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Problems Associated with Soils Stabilization in the Vicinity of Point Barrow, Alaska

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I. GENERAL LOCATION AND DESCRIPTION

Point Barrow is located in the northernmost extremity of the Arctic Coastal Plain (Figure 1). The coastal plain is an undulating surface of low relief, the major relief being in the vicinity of the major north-flowing rivers. The general lack of relief is largely due to the fact that the area is a recently elevated segment of the continental shelf, and thus, it has the low relief characteristics of most recently emerged coastal plains.

There are two major settlements near Point Barrow, the Eskimo Village of Barrow located about 4 miles south of the Barrow Base (Figure 2), having a population of approximately 1200 people. The Barrow Base is located about 5 miles south of the tip of Point

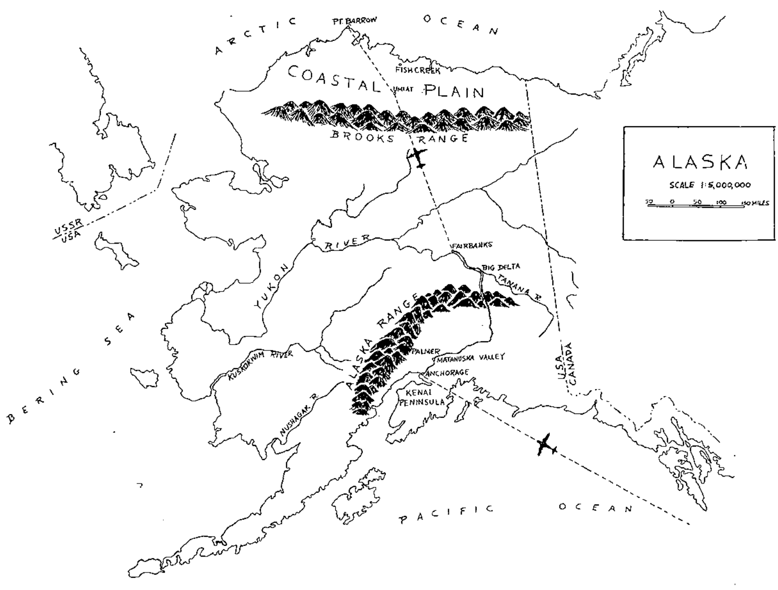

Figure 1. General location map of Alaska showing Point Barrow, and Arctic coastal plain.

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Barrow spit. Both of these are located on the margin of the tundra adjacent to the beach.

The topography in the vicinity of Barrow is one of little relief with rounded slopes into the main drainage, with relatively little stream dissection. The major relief features other than the stream valleys are the ancient beach ridges, remnants of former spits resembling in form the present spit at Point Barrow, and the shore lines of the oriented lakes, and associated drained basins. The minor relief features are either due to or are related to the ice wedge polygons.

