Application of Mechanical Stabilization To an Arctic Beach

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Beaches in some Arctic areas afford natural routes for summer transportation, since the tundra is then impassible to conventional rubber tired vehicles. In the vicinity of Point Barrow, Alaska, the beach materials have been rounded and sorted into size grades by geologic agencies of transportation. The rounded sand grains and the uniform particle size give the Barrow beach sands a low trafficability and one which constitutes an engineering problem in an area of potential strategic importance.

A possible solution to the Barrow beach road problem is to stabilize the beach sand by admixing locally available binder materials. At least two major problems are associated with the utilization of binder soil deposits. First, the presence of permafrost prohibits ordinary excavation of a binder material below a depth of 1 to 3 feet, depending upon the depth of summer thaw. Second, the Arctic climate restricts chemical weathering and soil profile formation so that those binder materials which are available contain large amounts of finely ground peat but very little mineral clay. It was found that extra amounts of binder produced higher strength in the compacted mixes. Laboratory tests indicate that with optimum amounts of a tundra clay and ice-rafted beach gravel, the soaked CBR of the compacted beach material is increased approximately ten times, from 3 to 31. However, for some purposes, this is not high enough, and other binders are now being investigated. A short discussion of these is included in the paper.

● EVEN to the most casual observer, the Arctic is an extraordinary region — notably different from all other areas on the North American continent, and remarkable for its extent. In northern Alaska, much of the area north of the Brooks Range is Arctic coastal plain — essentially flat and treeless, but everywhere squeezed and shaped by the slow, cumulative powers of localized growing masses of subterranean ice. The tundra, as the coastal plain is often called, is a gigantic patchwork of lakes, many of which are somewhat rectangular in shape, up to several miles in length, and oriented to the northwest. Between and in some cases extending under the margins of the lakes is a vast network of frost polygons. These polygons are believed to be formed by thermal contraction which cracks the ground; the cracks then fill with water which upon contact with permafrost freezes into ice. Permafrost in the northern Arctic extends from a depth of one or two feet down many hundreds of feet, and creates for the engineer a startling and profound array of problems. Even though the annual precipitation is low and would classify the region as arid, drainage is so prohibited by permafrost that during summer months the tundra remains quite soggy and wet. With the wet conditions and the low mean annual temperature (10 deg. F at Point Barrow) chemical weathering is almost absent and most of the ground above permafrost is a mixture of earth and peat. However, for most engineering purposes, the permafrost must be kept frozen. Thawing of permafrost underneath a structure results in the structure resting on soil saturated with water, with exasperating and well-known consequences.

Perhaps the most difficult engineering problem in the Arctic is that of summer travel on the ground. Travel by foot over the tundra is at best slow and difficult. The only alternative is the use of a track vehicle, such as a weasel. Track vehicles are slow; they are also expensive to operate and maintain. Roads, of course, are quite difficult to build over the tundra, partly because of the lack of suitable road-building materials. For this reason, it is fortunate that beach materials are available; and

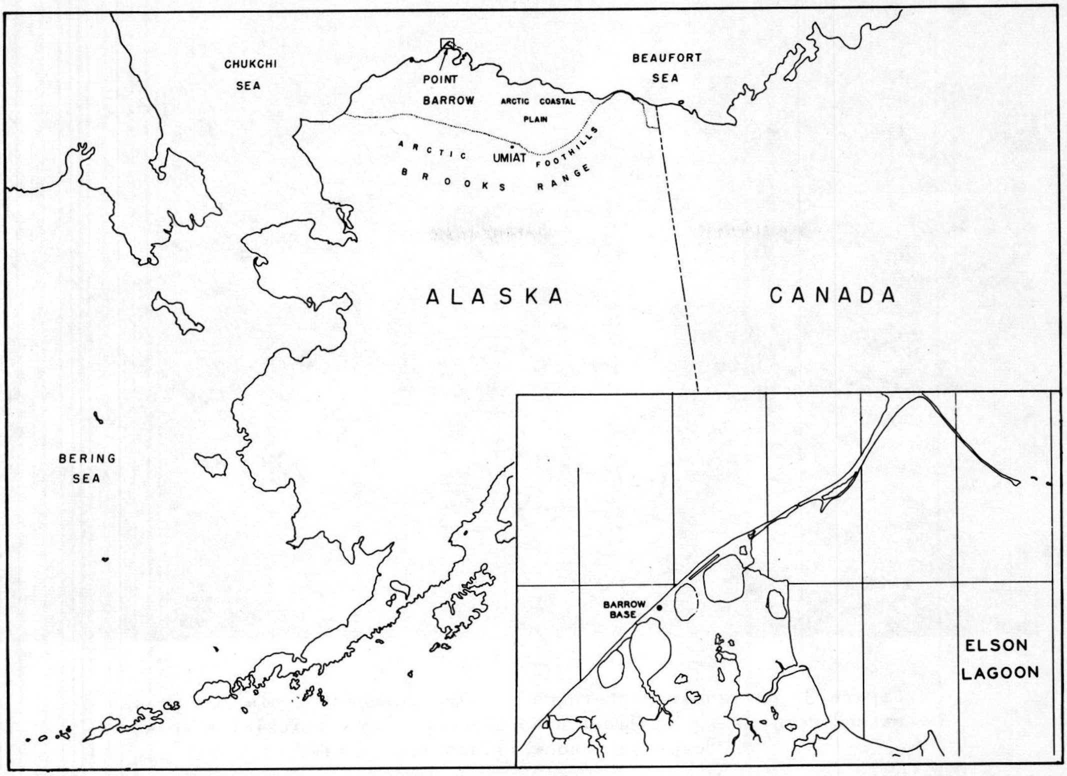

Figure 1. Map of Alaska showing the Arctic coastal plain and Point Barrow.

