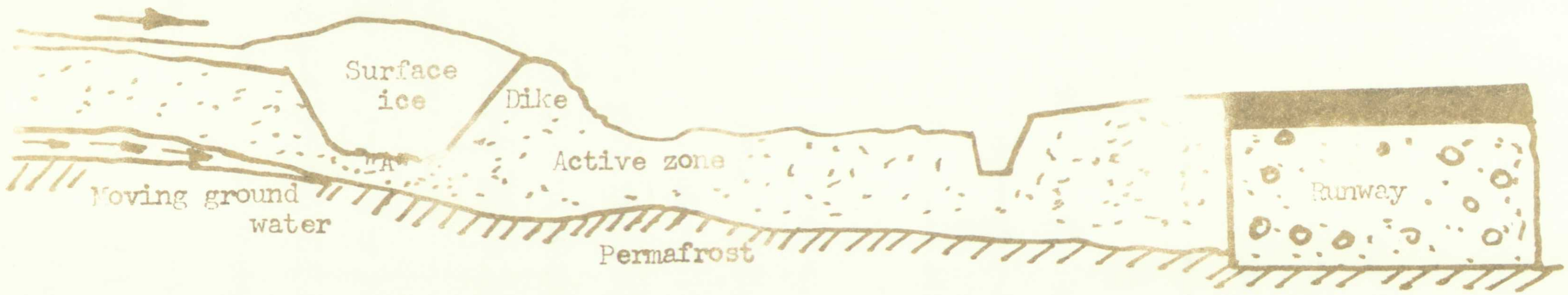

Fig. 11.-Method for causing an induced field of surface ice to form

With the exception of the large buildings such as hangars, power houses, boiler houses, fire stations, and other large structures; the buildings should be of the prefabricated variety. This type of construction facilitates the erection of the buildings in this region where weather-working days are at a premium. The specific type of prefabricated buildings should be of the six inch thick double wall type with cavity insulation of the Thule Airbase variety. All the buildings should be insulated and when the building is constructed on pilings this insulation should also be placed beneath the floor. An insulating tile of sufficient compressive strength should be used on the concrete slab of larger buildings.

The basic design of the buildings will be of the same type as used at large airbases in the temperate regions. The exterior of the majority of the buildings will be metal, steel usually, while the remainder will be wooden with a very few made of brick and masonry. Figure 13 in this thesis is a sketch of the hinged shields or aprons that are used on the lower portions of the exposed southern sides of the buildings to deflect the sun's rays.

The design of the hangar should be such that the largest airplanes that will use the airbase can use the hangar's services. A reinforced concrete ramp two feet thick should be constructed from the hangar entrance to the airplane handling surface and this ramp like all other surfaces which airplanes will roll over, should have a slope which is no steeper than one on fifty. Steeper slopes cause more damage to the surfaces from the greater forces needed by tugs and

With the exception of the hangars, [illegible]

power houses, boiler houses, [illegible]

the buildings should be of the prefabricated type [illegible]

construction facilitates the erection of the buildings [illegible]

where weather-working [illegible] The [illegible] type of

prefabricated buildings should be of [illegible]

type with ceiling insulation of [illegible] All

buildings should be insulated and [illegible]

pilings this insulation should also be [illegible]

insulating tile or [illegible] should be used on

the concrete slab of larger buildings.

The basic design of the buildings will [illegible]

used at large [illegible]

majority of the buildings will be [illegible] while the

remainder will be [illegible] with a [illegible] and [illegible]

Figure 13 in this [illegible] of the [illegible]

that are used on the [illegible] of the [illegible]

the buildings to deflect the [illegible]

The design of the hangar should [illegible]

airplanes that will use the airport [illegible]

A reinforced concrete [illegible]

the hangar entrance to the [illegible]

like all other surfaces [illegible]

a slope which [illegible]

more damage to the [illegible]

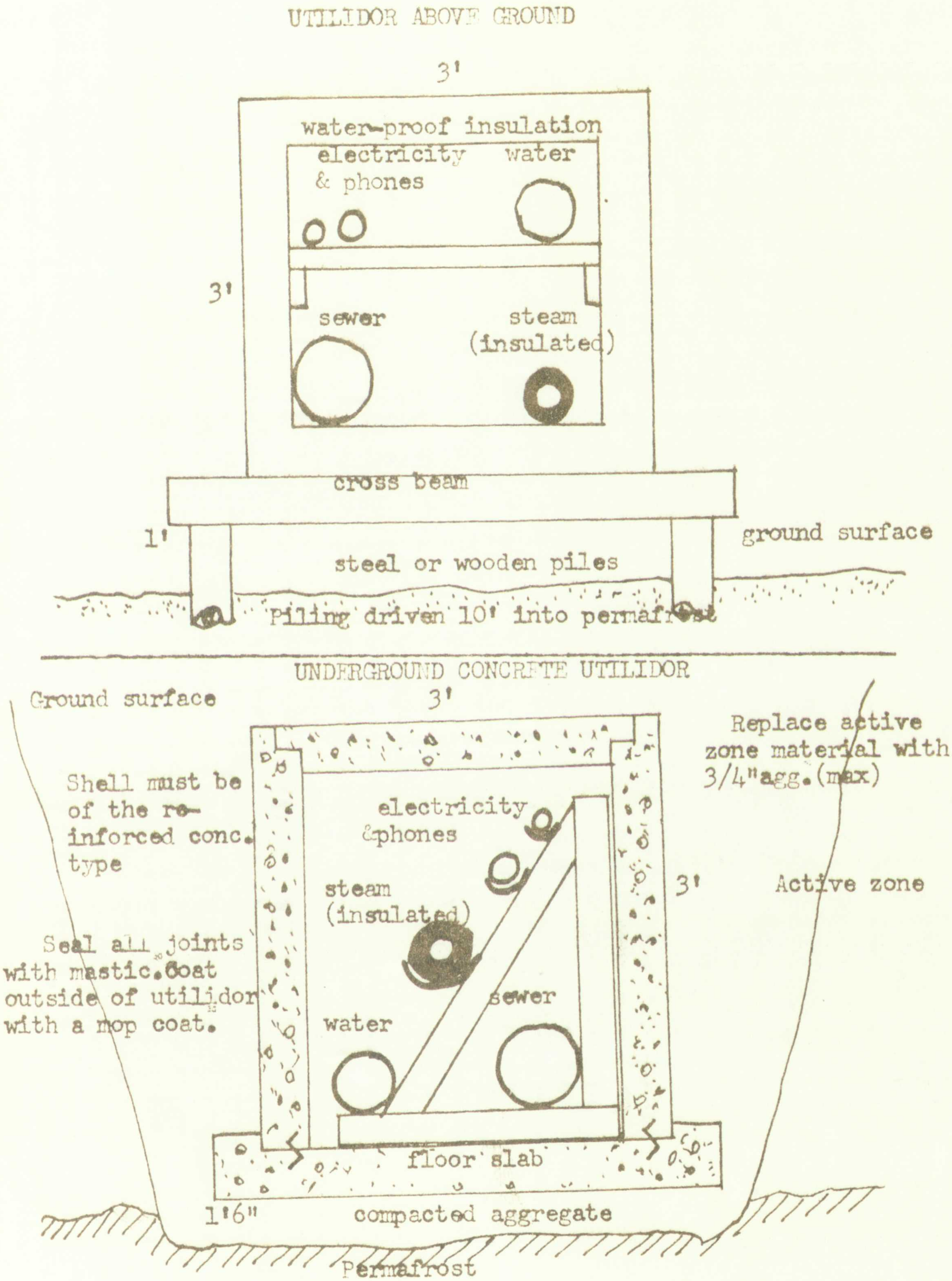

Fig. 12.-Typical sections through utilidors

tractors to move the planes and this same force tends to inflict damage upon the plane's landing gear.

All reinforced concrete slabs and ramps should be constructed of 3000 psi concrete using one inch diameter reinforcing bars space on one foot centers in two directions. No specific design of the concrete mix or steel requirement was entered into in this thesis or any other specific unit, but rather an overall design of the construction and operation of the entire airbase and its environs.

The buildings should all be designed to resist high winds with velocities up to 125 mph and heavy snow loads. Any large overhanging roof sections should not be constructed on any buildings as these will suffer much damage from the winds. To combat heavy snows and layers of snow and ice on the roofs, provisions must be made to allow for the use of equipment to remove any excessive weight of moisture. Studies should be made to ascertain the possibility of using fences, rakes, vortex generators, or other such devices to utilize the wind's force for snow removal. Thawing and freezing after a heavy snow will cause the layered snow and ice which when repeated several times puts a very large load upon a roof and necessitates immediate removal. These high winds will either block with drifting snow or blow off any door which opens outward. If an inward opening door can not be used, rolling or sliding doors should be utilized to lessen the possibility of damage or inconvenience.

The entire length of the runway should be lighted on each side with conventional all-weather runway marking lights. These identifying

tractors to move the plane and this same [illegible] [illegible] [illegible] [illegible]

upon the plane's landing gear.

All reinforced [illegible] [illegible] [illegible] [illegible] [illegible]

of 3000 psi concrete and [illegible] [illegible] reinforcement [illegible]

on one foot centers in both directions. No [illegible] [illegible] the

concrete mix or steel reinforcement was [illegible] [illegible] [illegible]

any other specific unit, but rather an overall [illegible] [illegible] [illegible]

and operation of the entire [illegible] [illegible] [illegible].

The buildings should all be designed [illegible] [illegible] [illegible] [illegible]

velocities up to 225 mph and heavy snow loads. The large [illegible]

roof sections should [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

suffer much damage from the winds. [illegible] [illegible] [illegible] [illegible]

of snow and ice on the roofs, [illegible] [illegible] [illegible] [illegible]

the use of equipment to remove [illegible] [illegible] [illegible].

Studies should be made to ascertain the [illegible] [illegible] [illegible]

rakes, vortex generators, or other [illegible] [illegible] [illegible] [illegible]

force for snow removal. [illegible] [illegible] [illegible] [illegible] [illegible]

cause the layered snow and ice [illegible] [illegible] [illegible] [illegible]

a very large load upon a roof and necessitate [illegible] [illegible].

These high winds will [illegible] [illegible] [illegible] [illegible] [illegible]

door which opens outward. [illegible] [illegible] [illegible] [illegible] [illegible]

rolling or sliding doors should be utilized [illegible] [illegible] [illegible]

of damage or [illegible].

The entire layout of the [illegible] [illegible] [illegible] [illegible] [illegible]

with conventional all-weather [illegible] [illegible] [illegible] [illegible]

lights should be mounted on brackets attached to an underground electric service tunnel that is similar in construction to the underground utilidor shown in Figure 12. The standard wind direction indicator should also be lighted and connected into the electrical circuit for the runway lights. The electric lines between these two facilities and the power house should pass underground in an enclosed wooden service tunnel of sufficient size that is a minimum of two feet beneath the surface. This type of service should be used to carry all of the electric circuits throughout the base. The underground electric tunnels will lessen the interruption of electric service during inclement weather which might occur if conventional utility poles and lines were used. Additional outside flood lighting should be provided on the hangars for after dark servicing of the airplanes. Outside lighting must also be installed on the personnel and equipment buildings to facilitate personnel movement during the evening hours.

The necessary radio and radar transmission antenna should be installed near the runway to complete the ground-control approach system. All radio and radar towers should be moored with insulated steel cables that are anchored concrete "dead men" to resist any wind loads. These towers should be marked with obstruction lights to prevent a possibility of accidents.