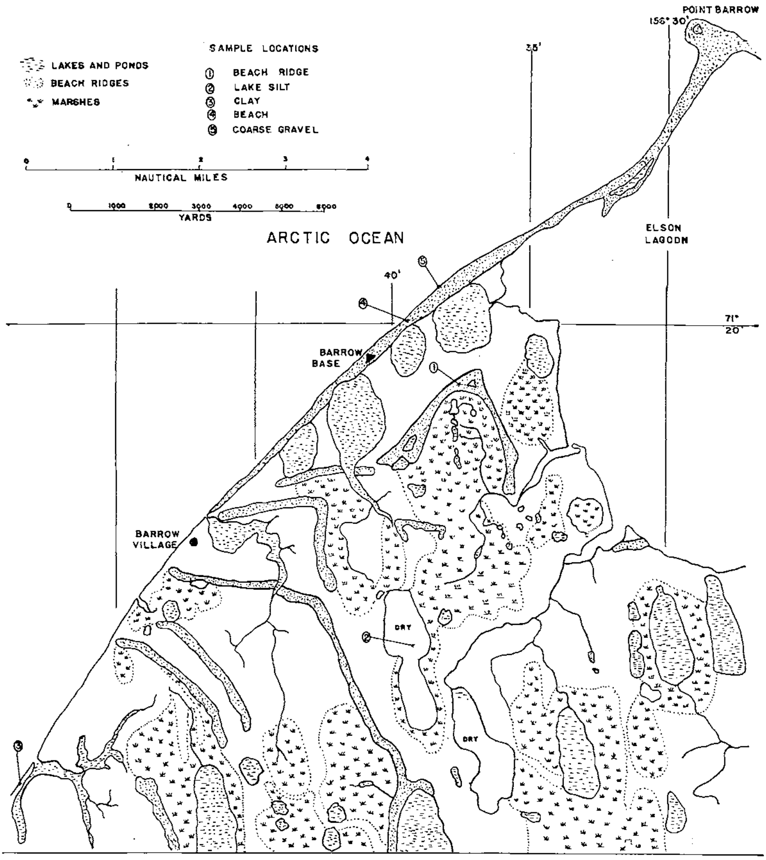

Figure 2. Map of Barrow area, with locations of samples to show areal extent of materials and distance from Barrow Base. (From unpublished field map of John Koranda, University of Tennessee.)

Many of the elongated lakes (Figure 3) are oriented with their long axis approximately 10° to 15° west of north in the vicinity of Barrow. This orientation is true especially for the more northern of the coastal plain lakes. The exact reason for this orientation is not obvious. Black (1) and Livingstone (2) have both appealed to the

Figure 3. Oriented lakes of the Northern Arctic Coastal Plain though polygonal ground is present, scale too small to be defined.

Figure 4. A view of the tundra with the ubiquitous Polygonal ground (Low centered Variety).

use of the wind as the orienting factor. Black calling for an ancient prevailing wind parallel to the long axis, causing a progressive thaw accompanied by wave action in a linear direction. Livingstone assumes no change in wind direction from past to present and appeals to erosion perpendicular to the wind direction, since the present prevailing winds as well a storm winds are perpendicular to the present long axis. The authors believe these mechanisms have not satisfactorily explained some of the observed facts associated with the orientation, and so, are seeking a different explanation.

In brief, the polygonal ground (Figure 4) found in evidence over practically the whole surface of the tundra is caused by the forming of contraction cracks in the frozen ground during the annual fall freeze-up. Water from the spring thaw fills these cracks and later freezes causing wedge shaped masses of ice to occur in the network of cracks. These wedges grow by annual accretion until, as in some areas, they may make up over 70% of the material immediately underlying the surface. These cracks ideally tend to develop in a hexagonal pattern comparable in expression to the pattern in columnar basalt, mudcracks, and lake icecracks, except on a much larger scale averaging 15 feet with exceptional ones over 50 feet. Since conditions are not ideal, due mainly to slope, heterogeneity of materials, and differential heat transfer, the ice-wedges are seldom arranged in the ideal hexagonal pattern. Such variations as squares, rectangles, and semicircles are common. Permafrost, perennially frozen ground, allows their growth and protects them from ordinary thermal destruction. The initial growth of the wedge displaces material laterally and upward causing the formation of micro relief. Surface drainage, which is largely controlled by the polygonal pattern, adds to the total relief attained.

II. Need for Stabilization

The Arctic is becoming increasingly more valuable in the defense of the United States. This is evidenced by the establishment of the Dew line (distant early warning) and its sister the Pinetree line of radar sites which are stretched across northern Alaska and Canada giving radar protection to the two countries. These radar sites as well as any military bases in the permafrost area are in need of roads and runways that can be used during all seasons. The problems associated with the various settings in which the sites are located will vary in a few respects in so far as strictly local conditions obtain, but generally they fall heir to the problem as typified at Barrow.

The possible future expansion of the Barrow Base and/or the radar sites will necessitate roads, but more critically, small runways capable of withstanding reasonable traffic. The Barrow Base will either have to be extended along the beach or built back off the beach, into the tundra. If the tundra is used for the construction area, the need for roads become immediate.

A slight attempt toward stabilization was made a few years back, the surface material from the tundra (mainly organic rich silt) was mixed with the regular well-sorted beach material and layed-down on the main street of the base, to improve the trafficability. The slight success of this procedure has allowed wheeled vehicles to be used somewhat more extensively, but they still have to be driven in a 4- or 6-wheel low range drive when they leave this strip for the natural beach. Heavily loaded vehicles though are practically unable to drive on most parts of the beach, and not at all on the tundra.

The major vehicles in use are Weasels, LVT's (landing vehicle tracked), jeeps, six-by-sixes, Cat-tractors and trucks with airplane tires. With the exception of the airplane-tired trucks, only tracked vehicles can drive on the tundra. In every case where they are used the modified trucks must be used with extreme caution and their use is still limited to the higher and better drained portions of the tundra. Therefore, for overall transportation, the tracked vehicles are much superior in the present circumstances, the major hauling being done by Caterpillar-tractors with tracked trailers in summer, and sleds in winter. The cost and operation of Weasels and LVT's vs. small payload in comparison to that of heavy duty trucks makes stabilization an economic necessity. This would hold especially true if private concerns were to undertake further exploration for oil and associated developments on the North Slope following that done by the Navy in the Petroleum Reserve.