The control tower should be seventy-five feet high and be located near the center of the runway and about 250 yards away from the edge. The tower should be of steel construction with the control cabin being insulated with double layer six inch insulated panels on all surfaces.

lights should be mounted in brackets [illegible] underground elec-
tric service [illegible] that is similar in construction to the [illegible]
utilities shown in Figure 17. The [illegible]
should also be lighted and connected [illegible]
the runway lights. The electric lines between the [illegible]
and the power house should be [illegible]
service tunnel of sufficient size [illegible]
the surface. This type of service [illegible]
electric circuits throughout the base. [illegible]
will lessen the interruption of electric service during inclement
weather which might occur if conventional utility poles [illegible] were
used. Additional outside flood lighting should be provided on the [illegible]
hangars for after dark servicing of the airplanes. [illegible] lights
must also be installed on the personnel and equipment [illegible] to
facilitate personnel movement during the evening hours.

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steel cables that are anchored [illegible]
loads. These towers should [illegible]
prevent a possibility of accidents.

The control tower should be [illegible]
near the center of the runway [illegible]
The tower should be of steel construction [illegible]
insulated with double layer [illegible]

The stairwell should be heated and service lines such as steam, water, sewerage, electric and telephone should be carried in this enclosed stairwell. The area enclosed by the tower legs at the ground surface should be four times the area of the bottom of the control cabin.

All the buildings will be heated by steam from a centrally located oilfired boiler house. All steam lines will be insulated with two inches of asbestos material and carried in above ground or underground utilidors. The buildings should also have "aprons" on the south side to protect the frozen material from a rapid and damaging thaw as shown in Figure 13.

In addition to supplying heat for buildings, the steam lines will be used to keep the water lines from freezing during the cold season. Sufficient standby oil heaters should be available to heat such buildings as housing, dining hall, control tower, office buildings, hangars, and fire stations in the event of a break-down in the central heating plant.

One of the more important service facilities which should be developed early during the construction phase is a suitable water supply. Any suitable lakes and streams may be developed as water supply sources by constructing retention dikes, channels, bowls, or underwater intakes. Such water bodies should be within five miles of the base and be of sufficient depth in order that the water does not freeze for its entire depth. The surface water sources should be supplemented with wells that penetrate to ground water that lies below the permafrost layer. If the permafrost layer is not over 100-125

the stairwell should be [illegible] and [illegible] water, [illegible], sewerage, electric and telephone should [illegible] stairwell. The area [illegible] by the [illegible] should be four times the area of the [illegible] of the [illegible] cabin.

All the buildings [illegible] located [illegible] boiler house. [illegible] two inches of [illegible] ground [illegible]. The buildings should also have [illegible] on the south side to protect the [illegible] them as shown in Figure 11.

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THESE DEVICES ARE TO BE PLACED ON THE SOUTHERN SIDE OF ALL BUILDINGS WHICH USE PILINGS FOR A FOUNDATION. THEIR USE IS INTENDED TO PROTECT THE FROZEN MATERIAL FROM THE SUN'S RAYS BY REFLECTION DURING THE WARM SEASON

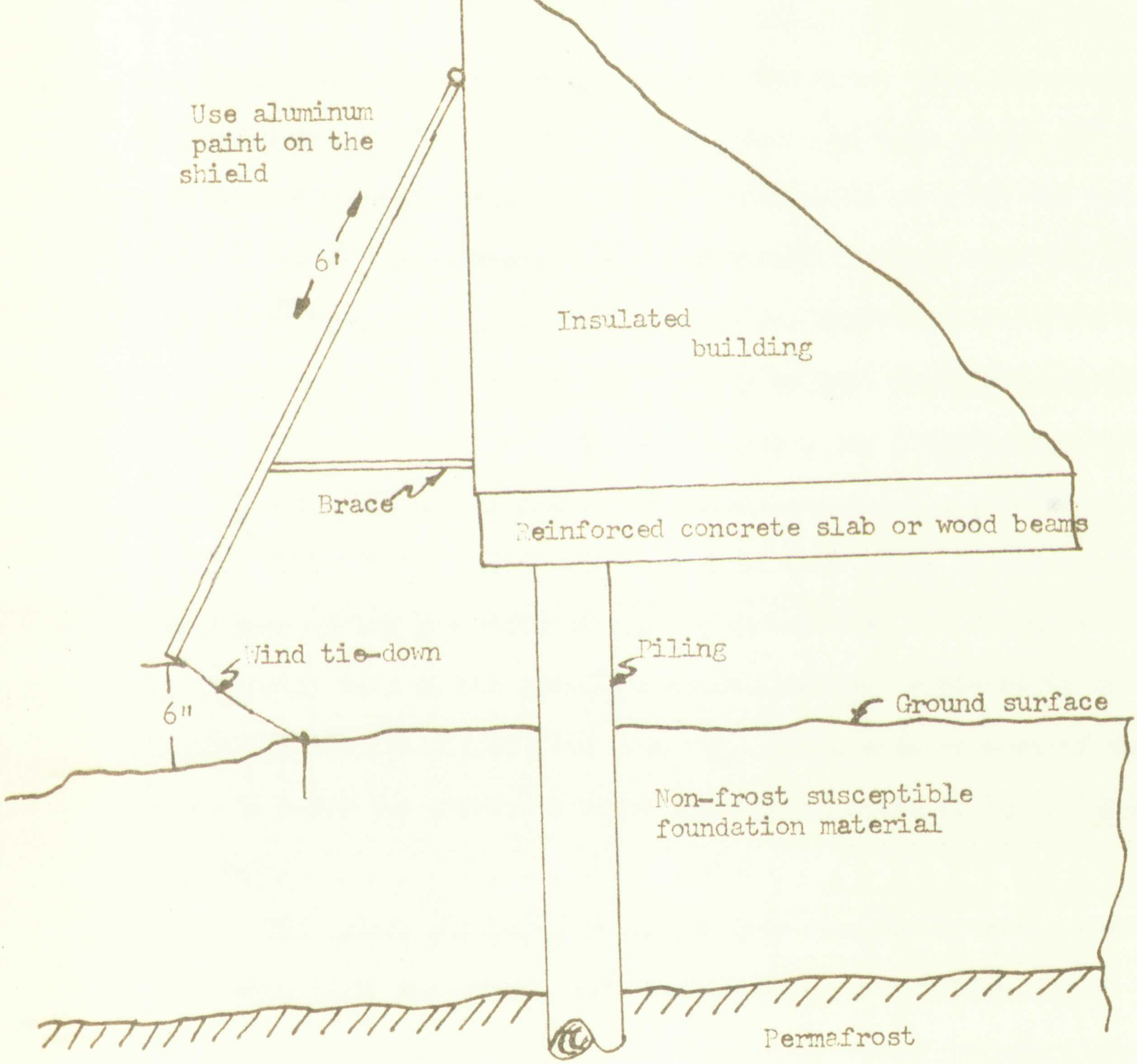

Fig.17.-Details of hinged shields or "aprons"

feet deep, the underground source may prove to be dependable. Wells have the advantage over surface water sources in that freezing weather does not interrupt the flow of water.

To make the distribution of the water easier, the source should be close to the airbase site but not near enough to cause a change in the ground water or the thermal regime at the site. The near perfect site would be one that has an unlimited amount of warm (above 36° F.) water at a higher elevation than the highest point at which the water will be used at the airbase. The water should be moved from the source to the site in an underground utilidor system carrying a six inch main. If the water at the source is warm, it may be kept from freezing by keeping at least a small amount moving through the distribution system at all times. The normal daily water requirements at a site of this size will satisfy this factor if a one-half inch valve is allowed to remain open during the slack evening usage periods. If the water is not naturally warm at the source, a steam line may be placed in the utilidor to keep the lines from freezing. Pumps will be used if the source is below the airbase's elevation such as wells or lower lakes and rivers.

The intake should be protected from clogging by silt, debris, drift wood, high velocities, and floating ice. A mechanical rake system must be available to free the intake of anchor ice and slush which forms at the intake during the winter.

The sewerage system is next in importance as a service facility to the water system, and due to a few special conditions found in the

feet deep, the underground sources are [illegible]. [illegible] have the advantage [illegible] does not interrupt the flow of water.

To make the [illegible] of the water supply, the source should be close to [illegible] the ground water or the [illegible] site would be one that [illegible] water at a higher elevation than the [illegible] will be used, [illegible] to the [illegible] system [illegible]. If the water of the [illegible] keeping at least a small [illegible] at all times. The [illegible] daily [illegible] size will satisfy this [illegible] is allowed to remain open during the [illegible] not naturally [illegible] utilized to keep the lines [illegible] source is below the [illegible] and rivers.

The intake should be protected [illegible] drift wood, high water [illegible] system must be available to [illegible] which forms at the [illegible].

The [illegible] system is [illegible] to the water system, and [illegible]

permafrost regions, the system is somewhat different from one that might be constructed in the temperate regions. The main condition to be considered is that the sewerage bacterial activity tends to remain at a minimum during cold temperatures, while the natural increase in such activity during the following warm months causes a great amount of offensive gaseous odors to be generated. This nuisance may be controlled by giving the sanitary wastes some primary treatment.

Sewage temperatures are generally higher than that of the water supply, however the sewerage system should also be carried in a heated underground utilidor system. The steam line which heats the utilidor should run into the primary treatment septic tanks, where such heat would serve to accelerate the bacterial activity. The sewage effluent line from the sewage treatment plant should also be heated and the discharge from the outfall sewer should be far enough away from the site in order not to affect the permafrost beneath structures and not cause any nuisance odors. Discharge should be into a drainage area or a stream, however in the latter instance, the discharge should not be upstream from a settlement using the stream as a water source. Treated wastes should be carried away from the site and deposited where they will not affect the permafrost at the base.

Besides heating the influent and effluent lines the following design modifications should be undertaken on a standard sewage treatment plant:

(a) Insulate and heat the entire sewage treatment plant.

(b) Increase the heavy debris or sludge collecting capacity.

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(a) Insulate and heat the entire sewage treatment plant.

(b) Increase the heavy debris or sludge collecting capacity.

(c) Build a bypass sewage line around the plant to be used when a break down occurs or when severe weather conditions prevent the operation of the plant.

The importance of heating sewage can best be expressed by citing the following facts:

(a) At least 50% more time is required to digest sludge at 70° F. than at 86° F.

(b) When the temperature is 50° F., approximately twice as much time is required for digestion as at 70° F.

However, the maximum temperature should not exceed 90° F.

F. Design and Construction of Drainage System

The axiom which defines a well designed drainage system as one which interferes the least with the natural passage of water is as binding in the permafrost regions as in the temperate regions. However the construction at the airfield site will change portions of the natural drainage system. The runway will quite naturally cause the most severe change in this drainage with the roads and buildings cause proportional changes. These alterations in the natural drainage system will have to be corrected by constructing an artificial system with features that are similar if not identical to the natural system.

The two major portions of the drainage system are:

(a) Provisions for surface drainage-precipitation run-off.

(b) Construction of subsurface drainage, including surface ice control.

The surface drainage system that is constructed in the permafrost regions encounters different drainage problems than those present in the temperate zones. Surface water will freeze during the winter months and the normal flow of water is interrupted causing surface icing or other adverse conditions to normal operations and construction. The freezing is troublesome, however the surface thawing when it starts is continuous and without a suitable system for accommodating the run-off it may also cause trouble. The following basic concepts of surface drainage must be considered:

(a) Culverts and pipes used to carry the surface drainage beneath roads and airplane handling surfaces must be of sufficient size to carry the large flood conditions during the spring breakup.

F. Design and [illegible]

The extent which [illegible]
which interferes [illegible]
binding in the [illegible]
the construction [illegible]
drainage systems. [illegible]
change in [illegible]
changes. These [illegible]
be corrected by [illegible]
are similar [illegible]

The [illegible]

(a) [illegible]

(b) [illegible]

The [illegible]
frost regions [illegible]
in the [illegible]
months and the [illegible]
icing or other [illegible]
The freezing [illegible]
is continuous and [illegible]
run-off [illegible]
surface drainage [illegible]

(a) [illegible]

(b) The conduits should be narrow and deep as opposed to the wide and shallow standard ones. Such design will increase the velocity of the water and thereby lessen the chances for freezing. Steam pipes and hot gas jets can also be used as methods of quick thawing of the culverts.

(c) Erosion-checking devices such as checks, rip-rap, and lining should be used in all channels.

(d) Wide shoulders should be constructed along both sides of all airplane-handling surfaces and roads to store any snow off the surfaces. Such shoulders should be located between the surfaces and the moisture collection channels.

The collection channels or ditches along the edges of the runway and other airplane handling surfaces should be approximately eighteen inches deep with side slopes of one on two. Such channels should encompass both sides of all surfaces at the airfield site.

One method of correcting any alterations caused in the natural surface drainage system is to make a study of the drainage areas and provide enough cross section area in the drainage laterals to handle the water. This study should take into consideration all the factors that a good hydrology survey would cover, namely the following: potential moisture, slopes of the drainage, run-off factors of the area, and how the construction installations affect all these factors. Steel or reinforced concrete barrel culverts of at least thirty inches in diameter should be used to take the water beneath the surfaces.

The problems encountered in handling the surface drainage for the roads will be the same as those for the runways, however additional problems will be involved, due to the fact that the roads usually will be located across much rougher country. In addition to the aforementioned

(b) The conduits should be [illegible] large as [illegible] the water and smaller [illegible] through the [illegible] the ditches for [illegible] and also to measure [illegible] culverts.

(c) Erosion-checking [illegible] such as [illegible], and [illegible] should be used in all [illegible].

(d) Side shoulders should be constructed along [illegible] all airplane-landing [illegible] areas to [illegible] snow off the surface. Such shoulders should be [illegible] between the surfaces and the [illegible] ditches.

The collection channels or ditches along the edges of the runway and other airplane handling surfaces should be approximately eighteen inches deep with side slopes at [illegible]. Such channels should encompass both sides of all surfaces at the airfield site.

One method of correcting any alterations caused in the natural surface drainage system is to make a survey of the drainage [illegible] and provide enough cross-section area in the ditches and [illegible] to handle the water. This study should take into consideration all the factors that a good hydrology survey would cover, namely the following: potential moisture, slopes of the drainage, runoff factors of the area, and how the construction [illegible] will affect these factors. Steel or reinforced concrete [illegible] culverts of [illegible] inches in diameter should be used to handle the water beneath the surfaces.

The problems encountered in handling the surface drainage for the roads will be the same as those for the runways, although additional problems will be involved, since the [illegible] will be located across such roads [illegible].

concepts of surface drainage, the following ones are required in draining water along the roads:

(a) Bridges and approaches should be high enough to pass river ice plus any icing caused at the abutments and piers.

(b) Surface interception drains must be constructed for hillside drainage. These drains will lessen the danger of wash-outs of the roads at such locations.

(c) Culverts should have cross section areas that are equivalent to the areas of the channels they are servicing.

(d) Cuts and fill embankments should be planted with native vegetation (possibly moss) to assist in erosion-control.

(e) Any excavations such as borrow pits which are close to the roads should be located as far as possible from the center line of the road and the shoulders should have slopes not steeper than one on four to prevent scouring. These excavations should be adequately drained.

(f) Ditches along each side of the road should be located as far as practicable from the center line. Scouring should be combated by constructing shoulders with slopes no steeper than one on five.

The ground surface around all buildings should be sloped away from the buildings to move the water away from the foundations. Native vegetation should be planted around the buildings to provide erosion control and to add to the landscape design. There will be no drains at the eaves of the buildings because freezing weather and winds would damage such devices. Concrete or bituminous gutters should be constructed beneath the eaves at ground level to prevent "ditching" of the ground by the run-off from the roof.

Ditches should be constructed around the edges of all areas

that have been replaced with non-frost susceptible foundation material. These ditches should be the type as previously shown in Figure 7 and they are to be connected to a hidden or "French" drain which shall carry any subsurface percolating water away from the airfield site. Care must be taken to see that these subsurface drains do not pass too close to any installation and thereby endanger the structure with frost heaving.

The permafrost regions, because the mean annual temperature is below freezing, do not permit an effective system of subsurface drainage. The usual direct result of this subsurface freezing is the formation of surface ice. Cooperation with natural laws to ease any potential interference with the airfield operations is usually best performed using surface ice control by the following methods:

(a) Efficient handling of surface water by rapid movement and proper protection.

(b) Constructing intercepting trenches which are of adequate size and far enough uphill to protect the pertinent installation.

(c) Constructing ditches and dikes to induce the formation of fields of surface ice at a safe distance uphill from the vital installation. See Figure 11 and the following paragraph for a description of this type of construction.

Wide ditches which penetrate approximately 75% of the active zone may be used to control the flow of ground water when the area exhibits ground icing characteristics. Figure 11, previously shown, is a sketch of how such a ditch together with a dike may be used to induce surface ice to form and decrease the chances of such ice for-

that have been replaced with [illegible] [illegible] for the [illegible].
These ditches should [illegible] [illegible] [illegible] [illegible]
they are [illegible] [illegible] [illegible] [illegible]
carry any [illegible] [illegible] away from the [illegible].
Care must be taken [illegible] [illegible] [illegible] [illegible]
too close to any [illegible] [illegible] [illegible] the structure
with frost heaving.

The permafrost regions, because the mean annual temperature is below freezing, do not permit an effective system of subsurface drainage. The usual direct result of this subsurface freezing is the formation of surface ice. [illegible] [illegible] [illegible] [illegible] potential interference with the [illegible] [illegible] [illegible] performed water surface ice control by the following [illegible]:

(a) [illegible] [illegible] of surface water [illegible] [illegible] and [illegible] [illegible] [illegible].

(b) [illegible]. [illegible] [illegible] trenches which [illegible] [illegible] [illegible] [illegible] [illegible] to protect the [illegible] installation.

(c) [illegible] [illegible] [illegible] [illegible] to induce the formation of [illegible] of surface ice at a [illegible] [illegible] [illegible] from the [illegible] installation. See Figure [illegible] and the following [illegible] for a description of this type of configuration.

Wide ditches which penetrate approximately [illegible] of the active zone may be used to [illegible] the [illegible] ground water [illegible] [illegible] [illegible] ground [illegible] [illegible]. [illegible] [illegible] [illegible] shown, is a sketch of how such a [illegible] [illegible] [illegible] [illegible] [illegible] to induce surface ice to [illegible] through the [illegible] of [illegible] [illegible]

damaging the runway. An explanation of the figure is: these ice control ditches decrease the depth of insulating earth over the moving ground water and thereby cause the water beneath the ditch to freeze earlier than it normally would, blocking the passage of the remaining ground water which breaks through the ground's surface uphill and flows down to be collected and frozen in the ditch.

Fields of surface ice which form at shallow stream crossings of road locations, can be controlled by constructing ditches or channels which extend across the stream and into each bank at approximately 100 feet upstream from the road. Log dikes located at least 500 feet upstream may also be used for surface ice control, however extreme care must be exercised in order not to cause too large a build-up of ice which might endanger the road during the first thaw.[1]

Surface ice that issues from deep ground fissures and usually appears adjacent to a road location, may be controlled by a device termed an ice fence. Ice fences are fabricated of a waterproof surface that is placed upon a wire fence. The surface water when stopped by the fence freezes in place and such a build up continues in layers until the top of the fence is reached at which time the height may be increased by another fence. The only force exerted against the fence is that from the head of water prior to its freezing.

All surface ice control devices (which are in reality sub-surface drainage control) must be connected to the surface drainage

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[1]U. S. Army, Construction Bulletin, TB5-255-3, op. cit., p. 49.

damaging the road. An explanation of [illegible] control ditches [illegible] ground water and [illegible] earlier than it normally would [illegible] the remaining ground water which [illegible] flows down to be collected and frozen in [illegible].

Fields of springs [illegible] road locations, can be [illegible] which extend across the [illegible] 100 feet upstream from the road. [illegible] upstream may also be used [illegible] care must be exercised [illegible] ice which might endanger the road [illegible].

Surface ice [illegible] appears adjacent to a road location, may be [illegible] termed an ice fence. The fence [illegible] that is placed upon a wire fence. [illegible] the fence [illegible] in place [illegible] until the top of the fence [illegible] increased by another fence. [illegible] is that from the hand [illegible].

All surface [illegible] surface drainage [illegible] must be [illegible]

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[1]U. S. Army, Construction Bulletin, [illegible]

system to handle the melting ice when the thawing cycle starts. The first year these control devices are in operation will demonstrate the effectiveness of the surface drainage system in handling the thawing ice.

The complete surface and subsurface drainage system will require constant inspection and maintenance and any deterioration in either system will require immediate and suitable corrective action. Portable steam generators and hot jets should be utilized to thaw any build-up of ice that has impeded the flow of water in the drainage system. A prerequisite of an effective drainage system, is that proper maintenenance and a rigid inspection schedule must each be adhered to in order not to curtail the operation at the airfield.

system to handle [illegible] of airfield pavements. The first year's [illegible] will demonstrate the effectiveness of the surface [illegible] pavement.

The complete surface and [illegible] drainage system will require constant inspection and maintenance. In any installation, the [illegible] system will require inspection and periodic [illegible] steam generators [illegible] should be [illegible] of ice that has [illegible] the flow of water in the drainage system. A prerequisite of an effective drainage system is [illegible] proper maintenance and a rigid inspection schedule that must be [illegible] in order not to curtail the operation of the airfield.

G. Maintenance at the Airbase Site

Maintenance of installations is a gigantic task in permafrost regions and in the case of one such as the airfield, the repair work must start prior to the completion of the construction. Consideration must be given during the early construction stages to the equipment and personnel requirements for maintenance. It should be noted that the maintenance concerned with in this thesis does not include the normal airplane and vehicle repair work conducted at the airbase.

A general listing of maintenance equipment that is required will include the following:

(a) Heavy earth-moving equipment.

(b) Rollers, graders, and spreading equipment.

(c) Trucks, tractors, and trailers.

(d) Concrete mixers and bituminous repairing equipment.

(e) Snow-removal and ice melting equipment.

(f) Snow fences and ice fences plus necessary erection equipment.

(g) Lumber and building materials for repairing any building. Such material should include cement, aggregate, steel reinforcement, steel building panels, roofing material, and various types of building hardware.

(h) Stockpiles of material for repairing the airplane handling surfaces and roads. These materials which will be mainly aggregate, should be stored at strategic points along these installations for immediate use if such a demand arises.

(i) Portable buildings which may be erected as replacements or temporary structures.

(j) An ample supply of the appropriate small hand construction tools and implements.

The fact that the airplane handling surfaces and roads will be located above the surrounding natural ground surfaces will enable most of the snow to be blown off and not cause much interference with the operations. However, because the airstrip is usually located with the centerline parallel to the prevailing winds, the snow will not generally be swept off the surface as it would on the roads.

The most successful method of controlling snow drifting is by erecting snow fences. The conventional wooden picket snow fence is the most efficient method of controlling the drifting, and such fencing will retain approximately thirty-five times its surface area[1] when it is erected at 30° to the prevailing wind.[2] The wooden fabricated fence may be supplemented with a fence constructed of snow blocks. The snow-block fence when finished will be approximately two feet in thickness with a height of four feet, and is about one-third as efficient as a wooden fence of equal area in the retention of snow.[3]

Snow removal equipment will have to be pressed into service to clear the airplane handling surfaces and roads of any drifting snow that is not retained by the fences as well as any snow that falls when there is no wind. After the snow has been removed from the runway, the maintenance crews will be faced with the added problem of removing ice and in general preparing a non-skid surface for the airplanes. Jet

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[1]Cary, C. O., "Winter Maintenance in Alaska", Aviation, (Sept., 1944), p. 245.