A rough idea of the economic life of the Weasels and LVT's follows: Weasel—2 to 4 miles per gallon at 5 to 10 m.p.h., approximately 1500 miles before complete track and motor overhaul is needed. LVT—½ to 1 mile per gallon at 5 to 10 m.p.h. Track lasts 3,000 miles and engine life is very short under full load.

Runways are especially vital in this day of jet aircraft where an extremely long runway and high take off speeds are necessary, this requires a smooth surface hardly attainable by steel matting laid on nonstabilized beach material of inherent low stability (Figure 5). Any use of heavy transports requires that a large strip be available, some of the planes landing on the strip at Barrow would be unable to take off if they were fully loaded; as it is, the strip is just long enough for take-offs when they are empty. Considering the conditions air freight is the only possible method of transportation in the summer since ocean travel is restricted to a few short unpredictable weeks, and the distance of passage and ground conditions over the tundra make surface travel impossible.

III. Problems

Connected with Area

The climate of Barrow is cold, windy and arid. The weather data has been collected there for the most part over a 21-23 year period by the United States Weather Bureau. The climatic factors can be averaged as follows:

Days with freezing temperatures (per annum)	321
Average wind velocity (m.p.h.)	11.8
Mean, ppt. annual. (snow included)	4.23
Mean. ppt. annual. Black's (3) estimate	9 to 15 inches
Snowfall (inches)	33.0
Cloud cover (%)	56.0
Relative humidity	60 to 90%
Annual mean temperature	10° F.
Annual mean maximum temperature	16° F.
Annual mean minimum temperature	4° F.

Barrow is within the area of perenially frozen ground or permafrost. The secondary boundary of this area is somewhat south of the Brooks range. The permafrost is on the average several hundred feet thick, but instances up to 2,000 feet have been recorded. The depth of summer thaw ranges from 3 inches to 7 feet (average between 8-15 inches) depending on the particle size, degree of drainage, and thickness of the organic insulatory blanket. The latter having the greatest effect upon extent of thaw. The permafrost is then the greatest obstacle to overcome, and since one cannot beat it he must either join it or agree not to antagonize it to any great extent.

The aforementioned climatic conditions coupled with permafrost cause saturated conditions to arise in the surficial thawed or "active" layer. There is neither drainage nor evaporation to any great degree. Actually this area cannot be classed as arid, even though it receives much less precipitation than many truly arid regions, because aridity is based on the relationship between precipitation and potential evaporation. Here the atmosphere is too cold to evaporate the available surface moisture. The amount of water present may be visualized by noting that the surface of the tundra is covered 50%-75% by lakes and marshes. There is also a tremendous quantity of water tied up in the permafrost beneath the surface in the form of ice wedges (Figure 6), horizontal sheets (separate from late stage ice wedge development), minute stringers (Figure 7) in many places and films surrounding and cementing the coarser material as well as often filling all the interstices. It is the disrupting of this equilibrium and allowing the thawing of the saturated materials that has to be assiduously avoided. In large areas the surficial material appears to be saturated to supersaturated in many cases. The depth to which this saturation extends is not clearly known, certainly in some places to depths of over 25 feet, yet in a meat cellar dug at Barrow Base the material seemed unusually dry at a depth of 25 feet. Sublimation may have removed some of the ice, but not to the existing extent. It could be expected that the degree of saturation with depth would vary somewhat widely, but the near-surface condition is the one of critical concern; the one demanding primary consideration in any stabilization project.

Figure 5. View of beach used as road at Barrow Base. Note "weasels" and deep ruts in low bearing capacity gravels. The deeper ruts are made by jeeps and trucks.

Figure 6. Ice wedges below surface of tundra as exposed in cliffs, about 8 miles below Barrow Base.

The beach, though better drained and not as particularly susceptible to the same road and runway construction problems as the tundra, will allow differential settling of any heavy structures placed on it unless proper precautions are taken.

The location of Barrow itself offers another problem, its distance from stateside materials. These either have to be shipped or flown in at great cost. Hence, it is very desirable to use locally available materials for construction purposes.