[2]Chekotillo, A. M., "Use of Snow and Ice", Moscow V.I.N.K. Oborny, (1943), p. 30.

[3]Cary, op. cit., p. 245.

The fact that the airplane handling surfaces and [illegible] will be located above the surrounding natural ground surface will cause the depth of the snow to be blown off and not cause much interference with operations. However, because the airstrip is normally located with its centerline parallel to the prevailing winds, the snow will not generally be swept off the surface as it would in dry [illegible].

The most successful method of controlling snow drifting is by erecting snow fences. The conventional wooden slatted snow fence is the most efficient method of controlling the drifting, and such fencing will retain approximately thirty-five times its section area when it is erected at 90° to the prevailing wind.[1] The wooden slat fence may be supplemented with a fence constructed of snow blocks. The snow-block fence when finished will be approximately two feet in thickness with a height of four feet, and is [illegible] as effective as a wooden fence of equal area in the prevention of drifts.[2]

Snow removal equipment will have to be provided [illegible] to clear the airplane handling surfaces and roads of any drifting snow that is not retained by the fences or will be blown off the fields when there is no wind. After the snow has been removed from the runways, the maintenance crews will be faced with the problems of [illegible] and in general preparing a non-skid surface for the airplanes.[3]

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[1]Gary, G. G., "Winter Maintenance for Airfields", [illegible] 1944), p. 245.

[2][illegible], A. E., "Use of Snow and Ice", [illegible] (1943), p. 30.

[3]Gary, op. cit., p. 245.

airplanes as yet have not devised a practical way of reversing thrusts for a braking action so they must depend entirely upon the wheel brakes.

Abrasives such as sand, cinders, or small angular aggregate particles are very effective for skid-proofing icy runways if previously treated with calcium chloride.

The recommended proportions for the skid-proofing mix are approximately seventy-five pounds of calcium chloride ($Ca\ Cl_2$) to each cubic yard of abrasives - the abrasives should be damp enough to dissolve the $Ca\ Cl_2$ particles. Another method is to treat dry abrasives with a water solution of four pounds of $Ca\ Cl_2$ to each gallon of water. A solution of seven gallons per cubic yard of sand or grit is adequate while eleven gallons should be used with each cubic yard of cinders.[1] The treated abrasives should be protected with a water proof cover to prevent possible dilution by rain or snow during storage. The treated abrasives should be stored in piles at strategic locations along the runway, airplane handling surfaces, and roads. The $Ca\ Cl_2$ may also be used to loosen the ice on the runway by spreading about 500 pounds of chloride over each mile of a width of twenty feet.[2] After the ice is treated and it has been weakened, the blade may be used to clear the surface. The corrosion of airplane parts due to the use of the $Ca\ Cl_2$ may be prevented by admixing 2% by chloride weight of $Na_2\ Cr_2\ O_7$

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[1]"Ice Control at Airports", Roads and Bridges, (Feb., 1944), p. 81.

[2]Ibid.

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[1]"Ice Control at Airports", Roads and Bridges, (Feb., 1944), p. 81.

[2]Ibid.

(a poly-phosphate-nitrate-nitrate mix).[1]

The snow and ice that has been removed from the surfaces after several snow storms should be spread out or dispersed in order not to damage any airplanes running into them and also to prevent a concentration of moisture when the snow thaws during the spring. A practical method of snow-dispersal is to use the trucks to transport it to a disposal site which is at a sufficient distance from the airbase to thaw and run-off without any resulting damage.

As previously mentioned, the excess snow must be removed from the roofs of the buildings to eliminate the possibility of any structural damage occurring and lessen the chance of injury or damage from from falling snow or ice.

A very important requirement of the maintenance phase at the airbase is that provisions must always be made for fire fighting equipment to arrive quickly at any location where such an emergency exists. Fire protection is an important function at any large installation, however the importance is greatly magnified in permafrost regions due to the difficulties involved in securing replacement facilities.

All areas which have indications of surface disturbances from water and ice action during the winter months, should be located on a map of the site so that corrective measures may be undertaken during the following summer. Repairs generally will not be undertaken during the winter season unless the damage is of such a magnitude that it can not

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[1]Lederer, J., "Winterization of Airport Facilities", Aero Digest, (Sept., 1949), p. 50.

(a poly-phosphate-nitrate-[illegible])

The snow and ice that may [illegible] from the surfaces [illegible] several snow stages should be spread out [illegible] in order not to damage any airplanes running into high snowbanks [illegible] the [illegible] tration of moisture into the [illegible] during the spring. A practical method of snow-disposal [illegible] is to transport it to a disposal site which is at a sufficient distance from the surface to [illegible] and run-off without any resulting damage.

As previously mentioned, the excess snow must be removed from the roofs of the buildings to eliminate [illegible] structural damage occurring and lessen the chances of injury or damage from falling snow or ice.

A very important requirement of the maintenance [illegible] airbase is that provisions must always be made for the fire-fighting equipment to arrive quickly at any location where such an emergency exists. Fire protection is an important function at any installation; however the importance is greatly magnified in cold weather due to the difficulties involved in reaching emergency locations.

All areas which have indications of surface disturbance from water and ice action during the summer months, should be located on a map of the site so that appropriate action may be undertaken during the following summer. Regular patrols will not be undertaken during the winter season unless [illegible] of the airfield [illegible] since it may not

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[illegible], [illegible], "Winterization of Airport Facilities", Engr. Digest, (Sept., 1953), p. 73.

effectively be put off until the spring and summer months. Inspection crews should regularly investigate all vital areas during all the seasons, however certain indications should be especially checked during the appropriate seasons. Frost heaves and all other similar effects should be ascertained during the winter months while slides and water that is standing in pools at unnatural locations should be noted during the summer season. The weather unit should keep records of all aspects of the weather with special emphasis being placed upon the snow fall and how much snow has accumulated in drifts at the site. This survey of snow depths and drifting is important in forecasting any potential flooding threats as well as locations for possible slides beneath drifts that are on the sides of slopes.

The fills or embankments along all airplane handling surfaces and roads should be observed very closely and especially if there is much snow drifted on these vital slopes. The majority of the moisture from the thawing snow drifts will be carried off through the non-frost susceptible fill material, however this drainage system may be overloaded by any severe snow drifting. Eight inch wooden posts may be driven into the face of the lower portion of the fill slopes to lessen the danger of any avalanches, slides, or other damaging snow and ice movements. These posts should be buried in the fill for a depth of six feet and protrude for a distance of approximately four feet.

The buildings will require maintenance both on the interiors and exteriors, however due to the more adverse conditions of these regions, the exteriors must have heavy duty finish and require constant

effectively be [illegible] as [illegible] rather [illegible]. [illegible] crews should regularly [illegible] the [illegible] seasons, however [illegible] during the appropriate seasons. [illegible] effects should be [illegible] during the [illegible] and [illegible] than in [illegible] noted during the summer seasons. [illegible] of all aspects of [illegible] the snow fall and [illegible] much snow [illegible]. This survey of [illegible] any potential [illegible] slides beneath [illegible] the sides of [illegible].

The [illegible] and roads should be observed very closely [illegible] much snow [illegible] slopes. [illegible] from the [illegible] snow [illegible] susceptible fill materials, however [illegible] by any [illegible] the face of the lower portion of the fill [illegible] any avalanches, [illegible]. These posts should be [illegible] protrude for a distance of [illegible].

The [illegible] and exteriors, however [illegible] regions, the [illegible]

upkeep to retain such a finish.

The maintenance unit at the airbase site will receive its most crucial test when the weather is more severe than usual. The service equipment at the site is generally under its most overtaxed condition at these times which accelerates any possible break downs. Curtailment of services during adverse weather conditions will ease the strain on the facilities and there by allow for a more efficient and continuous operation.

Lastly, maintenance is a continuing function and much of it will be peculiar to the site as well as weather conditions.

ICE AND SNOW SERVICE AIRSTRIPS FOR THE PERMAFROST AIRFIELD

This section of the thesis will cover the two main types of service airstrips which will be required as important facilities for maintaining operations at the main permafrost airfield. These two types of airstrips are:

(A) Located on ice sheets.

(B) Located on compacted snow.

Both types of strips should be in line with the normal routes to and from the airfields and at least one for each route. The airstrips on ice sheets will be dealt with first.

A. <u>Service Airstrips on Ice Sheets</u>

1. Introduction

The majority of mechanical malfunctions usually occur to an airplane during its take-off from an airfield; therefore, a location of one of the strips on ice sheets should be within a close proximity of the main airfield. The service strip located close to the main airfield may also be required to handle planes which cannot use the larger field because of crowded conditions, weather, shortage of fuel, or any number of reasons. The ice airstrip near the main airfield could also be used as a landing strip to handle planes carrying maintenance or service equipment when it is imperative the permafrost field be ready for its regular consigned combat airplanes.

Some airstrips built on floating ice sheets could be used to handle service planes that transport goods and equipment from the airstrip to ships or vice-versa. Service or emergency strips on ice sheets are also necessary to handle planes under emergency conditions which occur more readily in the Arctic and sub-Arctic than in the

temperate regions.

2. Planning For Airstrip

Generally no information pertaining to long-term ice-thickness or condition of ice is available for a given region for planning such an airstrip. However, the operation of the permafrost airfield is is such that an estimate will have to be arrived at as to whether and for how long airplanes can use the ice sheet as a strip. Any planning will hinge upon the estimate of ice thicknesses and thickness variations throughout the years.

The Corps of Engineers, U. S. Army through its Snow Ice and Permafrost Research Establishment has developed the following formula for estimating the thickness of ice:

$$h = a \times 1.06 \sqrt{s} \qquad (1)$$

h = ice thickness in inches.
a = a coefficient which includes the consideration of snow cover, past weather conditions, movement of water, and other local conditions. (see Table 9)
s = accumulated degree-days since freeze-up (°F. below freezing, 29° F.).[1] While fresh water freezes at 32° F., sea water freezes at approximately 29° F.

This formula was originally developed for ice from fresh water, but it can be applied as a very close estimate for sea ice.[1] The temperatures used in the formula are the daily mean, and the date of the freeze-up usually depends upon such factors as the size of the

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[1]Assur, Andrew, "Airfields on Floating Ice Sheets", Corps of Engineers, (Jan., 1956), p. 2.

[2]Ibid.

temperate regions.

2. Planning for Airfields

Generally no information on locations [illegible] or condition of [illegible] available for [illegible] planning an airstrip. However, the [illegible] of the [illegible] is such that an estimate of [illegible] for how long airfields [illegible] will hinge upon the estimate of the thickness and [illegible] throughout the year.

The Corps of Engineers, U. S. Army through [illegible] Permafrost Research Establishment has developed the modified [illegible] for estimating the thickness of ice:

$h = a \times 1.06 \sqrt{T}$ (1)

h = ice thickness in inches.
a = a coefficient [illegible] the [illegible] of the [illegible], [illegible] water, and other local conditions. (See Table [illegible])
T = accumulated degree-days since freeze-up (°F. below freezing, [illegible] water freezes at 32° F., sea water freezes at approximately 28° F.

This formula was [illegible] for the [illegible] fresh water, but it can be applied [illegible] very close [illegible]. The temperature [illegible] of the freeze-up [illegible]

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[1] [illegible], "[illegible]", Corps of Engineers, ([illegible], 195[illegible]), p. 3.

[2] Ibid.

water body, type of flow, and the velocity of the flow.[1]

TABLE 9

Values of A and B for Formulae (1) & (3)[2]

A	B	Conditions
1.00	3.6	Theoretically possible maximum that is never reached under natural conditions.
.90-.85	4.4 to 5.0	Maximum for ice not covered with snow.
.75-.70	6.7 to 7.3	Arctic sea ice at first estimate.
.75-.65	6.7 to 9.0	Medium sized lakes with a moderate snow cover.
.65-.60	9 to 10	Bays with brackish water.
.60-.50	10 to 15	Rivers with moderate flow.

These values are climatological averages and the variations each year from these averages are considerable because of changing snow conditions. At a given location, it could be expected that approximately 67% of the individual values of A will be the average ± 25%, however, extremes of up to 160% of the average are possible.[3]

Naturally the variation from location to location is very great. Due to its limitations, formula (1) may be used only in obtaining preliminary and general information and not as a replacement for information gathered during field ice surveys at specific locations. Formula (1) used with climatological information from the region in question will furnish enough data for the field survey to be inaugurated

[1] Ibid.

[2] Ibid.

[3] Ibid., p. 3.

water body, type of flow, and the velocity of the flow.[1]

TABLE 9

Values of A and B for Formulae (4) & (5)[2]

A	B	Conditions
1.00	3.6	Theoretically possible maximum that is never yet found under natural conditions.
.90-.85	4.4 to 5.0	Maximum for [illegible] covered with snow.
.75-.70	6.7 to 7.3	Arctic sea for average conditions.
.75-.65	6.7 to 9.0	Medium sized lakes with a moderate snow cover.
.65-.60	9 to 10	Bays with brackish water.
.60-.50	10 to 15	Rivers with moderate flow.

These values are climatological averages and the variations each year from these averages are considerable because of changing snow conditions. At a given location, it would be expected that approximately 67% of the individual values of A will be the average ± 25%, however, extremes of up to 100% of the average are possible.[3]

Naturally the variation from location to location is very great. Due to its limitations, formula (1) may be used only in obtaining preliminary and general information and not as a replacement for information gathered during field ice surveys at specific locations. Formula (1) used with climatological information from the region in question will furnish enough data for the field survey to be conducted

[1]Ibid.

[2]Ibid.

[3]Ibid., p. 7.

without any long-term ice-thickness information being available.

Sea ice will continue to grow when the temperature is colder than 10° F., while at approximately 10° F., sea ice begins to diminish in thickness and strength.[1] Sketchy information that is available indicates that the ice thickness diminishes according to the following:

$$Dh = \frac{z}{30} \qquad (2)$$

where: Dh = reduction in ice thickness (inches)

and: z = the accumulated degree-days above 10° F. See formula (1) for meaning of degree-days and freeze-up date.[2]

Actual Example[3]

Cambridge Bay, NWT, Canadian Arctic
Long-term temperature curve crosses 32° F. to lower temperatures on 13 September. The temperature curve crosses the 10° F. line to higher temperature on 8 May. Total accumulated degree-days below 32° F. between these dates is 10,120. Using formula (1), with a= .70 for Arctic sea ice.

$$h = .70 \times 1.06 \sqrt{10,120} \quad 75 \text{ inches}$$

The actual ice thickness measured on 1 May in a shallow protected bay was seventy-three inches.

Approximately on 8 May, the ice will decrease in thickness, and the total accumulated degree-days above 10° F. on 15 June are 942.

Hence the expected decrease in ice thickness according to formula (2) is:

$$D\,h = \frac{942}{30} = 31 \text{ inches}$$

and the expected ice thickness is 75—31= 44 inches.

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[1] Assur, *op. cit.* p. 4.

[2] *Ibid.*

[3] *Ibid.*

without any long-term ice-thickness information being available.

Sea ice will continue to grow when the temperature is colder than 10° F., while at approximately 10° F., sea ice begins to diminish in thickness and strength.[1] Further information that is available indicates that the ice thickness will decrease according to the following:

$$Dh = \frac{s}{30} \qquad (2)$$

where: Dh = reduction in ice thickness (inches)

and: s = the accumulated degree-days above 10° F. See formula (1) for meaning of degree-days and freeze-up date.

Actual Example[2]

Cambridge Bay, NWT, Canadian Arctic
Long-term temperature curve crosses 10° F. to lower temperatures on 23 September.[3] The temperature curve crosses the 10° F. line to higher temperature on 8 May. Total accumulated degree-days below 29° F. between these dates is 10,120. Using formula (1), with a = .70 for Arctic waters,

$$h = .70 \times 1.06 \sqrt{10{,}120} = 75 \text{ inches}$$

The actual ice thickness measured on 1 May in a shallow protected bay was seventy-three inches.

Approximately on 8 May, the ice will decrease in thickness, and the total accumulated degree-days above 10° F. on 15 June are 942.

Hence the expected decrease in ice thickness according to formula (2) is:

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[1]Assur, op. cit., p. 4.

[2]Ibid.

[3]Ibid.

3. Choice of Site For Airstrip

Many factors influence the location of an airstrip on an ice sheet. Besides the many natural factors such as availability of suitable ice and geographic features, there will be operational requirements at the permafrost airfield. These factors may influence the choice of the location on an individual basis or as a group.

Due to the fact that the ice thicknesses and geographic features cannot be or may not be easily changed by man, it is usually good engineering practice to decide the choices of location from these considerations first.

An airstrip located on sea ice usually should be situated in a bay or behind a point of land. Such a location will protect the strip from horizontal pressure which causes extensive cracking which could cause the strip to be carried away or destroyed at its location. The horizontal pressure may be attributed to the water currents which are constantly influencing sea ice. Generally with no data available on currents, the direction of the coastal currents, looking out from the land, is to the left south of the Equator (Antarctic) and to the right north of the Equator (Arctic).[1] Thick ice which moves off the land at the edge of the sea or forms on the coast line is known as shelf-ice and in many cases it forms protected bays for locating ice airstrips. An added advantage not to be overlooked that is offered by this shelf-ice, is that ships may unload cargo directly onto the

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[1]Office of The Air Engineer, Airdromes on Ice Caps, (1946), p. 20.

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[1]Office of the Air Engineer, Airstrips on Ice Caps, (1946), p. 20.

ice and thereby save the added expence of providing unloading facilities. Due to its great thickness, the shelf-ice will offer an excellent location for an all year airstrip with few limitations during the warmest summer days.

The active cracks where the ice will move in a vertical and horizontal direction, most commonly develop from points of land and move in the direction of the current and in towards the coast. These active cracks will tend to separate the ice in a bay from that in the open sea. Any bay chosen for an airstrip site should be of such length that there will be enough ice left for the strip after the active cracks have appeared and run their course.

The ice field that covers the open sea is known as pack-ice and it may be either a monolithically frozen solid or broken by constant forming leads or cracks, usually the latter. The condition of the pack-ice is dependent upon such things as the weather, season of the year, and the geographic location. Reports from "Operation Deepfreeze" in the Antarctic in 1956 indicate that oversea tractor transportation is possible over some pack-ice and in many instances it would have been possible to locate an airstrip had one been required. The Russians, through their military forces, after many years of field trials have found that it is feasible to operate airplanes and other equipment on the Arctic pack-ice.[1]

Generally the limiting factor offered by pack-ice for use as

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[1]Bernshtein, S., Instructions for Construction, Maintenance, and Operation on Ice, (1929), p. 98.

ice and thereby give rise to [illegible] operating difficul-
ties. As to its recent [illegible] it will offer an excel-
lent location for small year-round [illegible] the
the warmest summer days.

The author grants that ice will move in a [illegible]
horizontal direction, most generally [illegible] and
move in the direction of the current and in [illegible]. These
active cracks will tend to [illegible]
open sea. Any [illegible]
length that there will be [illegible]
active cracks have [illegible] and run their course.

The ice field that [illegible]
and it may be without [illegible] or [illegible] con-
stant forming leads or cracks, [illegible]. The [illegible]
the pack-ice is dependent upon [illegible] of the
the year, and the geographical location, [illegible] "Operation
Deepfreeze" in the Antarctic in 1956 [illegible]
transportation is [illegible]
it would have been [illegible]
required. The [illegible]
years of field trials have found that it is [illegible]
airplanes and other equipment on [illegible].[1]

Generally the [illegible]

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[1]Bernstein, [illegible] and Operations on Ice, [illegible]

airstrips is not its bearing capacity but rather the pressure ridges. These pressure ridges are where the pack-ice has been fractured and built up mounds or ridges of ice due to the horizontal pressures. Fields of ice between the pressure ridges are generally found after more careful examining.[1] Another factor to be considered is that ice fields larger than one mile in diameter are more in danger of being broken up than the smaller fields. Aerial photographs usually will furnish enough information to show the frequency of fields of necessary size for the airstrip.

Using the ice on a river is feasible, but this ice is not reliable mainly due to the fact that the thickness may vary over a very short distance. The width of the river should be less than the resonance width which is two times load influence radius (see Table 10 in next portion of this section of the thesis). By studying aerial photographs of the river, the configuration of its course can be analyzed for location of the fastest currents where the ice is the thinnest. Further study will show the location of dead arms of the river and oxbow lakes both of which are formed by a frequent occurrence in the sub-Arctic, namely parts cut off from a meandering river. Each of these locations is the most desirable place for an airstrip on river ice. When a river freezes enough to restrict the flow in the normal channel the water may flood onto the surface of the ice and cause a double ice layer which is dangerous because the top layer of ice us usually weak. This double layer of ice can be detected by using suitable filters during the photographing.

airstrips is not [illegible] [illegible] [illegible]. [illegible] [illegible] [illegible] ridges. These pressure ridges are usually [illegible] [illegible] [illegible] [illegible] built up mounds of [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]. Fields of ice [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] more careful [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] that ice fields larger than [illegible] in diameter are [illegible] [illegible] broken up than the smaller [illegible]. [illegible] [illegible] [illegible] [illegible] furnish enough information to [illegible] [illegible] [illegible] [illegible] of [illegible] easy sites for the [illegible].

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Lakes generally present better locations for an airstrip than rivers, however, the large lakes (for example: Great Slave Lake in NWT, Canada) are not as good as the medium size ones. These large lakes have the characteristics of having very few, if any, bays and other features that would be suitable for an airstrip location. Winds and excessive thermal action cause leads even in the thick winter ice of large lakes and in addition if a large enough ice field is located, it is usually very smooth ice and makes a poor braking surface for planes.

The choice of the airstrip site is primarily done with maps and aerial photographs each of which should have a scale that will show details clear enough to make a decision. The sites chosen from the maps and photos will then be inspected for ice conditions in the field before the final location is decided.

4. Principles of Design of Airstrip

The bearing capacity of large fields of ice that could be used as an airstrip is based upon the flexural strength of the ice sheet. When a load is placed on a large ice sheet, deflection or bending occurs which is dependent upon the following:

> Type of ice, thickness of ice, type of load and contact with ice, Poisson's ratio for ice, modulus of elasticity for ice, and pressure furnished by water when the ice deflects under a load.

The bouyant effect of the water upon the ice sheet only effects the bearing capacity when a load is placed upon the sheet that is within 90% of the difference between the bouyant forces and the

weight of the ice sheet. When the ice sheet is large enough for a strip, this weight difference will probably never be approached by the weight of airplanes and other goods that could be loaded on the sheet without first having a flexure failure appear in the ice.

When a load is placed upon an ice sheet, the ice deflects in a concentric fashion outward about the loaded portion. The deflection of the ice passes from a maximum at the load through zero displacement to an upheaval and thence to the original surface.

This upheaval is commonly called the "influence radius" and the distance to its center from the center of loaded portion together with the distance to the zero displacement are each dependent mainly upon the ice thickness and have no relation to the magnitude of the load.[1]

A survey conducted by the SIPRE Unit of the U. S. Army Corps of Engineers after actual field experiments arrived at the results shown in Table 10.