Since this is a territory in which very little if any work has been done on this type of problem, much experience must be expected to be obtained the hard way, by trial and error. The information on road conditions in Fairbanks will be useful, but conditions are still very different from those encountered here. An example of experience learned the difficult way is illustrated by the so-called "Alligator Road" at Umiat (Umiat is a base on the Colville River used by the contractors during drilling operations in the Naval Petroleum Reserve; it is located approximately 170 miles southeast of Barrow). Construction workers hoping to facilitate movement of vehicles to a drilling site, over a typical hummucky, "polygonized" stretch of tundra bulldozed a road from the valley bottom up to surrounding upland. This removed the vegetation and organic tundra mat allowing thaw and accompanying solifluction, and especially the erosion of the heretofore inconspicuous but omnipresent ice wedges. The removal of these wedges produced a cross-work of deep trenches (Figure 8) which from the air resemble the scaly pattern of an alligator hence the name. Some of the ditches, caused by the thaw of the wedges became very large and deep depending on rate of erosion and slumping, widths of over 7 feet and depths of over 10

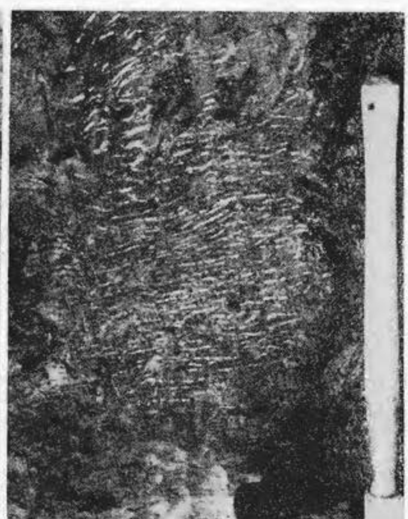

Figure 7. Ice lenses formed in clay-silt by segregation of ice during freezing. Location a few feet below surface of tundra.

Figure 8. Trench formed by thaw and accompanying erosion of an ice wedge; picture location along shore of Elson Lagoon. Bulldozing of tundra will initiate this condition.

feet have been observed; thus eliminating the use of the route as a road by any vehicle.

Efforts must be made to determine a method by which the proposed road or runway can be made so as to deny the infiltration of water and at the same time not disturb the permafrost. The method must also provide for relatively easy repair with minimum time, effort and expense.

Associated with the Available Material

These problems are also somewhat greater due to the previously mentioned climatic conditions as well as those associated with the geologic agents operative upon the material in the past. The major types of material used in this study of the methods for stabilization are:

(1) silt
(2) gravel and sand (natural beach)
(3) clay
(4) ancient beach ridge (composite)
(5) coarse gravel
(6) natural asphaltic crude oil

(See Figure 11 for size range of materials being studied.)

The Arctic Coastal Plain is composed of unconsolidated (except by ice) materials overlying consolidated sediments. The surficial material in the vicinity of Point Barrow is the Gubik formation of Plio-Pleistcene-Recent age which unconformably overlies the Cretaceous sandstone. The Gubik formation is composed of a marine clay and silt unit overlain by an interfingering marine-fluvial, channeled sand and gravel (Figure 9). These sands and gravels have been worked to a large extent during their transportation as well as having been derived from reworked sediments. The softer materials have been almost totally removed, with the remaining resistant material having attained a high degree of roundness and sphericity with a rather high polish on many of the fragments.

The predominant material, at Barrow at least, is a dense black chert, with much dark varicolored chert, quartzite and other siliceous material. The amount of igneous material is small, on the order of $< 1\%$. The composition is ideal for stabilization, but the high degree of rounding, sphericity, and sorting (i.e. tendency toward same size) leads to an extremely low bearing capacity, approximating that of ball bearings.

The abundant sand and gravel of the Gubik would be difficult to use, aside from wresting it from the permafrost, in that its variability from place to place within a small distance is tremendous and leads to a high degree of unreproduceability of size in materials ob-

Figure 11. Particle size cumulative curves for materials used in the investigation of mechanical stabilization.

Figure 12. Size variation of beach using samples collected from the whole beach and spit, both surface and w/depth. 90% of samples represented (total of 62 samples). With a comparison to average beach and coarse gravel as collected for investigation.

tained. This would the necessitate a screening down to relative size fractions and then recombination of the desired quantities of each size.