TABLE 10

Influence Radius of Loads on Floating Ice[2]

Ice Thickness (inches)	Basic Load Influence Radii (feet)	
	Fresh Water Ice	Sea Ice
10	90	80
15	120	110
20	150	140

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[1]Assur, op. cit., p. 4.

[2]Ibid, p. 5.

weight of the ice sheet. [illegible] being a [illegible]
strip, this weight difference will [illegible]
the weight of airplanes and other goods [illegible]
sheet without first making a [illegible]

When a [illegible] ice sheet, [illegible]
a concentric [illegible] load moving. The [illegible]
of the ice passes from a [illegible] at the load through [illegible]
to an upheaval and [illegible] surface.

This upheaval [illegible]
the distance to the [illegible]
with the distance to the [illegible]
upon the ice [illegible]
load.[1]

A survey [illegible]
of Engineers [illegible]
shown in Table 10.

TABLE 10

Influence Radius of Loads on Floating Ice

Ice Thickness (inches)	Radius of Influence (feet)	
	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[1][illegible], op. cit., p. [illegible]

[2]Ibid., p. [illegible]

TABLE 10--Continued

Ice Thickness (inches)	Basic Load Influence Radii (feet)	
	Fresh Water Ice	Sea Ice
25	180	160
30	200	180
35	230	210
40	250	230
45	270	250
50	300	270
60	340	310
70	380	350
80	420	380
90	460	410
100	500	450

These values were calculated using normal ice conditions and slowly-moving (5-10 mph) loads. Parked or static loads would have smaller radii and conversely faster moving loads would produce larger radii.[1] If it becomes necessary, these distances may be reduced as much as 20% and snow ice (ice containing many air particles) will produce smaller radii than clear ice.[2] The influence radii are very important in determining how close to park planes or goods and spacing when the planes are taxiing. Any time two or more influence radii intersect, cracking of the ice will usually occur.

It has long been regarded that when the first cracking appeared in an ice field that was the criterion to stop using the ice, however, large-scale field tests by the military of the U. S. A., Canada, and

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[1]Assur, op. cit., p. 4.

[2]Ibid.

Russia have indicated that the cracks will usually heal overnight or within twelve hours. The load was allowed to remain on the ice during these tests. Usually the first cracking is the ice deflecting downward until it bears down upon the water surface at which time the ice sheet is generally able to resist more load than prior to the cracking. Many people, especially children, have proved this point in early winter when they walk out onto one and one-half or two inch ice on a pond and have the ice crack all around them without failing completely. If the same person had taken a one and one-half or two inch ice sheet about four feet square, supported at the edges, and stepped upon it, the ice would immediately have failed.

The military forces mentioned previously, have found that there are critical velocities for loads on ice. In shallow water that is four to thirty feet deep, the velocity is based primarily upon the depth and to some extent, on the ice thickness. The critical velocity, with marginal ice thickness, varies as the following:[1]

Water Depth (feet)	4	6	8	10	15	20	30
Critical Velocity (m.p.h.)	9	11	12	14	17	19	22

The critical velocity in water over fifty feet deep depends upon the ice thickness only and this variation is as shown in Table 11.[2]

TABLE 11

Ice Thickness (feet)	Critical Velocity (m.p.h.)	Minimum Water Depth (feet)
1	23	60

[1]Assur, op. cit., p. 6.

[2]Ibid.

Russia have indicated that this practice will usually [illegible] within twelve hours. [illegible] these boats. [illegible] ward until it [illegible] sheet is generally able to [illegible] Many people, especially children, [illegible] winter when they walk out onto the ice and [illegible] pond and have the ice crack all around [illegible] If the same person had taken out and [illegible] about four feet square, [illegible] the ice would immediately have failed.

The military forces [illegible] there are critical velocities [illegible] that is four to thirty feet deep. The [illegible] upon the [illegible] velocity, with [illegible] which [illegible]

Water depth (feet) [illegible]
Critical velocity [illegible]

The critical velocity [illegible] ice thickness [illegible] in Table 1.[2]

Table 1

Ice Thickness (feet)	[illegible]	[illegible]
1	[illegible]	[illegible]

[1] [illegible], Op. cit., p. [illegible]

[2] Ibid.

TABLE 11--Continued

Ice Thickness (feet)	Critical Velocity (m.p.h.)	Minimum Water Depth (feet)
2	31	100
3	37	140
4	41	180
6	48	290
8	53	410

These critical velocities are approximately the resonance velocity of the ice under the conditions stated. The shallow water causes a lower critical velocity due to the fact that the disturbance travels from water, and the upheaval or "influence radius", the individual ice particles making up the sheet will have to move slower in transmitting the radius through the ice or the particles will separate and thereby cause failure of the ice sheet.

5. Field Survey and Considerations for Final Location of Airstrip

After possible strip locations have been selected from aerial photos and maps and their distance plus direction from the airfield considered, a survey will be conducted before the final location for each strip is chosen. The survey made with a light reconnaissance plane, is initiated with a close-up aerial inspection and a sketch of such items of information as the location of pressure ridges, cracks, rafted ice, geographic configuration, and any other important details. Before a landing is attempted, formula (1) should be used to estimate the thickness of the ice and this thickness should be twice as thick as required to support the plane.

If a site is a suitable location with the exception that the

ice is not thick enough yet, the following formula may be used to determine the length of time for the ice to increase to the required thickness.[1]

$$Dt = \frac{B(1+h)}{32-F} \qquad (3)$$

where Dt = time necessary for ice thickness to increase by an increment of two inches, (days).

h = measured ice thickness (inches)

F = average expected air temperature ($^{\circ}F.$).

B = coefficient. (see chart of values at beginning of this section of the thesis).

Actual Example[2]

It is proposed to utilize a given lake. An advance survey party measures an ace thickness of sixteen inches. The airplane requires twenty-two inches. The expected mean air temperature is 12° F. and B = 8. thus using formula (3):

From 16 to 18 in. $Dt = \frac{8(1+16)}{32-12} = 6.8$ days.

From 18 to 20 in. $Dt = \frac{8(1+18)}{32-12} = 7.6$ days.

From 20 to 22 in. $Dt = \frac{8(1+20)}{32-12} = 8.4$ days.

Total = 22.8 days.

In approximately three weeks the ice will be safe enough to attempt a landing.

A bay that may be suitable in many respects for a strip location will not be a good location if rafted ice and hummocking (ice curved downward from the shore to the ice sheet) are present, as these would demonstrate excessive tides in the region. Naturally the regular change in the elevation of the water surface would prevent thick ice from forming near the coast and maybe any ice from forming at all.

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[1] Assur, *op. cit.*, p. 18.

[2] *Ibid.*

After landing with the reconnaissance plane at a suitable location, the ice shoule be checked for cracks, thickness, snow cover, quality of ice, and any other important factors. An ice auger and ice-measuring device can be used to measure the thickness and quality, while the other factors may be ascertained by visual observations. Drill one inspection hole at each end of the runway and one at each side of the runway at the midpoint. If the ice thickness is near the minimum, more spots along the proposed runway should be checked. The parking or storage areas should also be checked as extensively. The snow cover should be measured and in milder regions where snowfall is abundant it would be doubtful to choose a strip location where the depth of snow is more than one-third the ice depth. Lakes that have smooth and slippery surfaces should be explored for the availability of enough snow to compact (with rubber-tired equipment) a two to three inch compacted layer of snow on sea ice which will be used as a traction layer to lessen the high salf-friction. This lessening of the friction will cut down on the length of runway required for ski-equipped airplanes on the take-off.

Investigations should be made to find parking areas for approximately six airplanes. Such parking should be located at least one-half mile from any part of the strip so the loads on the ice will be distributed over a larger area and in addition, so the parked planes will not interfere with planes that are landing and taking-off.

If the strip has to be located on pack-ice that is on open sea, checks should be made daily on the location of the strip as the

After landing with the reconnaissance plane at a suitable location, the ice should be checked for strength, thickness, snow depth, quality of ice, and any other important features. An ice auger and ice-measuring device can be used to measure the thickness and quality, while the other factors may be ascertained by visual observation. Drill one inspection hole at each end of the strip and one on each side of the runway at the midpoint. If the ice thickness is only the minimum, more spots along the proposed runway should be checked. The parking or storage areas should also be checked in similar manner. The snow cover should be measured and in milder regions where snowfall is abundant it would be doubtful to choose a strip location where the depth of snow is more than one-third the leg length. Ice that has smooth and slippery surfaces should be considered for the availability of enough snow to compact (with snow-wheeled equipment) a two to three inch compacted layer of snow on the strip which will act as a traction layer to lessen the high skid-friction. This lessening of the friction will cut down on the length of runway required for ski-equipped airplanes on the take-off.

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If the strip has to be located on pack-ice with leads open to sea, checks should be made daily on the location of the strip on the

entire ice field could be blown out to sea and broken up by the ocean currents and the wind. The pack ice should be chosen only as a last resort and then only as an emergency strip as opposed to a service strip. In addition, investigations should be made to determine whether there will be any possibilities of large blocks of ice or ice bergs falling off pack-ice or glaciers and thereby causing sudden tidal-like waves that could damage ships or break up the ice sheet.[1]

It is possible to have a strip on sea-supported ice and use the immediate connecting land-supported ice for parking and servicing areas. The tidal crack that occurs between the two ice fields should be inspected and if it is over two inches in width, the crack should be "bridged" with wet snow or slush. The military have used small emergency metal bridges to connect ice fields where the cracks were around six feet in width, however this is not good practice as the metal bridge would be constantly melting its way into the ice when the sun shone and the metal absorbed the heat.

Some basic considerations for the final location of the strip are the following:

(a) The strip should be 5000 to 9000 feet long with a thickness of at least forty-eight inches (see chart II-1 for variations of thickness required for a given airplane).

(b) The best location for the strip is one that produces an angle of 45° between the center line of the strip and the shore with no part closer than twice the influence radius from shore.

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[1]Victor, Paul-Emile, "Wringing Secrets from Greenland's Icecap", The National Geographic, (Jan., 1956), p. 123.

(c) Approaches at each end of the strip should be free of obstacles with a height of at least fifty feet for a distance of 300 feet from the end of the runway.

(d) The strip should not be close to a shore that is made up of high (100 feet or higher) bluffs, as the turbulent wind at such a location may create air that is too rough for landings or take-offs.

(e) Generally, ice on lakes will be wind-swept and smooth while sea ice will be rough and have snow cover which remains on the ice due to the frictional drag of the surface.

(f) Extreme care should be taken where the depth of the snow cover is over one-third the depth of the ice as this weight depresses the ice enough to allow water to seep through and cause slush which is a poor surface on which to land. The slush would freeze to the plane's surfaces and create a flying hazard.

(g) The ice surface of any spring-fed lakes should be investigated thoroughly to determine if any underwater gas, springs, or petroleum formations have caused thin and weak porous ice.

(h) River ice can prove to be the least reliable so it should be checked very closely. The thinnest ice will appear in places where the water is shallow and turbulent and snow drifts in protected places on the ice will cause rotten or poor quality ice. Watch for double layers of ice caused by flooding; usually this will cause the top layer of ice not to be suited for a landing strip.

(i) In general, a strip should not be located on ice subject to horizontal movement. An indicator of such movement are rupture corners at intersecting cracks. These corners may eventually be raised as high at ten feet and thereby destroying the location's effectiveness as a strip.

The outline of the strip, parking and service areas, taxiways, and other areas should be marked with orange flags. Any large cracks should be also marked with flags. Because of "Arctic white-outs" which are caused by the uniform radiation properties of the entire landscape and sky under overcast conditions, a loss of contrast occurs, therefore large orange panels should be lined up perpendicular to both sides of the runway to indicate the location of the point of touchdown. Fuel drums with kerosene-soaked earth or rags may be used at the sides

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of the strip and at each end, and are to be used in the evenings or under overcast conditions. Smoke bombs or generators may be used to determine the wind direction or to locate the strip.

The strip should be first subjected to several touch-and-go landings with the planes that may use it before the final acceptance is considered. The ice should be inspected prior to the first landing after the trial landings.

TABLE 12

Table of Ice Thicknesses Required for Specific Airplanes on Fresh Water and Sea Ice

Plane & Gear	Gross Weight (lbs)	Fresh water ice thickness (inch)						Sea ice thickness (inch)					
		Emergency operation			Regular operation			Emergency operation			Regular operation		
		Air temperatures (°F)						Air temperatures (°F)					
		14	22	31	14	22	31	10	19	28	10	19	28
C-46 wheels	48600	15½	17½	20	22	24	28	25	28	33	33	37	44
C-47 wheels	29000	12½	13½	16	17½	19½	22	19½	22	26	26	30	35
C-47 skis	30500	11	12	14	15½	17	19½	17½	20	24	23	27	32
C-54 wheels	67500	17½	19½	22	25	28	32	26	30	36	36	41	49
C-119 wheels	61800	16	17½	21	22	25	28	25	28	34	34	37	45
XC-123 wheels	46500	16	18	21	22	25	29	24	28	33	33	37	44
C-124 wheels	168000	28	32	36	40	45	51	40	46	54	54	62	74
YC-124 wheels	202000	32	36	41	44	49	57	44	50	59	60	68	81
SA-16 wheels	31400	13	14½	16½	16½	18½	21	21	24	29	28	32	38
SA-16 skis	31400	13½	15	17	18½	21	24	21	24	29	28	32	38
DHC-3 wheels	6540	6	6½	7½	8¼	9¼	10½	11	12	14	14½	16	19
DHC-3 skis	6540	4½	5	5½	6½	7	8¼	9	10	12	12	13½	16
Otter wheels	6890	6	7	8	8½	9½	11	11	12½	14½	14½	16½	19
Otter wheels	6890	4½	5	6	6½	7¼	8½	9¼	10½	12	12½	14	16½

(Remarks concerning Table 12)[1]

(a) Takeoff run is given for standard conditions: maximum gross weight sea level and 59° F. air temperature. This is not the required runway length, which must be decided by the operations.

(b) Figures given for emergency landings involve some risk of breakthrough (of landing gear only: aircraft will not sink). Move aircraft around on ice or, better, remove it from the ice as soon as possible.

(c) Air temperature is the average over the following number of days:

Ice thickness, inches:	below 20	20 to 40	above 40
Number of days:	3	4	5

(d) If operations have to proceed under average air temperatures higher than 31° F. on fresh water ice, and higher than 28° F. on sea ice, the required ice thickness, given under these columns, have to be gradually increased by up to 20% more, until deterioration of surface conditions (slush or candling) prevents further operations. In any case, suspend operations if maximum air temperature exceeds 40° F.

(e) The recommended ice thicknesses are not in a simple relation to the gross weight, since gear configuration is also considered.

(f) Gross weight is given as normally expected for operations on ice. For C-47 and other ski-equipped aircraft a 5% weight allowance was made for ski and additional fuel.

(g) If weight exceeds indicated gross weight, add 6% to ice thickness for 10% weight increase.

If weight is less than indicated, 5% ice thickness may be deducted for 10% less weight.

(h) Parking up to one hour under regular operations. Increase required thickness by 25% for twenty-four hour parking and move aircraft daily under low temperature conditions (below 10° F. for sea ice, or 14° F. for fresh-water ice). Under medium temperature (19° or 22° F.) only six hour parking is allowed with 25% more thickness than required by table. Consider remarks d, g, and i. Under higher temperature (28° or 31° F.), prolonged parking beyond one hour is not recommended, unless the ice thickness substantially exceeds requirements.

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[1]Assur, op. cit., p. 23.

(i) Increase required ice thickness by 10% for dry cracks (width often about one and one-half inches) and by one third for wet active cracks over two and one-half inches wide. Disregard hair cracks.

Snow should be removed from the strip and parking areas immediately after a snowfall and snow drifts that are three feet deep or two-thirds the ice thickness, whichever is higher, should be leveled out prior to attempting landings. Dispersing the snow will decrease the danger of damage to landing gears and reduce the slow plastic yielding which causes deep ditches beneath the drifts. The wind-packed Arctic snow is extremely hard and using any piece of snow removal equipment that is not at least as strong as a D-4 tractor will not be very efficient. The planes should never land or taxi in snow where the depth is over one-third of the diameter of the main wheels. If planes have to land in deeper snow to deliver snow-removal equipment, skiis may be used in lieu of wheels for landing gear.

Daily inspection should be conducted for cracks and after the location has been noted, the cracks are to be repaired with slush or wet snow. If a crack parallels the strip for at least two-thirds of its length and is within fifty feet of the center line, the strip will have to be abandoned until the crack is healed or the strip is relocated.

The orange markers and flags should be checked daily, and any snow that may have covered the marker should be removed so they may be viewed from the air. Oil drums painted orange and spaced about 300 feet apart may be used to mark each side of the runway. An oil drum filled with kerosene soaked rags or sand should be placed about

one mile from each end of the runway in line with the center line.

These smoke generators as well as smoke bombs will serve as markers to aid the pilot during adverse weather conditions. A portable generating unit with enough lights to mark the runway (lights every 100 yards on each side - staggered) should be used if the strip is to be used very often during darkness.

The thickness of the ice at the middle of the runway and at each end should be checked daily and a record kept of this information. A new hold should be drilled for each check. Daily checks should also be made of the ice thickness in the service and parking areas. Too much importance cannot be placed upon checking the ice thickness as well as crack location and propagation.

If cold or warm fronts do not move into the area, the ice usually reaches its coldest temperatures just before dawn, and from this standpoint the early morning hours is the safest time to land on ice.[1] Fog usually appears over patches of open water in the Arctic the morning hours - another factor calling for early morning use of the airstrip.[2]

Jet airplanes present a special problem from the extreme temperatures at the aft portions of their engines, however these types of airplanes need practically no warm-up, consequently they will not be

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[1]Owen, S. Lee, Sea Ice Investigations in Support of NEAC Operations, U. S. Navy Hydrographic Office, (Oct., 1956), p. 6.

[2]Assur, op. cit., p. 11.

at any one spot very long. In landing and taking-off, the planes could be staggered and the strip's width could be increased so the previously melted section could be resurfaced with water and cold temperatures.

An engineer's level and rod should be used to measure the elevation of the ice surface in the parking and storage areas at least once each week. The sagging or deflecting of the ice should be recorded at a load's location when the load is first moved into position. The ice will usually deflect until the ice is supported by the water, and such deflections should not cause any alarm unless the deflection increases rapidly.

It is excellent to have alternate parking and storage areas so the loads may be relocated approximately every two weeks, or sooner if the deflection is adverse.

Finally, the strip should have such facilities as:

> Wind direction indicators, radio and radar equipment, airplane moving equipment, snow removal equipment, service equipment (fueling equipment, fire-fighting equipment, generators, etc.), an area for handling helicopters, and necessary buildings for personnel and equipment.

The buildings for the personnel and equipment may take the shape of conventional buildings or ones on wheels. The shelters on wheels are usually the best because they may be moved about the site as the need arises. If there is such a requirement, warehouse-type buildings may be constructed from ice by temporarily supporting the roof until poured water freezes and holds the ice blocks in place.[1] Care must be

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[1]Krylov, M. M., Isothermal Ice Storage Houses, (1942), p. 7.

taken where any heated building would tend to melt the ice.[1]

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[1]Chekotillo, A. M., Ice Isothermic Warehouse, (1951), p. 45.

B. Service Airstrips on Compacted Snow

1. Introduction

Compacted snow airstrips will be utilized more often than ones on ice sheets if the airfield is a great distance from any bodies of water. With the exception of servicing ships, these strips will serve the same purpose as the strips on ice sheets.

2. Planning and Design of Airstrip

Because the snow is normally on the frozen active zone in the winter, the snow when properly compacted offers a very suitable surface for an airstrip. The snow before compaction may be graded and thereby used to cover any irregularities that may exist on the ground surface. In Russia, frozen marshlands, meadows, and fields under cultivation with optimum snow covering of five to six inches have been used for airstrips by clearing obstacles and compacting the snow.[1] The Russians in this particular instance found that a minimum of three and one-half inches of snow cover was necessary to obtain a satisfactory compacted strip.[2]

The U. S. Air Force and Navy in a joint venture during the winter of 1953 constructed and tested a packed-snow base not far from the North Pole. The base was constructed using snow that was approximately three feet deep on solid ice. Nine Navy Seabees with four

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[1]Mogilevskii, D. A., "Winter Airfields", Russian Publication, (1942), p. 34.

[2]Mogilevskii, op. cit., p. 35.

graders and three wobble-wheel rollers built the one mile long snow-compacted 150 feet wide strip on virgin snow starting in March. The project was supervised by a Navy Civil Engineering Corps officer, and was performed without the use of admixtures. My May take-offs on the strip were made by ski-equipped airplanes which could not have become airborne off virgin snow under normal power. The runway, in early June was adjudged satisfactory for use by some wheeled cargo planes, at which time landings and take-offs were made with wheels carrying the loads of the planes.[1] This case was chosen to demonstrate the feasibility of such a snow compacted strip.

Planning and design of a strip on compacted snow is not as involved as on ice sheets, mainly due to the fewer factors that would influence the location of the strip. The snow strip, however, may require the additional task of levelling any surface irregularities, and will usually be longer than the ice strip. Portions of this compacted strip may even be constructed across small ponds, bogs, or other small water bodies.

Snow compacted by natural or artificial means as required in the construction of the strip is known as 'snowcrete'[2] and is the only material used in the preparation of the strip. The hardness, and thereby the strength of the snow-crete increases with decrease in

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[1]Aviation Intelligence Section, Aviation Age, (Aug., 1953) p. 12.

[2]Roberts, Palmer, "Effects on Materials in the Arctic", Military Engineer, (May, 1950), p. 177.

graders and these mobile-[illegible] [illegible] will [illegible] with [illegible] compacted [illegible] [illegible] with [illegible] [illegible] [illegible] in [illegible]. The project [illegible] [illegible] for [illegible] [illegible] [illegible] [illegible] [illegible] was performed [illegible] the [illegible] of [illegible] [illegible] the [illegible] strip were [illegible] by [illegible] airplanes [illegible] [illegible] [illegible] [illegible] airborne [illegible] [illegible] [illegible] [illegible] [illegible]. In early June was [illegible] [illegible] [illegible] for [illegible] [illegible] [illegible] [illegible], at which [illegible] landings and [illegible] were made [illegible] [illegible] [illegible] the [illegible] of the planes.[1] This [illegible] [illegible] [illegible] to [illegible] the feasibility of such a [illegible] [illegible] strip.

Planning and design of a [illegible] [illegible] [illegible] [illegible] involved [illegible] on [illegible] [illegible], mainly due to the [illegible] factors that [illegible] influence the location of the [illegible]. The [illegible] [illegible], however, [illegible] require the additional [illegible] [illegible] [illegible] [illegible] [illegible], and will [illegible] be [illegible] than [illegible] the [illegible]. Portions of this compacted strip may [illegible] be [illegible] [illegible] small ponds, [illegible], or other small water [illegible].

Soil [illegible] by natural or artificial means [illegible] [illegible] in the construction of [illegible] [illegible] [illegible] [illegible] [illegible].[2] [illegible] [illegible] material used in the [illegible] of [illegible] [illegible]. [illegible] [illegible], [illegible] thereby the strength of the [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]

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[1] Aviation Intelligence [illegible], *[illegible] [illegible]*, [illegible] [illegible] p. 12.