The marine clay member of the Gubik is a black carbonaceous, sulphur bearing material. When thawed, it is well saturated and highly plastic. It is predominantly illite and kaolinite with approximately 37% less than 1 micron. Unfortunately it is not exposed to any great extent except in a few places, the closest being approximately seven miles south of the Barrow Base. This is the only local deposit that could be used as a cohesive binder in any stabilization process calling for clay. The relative lack of clay in the area is due to a combination of environmental factors; the relatively recent emergence of the area from beneath the sea, with accompanying short interval of weathering, the lack of what are considered to be parent materials for clay genesis, and the climatic conditions which are definitely not compatible to chemical weathering. The small plasticity associated with the more recent surface materials is due mainly to finely divided organic material and not to mineral clay, what little is tentatively identified as illite may well be derived from erosion of the marine Gubik clay.

The silt, available in large quantities, can be obtained from the marine Gubik as well as from the drained lake basins. The latter is the source of silt currently being studied. This lake silt is apparently derived from the marine silt and appears to have been deposited by wind in the lakes. This silt varies in thickness up to more than five feet and is extremely clean in all of the lakebeds so far examined.

The ancient beach ridges are remnants of features akin to the present spit, which were developed during the emergence of the coastal plain. The younger ones are definite topographic features, but the older ones are so reduced as to be almost invisible in the field. The difference in vegetation associated with them vs. that growing on the more poorly drained surroundings makes them quite distinct on the aerial photos. The beach ridges are composed of sandy gravel with fines deposited by the wind concentrated in the upper portions, but carried down into the gravel to some extent by rain and melting snow. As a rule they are well drained and therefore not as subject to frost heaving or ice wedge formation as adjacent areas. The thickness containing large portions of silt is variable from ridge to ridge depending on age, but that from which quantity samples were collected is over 5 feet, though in other places and other ridges it varied down to as little as 2.3 feet, still other ridges had so much as to be practically indistinguishable, on the basis of overall particle size, from the normal tundra. This then gives a natural mix which is more reproduceable than the channeled crossbedded sands of the upper Gubik and modern beach mentioned before. These ridges then being drained and somewhat stable due to the silt addition are ready made for either construction of roads (as base) or as a source of material which can be readily removed since the thaw is over 5 feet.

The roundness of the average beach material may possibly be overcome by crushing and/or the addition of crushed material. But still in order to obtain the proper size gradation with a satisfactory degree of irregularity, larger materials than usually present in the beach must be obtained in quantity. There is a considerable amount of coarse gravel available (Figure 12), other than by concentration of that coarser fraction of the natural beach with sieves. This coarse material has been concentrated by the storm waves along certain sections of the beach, the last large storm of sufficient magnitude to transport large gravel occurred in October of 1954. A large quantity of coarse gravel lies immediately off shore and could be dredged up by a drag line. The material studied in the laboratory was collected from the storm concentrate, its size in relation to the normal beach may be noted in the size diagram.

An asphaltic base crude oil is available in quantity from a Naval Petroleum Reserve well drilled at Fish Creek. This is near the coast and approximately 130 miles east-southeast of Barrow. This would be accessible in the summer by boat, or in the winter by Caterpillar train (i.e. Caterpillar tractor pulling heavy duty sleds). The oil is classed as SC-1 i.e. contains a large percentage of low-medium volatile range material. The slow curing properties of this oil make its use in its present state impossible, since low temperatures and saturated conditions would prevent its curing and accompanying increase in strength.

The procurement difficulty is great for the silt and clay since they lie well within the realm of permafrost and annual thaw does not effect them to any great depth. The surficial organic layer as well as the organic rich silt of the lake surface would have to be removed in order for thaw rate to be compatible to economic removal.

This method though would not work for the clay which has a large overburden of about 7 feet of frozen material. It would have to be mined in the solid or semi-solid state with thaw progressing only at the exposed face of the outcrop. This would amount to about 6 feet vertical for a horizontal distance of about 100 feet.

The saturated condition of these materials would require some amount of drying in order for them to be used in any method of stabilization. Drying would be a slow process under normal condition and would most likely need some thermal dryers, as a small kiln, before use.

A crushing plant of some size (small jaw crusher most likely) would also be necesasry if some form of crushed material were found to be a satisfactory solution.