[2] [illegible], [illegible], [illegible] [illegible] [illegible] [illegible] [illegible], *Military Engineer*, ([illegible] 1950), p. 17[illegible].

temperature, and experience of the U. S. Army has indicated that about ten "passes" to each six inch layer or 'lift' of snow gives the runway optimum strength.

3. Field Survey, Final Location and Construction of Airstrip

Maps and aerial photographs should be studied to find locations for snow strips that will be able to service the permafrost airfield just as the ice strips do. These strips do not necessarily supplement each other but rather they act as co-service strips for the airfield.

A factor to be considered in the location of a snow strip is whether equipment can be moved in to do the necessary work in preparing the site. An extreme method of getting the equipment in is by parachute, but generally the method of moving overland is used as in the following case.

A"snow port" 10,000 feet long by 200 feet wide was built in June, 1954, on compacted snow near Aniak, Alaska, by moving a Cat D6 tractor, a No. 12 motor grader, a track-type personnel vehicle, and a wobble-wheel roller all overland under their own power.[1] The Corps of Engineers' plans called for a smooth stretch of tundra free of dry holes and chuck holes. Several lakes were investigated as potential sites but due to a thickness of only twenty-six inches of ice they were not suitable. After the desired area had been chosen, the field survey was made on foot and by using a D6 tractor. The heavy equipment

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[1]"Secrecy Curtain Lifted on Alaskan Snow Port", Roads and Streets, (Sept., 1954), p. 64.

used to construct this strip was driven through six miles of timber and over nineteen miles of tundra to arrive at the construction site.

The amount of snow available is a factor for consideration, but because snow is the usual form the precipitation takes in this region, and there are usually large amounts, this factor does not play an important part. Motor graders and tractors are preferred in that order for levelling the snow and grading it onto the strip in six inch "lifts" so the wobble-wheel roller may be used for compaction. Depending upon the snow, two six inch compacted "lifts" will generally yield four to six inches of thickness on the strip. By mixing the snow with disc harrows, gripper harrows, or cultivators, the compaction is doubled and the initial hardness increases by six times.[1]

Parking areas and taxi strips will be built on compacted snow using the same methods used on the strip. Barriers of snow blocks may also be constructed to protect the planes somewhat from the elements.

4. Operation and Maintenance of Airstrip

Airstrips on both ice and compacted snow should be protected from blowing and drifting snow by using snow fences made from snow blocks or wooden slats and wire fence. The conventional wooden snow fence retains up to thirty-five times the surface area in volume.[2] The snow blocks are about one-third as efficient as the fabricated

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[1]Zamorin, P. K., Construction of Airfields in Deep Snow, (1942), p. 36.

[2]Mizerenkov, A. V., Airfield Operations, (1943), p. 49.

used to construct this stationary [illegible] of 14 to [illegible] and over nineteen miles of terrain to [illegible] the construction site.

The amount of snow available is a factor for consideration, but because snow [illegible] the snowfall [illegible] in this region, and there are [illegible]. This factor does not play an important part. [illegible] in this order for landline [illegible] all inch [illegible] to the [illegible] for operation. Depending upon the [illegible] will generally yield four to six inches of [illegible]. The [illegible] the snow with [illegible], [illegible], the [illegible] portion is [illegible] and [illegible] by [illegible].[1]

Parking areas [illegible] will be built [illegible] snow using the same [illegible]. [illegible] also be constructed to [illegible] the [illegible].

h. Operation and Maintenance of Airfields

Attention [illegible] should be [illegible] from blowing and drifting snow by using snow fences made from snow blocks or wooden planks and board fences. The more efficient device [illegible] fence [illegible] up to [illegible] the surface [illegible].[2] The snow blocks [illegible] as [illegible]

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[1] [illegible], [illegible], Construction of Airfields in [illegible] (1942), p. 95.

[2] [illegible], [illegible], Airfield Construction, ([illegible]), p. [illegible].

fence in the retention of snow.[1] Fences should be set at 25 - 30° to the wind when the prevailing wind and the runway directions coincide.[2] Continuous rolling prevents snow heaps and raking reduces ice formation during a storm (such maintenance is usually undertaken during "breaks" in the storm).

Personnel and equipment may be housed in snow huts or caves, but generally portable buildings or mobile carriers will be used. The snow construction would be destroyed by the heat required by the personnel or given off by the equipment.

The center line of the strip will be located with orange marker dye for easy identification from the air while the same devices used to mark out the ice strip will be used here. If timber is close by, spruce boughs may be used to mark the strip or as smoke generators.

The ice and snow service strips will each require continual inspection, maintenance, and study to maintain their importance to the permafrost airfield.

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[1] Rowley, Graham, "Snow-House Building", Polar Record, (July, 1938), p. 115.

[2] "Winter Flying Problems", Intelligence Bulletin, (Feb., 1943), p. 60.

DISCUSSION AND CONCLUSION

Any discussion covering the specific operational aspects of the airbase would be somewhat limited because of the military security classification of such information - a fact which would restrict the use of such information. Because of this limitation, the following immediate discussion is submitted as an hypothesis of the character of the general operational aspects of the airbase.

The military forces operating an airbase tend to put forth their maximum efficient effort in accomplishing the particular mission being undertaken at the time - that is when the airfield's mission is to serve as a readiness or deterent base, a large number of planes will be assigned and much flying will be performed to keep the crews and planes operating at top capacity. If aggression should start, the airfield would probably be assigned a retaliatory and defensive role which would also be conducted in the forementioned maximum effort fashion. The accomplishment of these missions will require that the airfield be in operational condition at all times. Maintaining this operational condition would be defined as that time when the airfield was servicing the maximum compliment of airplanes on an efficient basis without any deterioration of future airfield operations. If the planning and other aspects of this thesis are followed, the airbase will handle its maximum compliment of airplanes without any portion of the airbase becoming inoperative due to weather or usage conditions.

The operation of the airbase should be examined at regular

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The operation of the airbase should be examined at regular

intervals to determine whether the operation is the most efficient available at the time. It would be rather senseless to have an installation that has been designed to be as efficient as possible while the personnel and equipment are only able to use a small quantity of these design features. This examination of existing facilities should be performed under the philosophy that any new and more efficient materials as well as methods will be tested to ascertain their possible use. An example of this is ceramic blocks which are a new surface material that could be used at locations where the high jet temperatures and blasts are severe and prolonged. Snow removal and snow packing equipment will also be influenced by more efficient designs and methods.

Stage or continued construction and improvements at the airfield must also be planned in such a fashion that new facilities may be incorporated into the overall plan through the use of a smooth transition period. The new facilities may include such installations as missile handling and firing equipment plus storage and handling equipment for atomic and nuclear weapons. Other new facilities might also include such installations as a more efficient electronic detection equipment and electronic equipment used for all-weather flying. The transition to a more improved installation can generally be accomplished without any interruption if the older installation remains in operation until the new one is completed and checked out for use.

Another factor to be considered under future airfield improvements would most certainly be an additional airstrip or possibly an extension of the existing strip. Revetments or parking areas may be

intervals to determine whether the [illegible]
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Another factor to be considered [illegible]
ments would most certainly be [illegible]
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increased in number as more airplanes or units are assigned, while increases in the number of buildings would normally be in a direct ratio with any increase in or improvement of the airplane handling surfaces.

The lifesaving and rescue mission will be one of the ever-present tasks of the airfield, and for this reason the field's operation should be such that this mission may be carried out under all conditions. Possibly the majority of the rescues will occur during adverse weather conditions which establishes the requirement that equipment and personnel be capable of performing their duties at such times. The rescue units should be equipped with all the necessary gear to conduct their mission on an efficient and expeditious basis because the fatalities of the victims are usually as a result of exposure to the weather conditions. The airplanes and helicopters used on the rescue work should be supplemented by overland equipment such as conventional and snow tractors, sleighs, sled dog team, and any other specialized rescue equipment. Some of the rescue equipment and personnel should be capable of being parachuted into an otherwise inaccessible rescue location. The dog team could not be air dropped but would have to move overland to where they were needed. The dog team is a very valuable asset at any large installation in these regions because of the dogs' ability to cover terrain during all types of winter weather. The standard procedure would be to have the rescue unit administered such that personnel and resources will be available when needed (generally on a short notice).

General administration at the airbase will also be concerned with keeping all communication lines which include the service road to the harbor facility passable throughout all the seasons. Adverse weather conditions may hamper the flow of traffic on the roads, however this should be only a temporary situation, lasting until the snow removal crews have cleared the obstacles.

The movement of cargo by ships into the harbor should be planned so that the materials will be stockpiled when the sea lanes are relatively free of ice. The movement of materials overland to the airbase will be conducted as the appropriate needs arise during the year. Transportation of fuel supplies will be furnished a very large portion of the traffic between the harbor and the airbase.

The possibility may arise whereby the airfield will be called upon to handle a greater number of airplanes than was considered in the original design. This is a rather nebulous possibility, however, it must be considered in a discussion of the airfield's many aspects. The author will make the assumption that studies would be conducted by the Air Force to determine by how much the installation design could be exceeded for a definite period of time. This overtaxing of the installation and its services will usually be limited to a period of a few months. Maintenance and servicing at the airfield will be accelerated to meet the increased demands during such times. The dearth of information on this subject restricts any discussion beyond the preceding generalities.

Another very important aspect of the airfield's operation that

must be considered is that portion of the year when there are more daylight hours each day than would be found in the temperate regions. Naturally during the winter months, darkness will replace the daylight hours until the earth once again tilts and allows the sun to climb higher into the sky. These natural phenomenon will call for definite courses of action in order to utilize the facilities at their greatest potential during the long daylight hours of the summer and the equally long hours of darkness in the winter. The power source for the lighting system will not be required during the non-dark days of summer, a fact that will offer an excellent opportunity for overhauling this equipment in preparation for another year of operation. The demand on the generating equipment will be very great during the all-darkness days of the winter months, and consequently any work done in overhauling should be aimed at eliminating any break-down during the vital winter season. The basic reason for placing all electrical supply lines in below ground service tunnels rather than on poles above the ground surface is that the chances of failures occuring in the circuits from storms is greatly minimized especially during the winter season.

The high gross weight bombardment airplanes used by the Air Force, have in recent years used rocket type power packs to assist in their take-off. These ATO (assist take-off) units make it possible for an airplane to use a shorter take-off length with a standard load or to take-off in its standard runway length requirement with a very large or high gross weight load. These assistance devices produce

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The high gross weight bombardment airplanes used by the Air Force, have in recent years used rocket type power units to assist in their take-off. These ATO (assist take-off) units make it possible for an airplane to use a shorter take-off length with a standard load or to take-off in the standard runway length requirement with a very large or high gross weight load. These assistance devices produce

concentrated areas of heat and blast during their operation which can cause great damage to the runway. The damage caused by these devices is usually greater than that resulting from operation of the jet engines because the forces are generally directed down and to the rear with very little being directed toward the runway. The use of such devices must be considered during the operation of the airfield, which will include such items as storage of these propellants and the removal of any loose matter from the runway which could be blown against the surfaces of the airplanes where damage could result.

The conclusion of this thesis could be broached with the comment that the airfield's future existence and importance will be somewhat dependent upon how the operations of the past have been conducted. These past operations are important as measuring qualities, however the future of the airfield will largely be dependent upon such other factors as, the airfields location relative to other facilities on an overall military plan, technological advances which may decrease the need of such an installation, the expense of operating the installation may justify replacement through the construction of another installation in the warmer regions, and international tensions may become eased to a point when such an installation will no longer be a requirement. The author believes, however, that airfields of this design and located in such regions will continue to enact a a very important role for at least a generation into the future. - - - Thus the basic reason for preparing this thesis.

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