One must keep in mind that in mechanical stabilization, the most practical approach or rather solution is one attaining the necessary

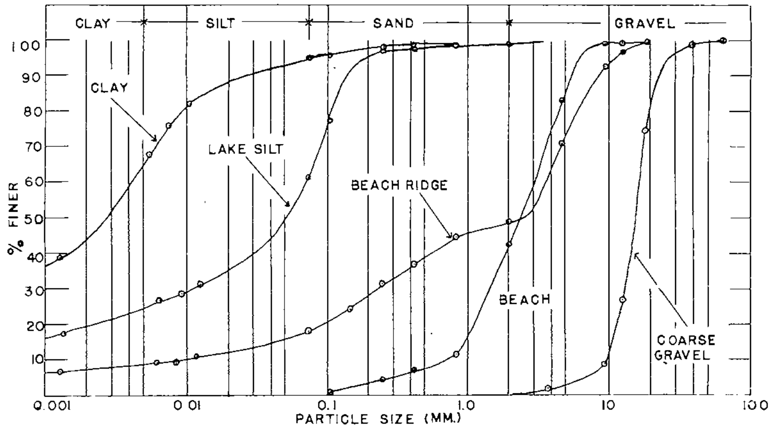

Figure 9. Cross-bedded sands and gravels of Gubik fm. as exposed in cliff, at many places south of the village. (Note variability.)

specifications with a minimum of components in the admixture, since each component represents another variable as well as an expensive step.

Bituminous stabilization using the crude oil in some treated form is another possible solution, with the added property of imperviousness an important consideration in this land of frost phenomena (Figure 10). The fact of one or two major freezing cycles with respect to the many encountered in the northern United States, helps offset the disadvantage of the saturated conditions. However the low temperatures coupled with the knowledge of phenomena associated with this and the available water, makes one wary of any method allowing any water penetration.

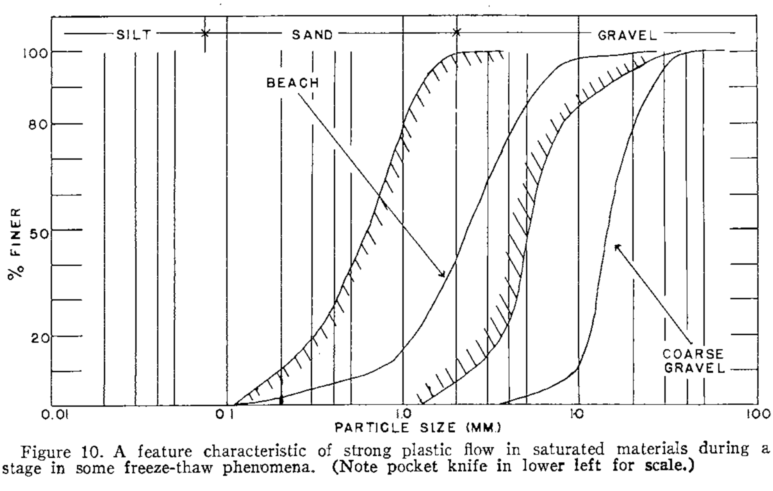

Figure 10. A feature characteristic of strong plastic flow in saturated materials during a stage in some freeze-thaw phenomena. (Note pocket knife in lower left for scale.)

The most applicable solution may be a combination of the aforementioned possibilities with the coarser material (i.e. mechanical stabilization) solving the problem of a base course with an imperious bituminous wearing surface sealing the permeable material below.

The segregation of ice in fine grained material during freezing as shown by Taber (4) warns one against filling the voids of a gravel with silt for stabilization unless the material is well drained as well as semi-sealed from surface drainage.

ACKNOWLEDGMENTS

This research is being carried on by the Iowa State College Engineering Experiment Station (Project 320-S) on Task Order Nonr-530(04) for the Geography Branch, Office of Naval Research, U. S. Navy. Three parties have visited Barrow for field investigation. The first in 1954 consisted of Dr. D. T. Davidson, professor of Civil Engineering; C. J. Roy, professor of Geology, and R. L. Handy, assistant professor of Civil Engineering, all of Iowa State College. The second and third parties included Dr. K. M. Hussey, professor of Geology, and John O'Sullivan, research assistant of the Engineering Experiment Station, with a visit by R. L. Handy in 1955.

Part of this work has already been completed by Capt. Ira J. Ward, U. S. Army, whole M.S. thesis (limited publication) concerned the initial study of the possibilities of mechanical stabilization. Dr. R. L. Handy et al. has written a summary of this which was presented at the Highway Research Board, January, 1956. The work is being completed by Paul R. Carlson and John B. O'Sullivan as fulfillments of their M.S. requirements, and into whose theses the authors' could not too deeply delve.

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