Figure 2. Oriented lakes of the Arctic coastal plain.

Figure 3. Polygonal pattern on the Arctic coastal plain. Cracks extend down into permafrost and are occupied by vertical ice wedges. Seaplane shadow illustrates scale.

most installations, depending on supplies brought in by the sea, are located on or near a beach. The beaches themselves afford a natural route for summer transportation. In the winter, ground transportation is much less of a problem.

The Arctic beach, unfortunately, is not always in itself trafficable. In the Point Barrow area chosen for this study, the beach is composed of highly rounded sand and gravel particles which act somewhat as ball bearings under foot. In walking, one quite properly gets the feeling that each step is into and out of a hole. The Barrow beach will not support ordinary wheel traffic; although for track vehicles or trucks with airplane tires, it is quite adequate. The problem, then, is to improve the stability of the beach so that it will be suitable for truck traffic.

The requirements for a road on the Barrow beach are not easily met. The road must be readily repairable, because of the possibilities of damage from heavy tractor traffic, permafrost subsidence, or storm waves or winter ice-push from the sea. A simple construction using low-cost available materials would be desirable. Flexibility of the pavement structure would be desirable because of permafrost subsidence, and a high bearing capacity is necessary for the heavy, slow-moving traffic frequent in a construction area. At the time that the first Iowa Engineering Experiment Station research group was at Point Barrow, a soil-aggregate method of road construction appeared to be the best possibility for satisfying these requirements, and several samples were taken and transported back to the laboratory in Iowa for an appropriate evaluation.

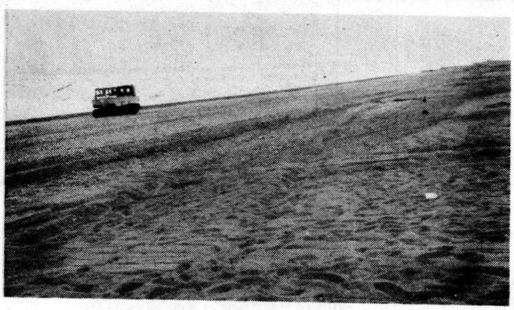

Figure 4. The beach near Point Barrow. Materials are mainly gravel and coarse sand, both composed of black chert. Vehicle at left, center, is a weasel.

MATERIALS

The beach sand at Barrow varies as beach sands do — along the beach, across

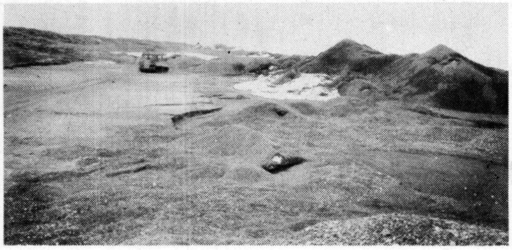

Figure 5. 1955 ice-rafts melting and depositing sand and gravel on the beach south of Barrow. The sea is to the right. The weasel may be seen just left of center.

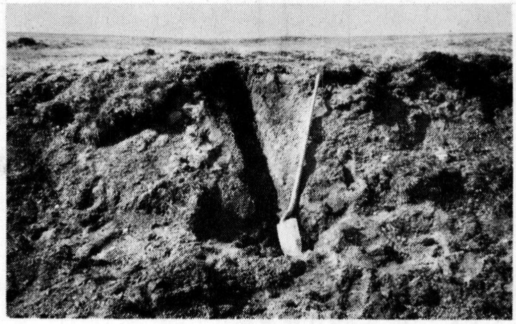

Figure 6. Section through an old beach ridge on the arctic tundra. The gravel is capped with a layer of gravelly sandy silt.

the beach, and with depth into the beach. Individual layers or lenses of the sand are well sorted; that is, the grains in a layer tend to be of one size. This contributes to the lack of stability of the natural sand under traffic. The mineralogical composition of the sand is ideal for mechanical stabilization; it is 85 to 90 percent hard, black, dense chert, the rest being mainly quartz, quartzite, and sandstone (5). The other objectionable feature of the sand for engineering purposes is its very high roundness, which is discussed below.

A composite beach sample (No. B-7) was obtained for laboratory work; the size-analysis of this sample is shown in Figure 7. The sphericity of material passing the No. 10 sieve averages 0.81. A value of 1.0 would indicate a material consisting entirely of spheres. The sphericity was determined with the aid of Rittenhouse charts (6), and for each grain, indicates the ratio of surface area of an equivalent volume sphere to the surface area of the grain. Sphericity is a measure of the shape of the whole grain; roundness, strictly defined, applies only to the shapes of the grain corners. The average roundness values for the composite beach sample are shown in Table 1, along with sphericity values. Greater rounding occurs in larger grains; this is the normal condition in a granular sediment, since large grains are more readily abraded.

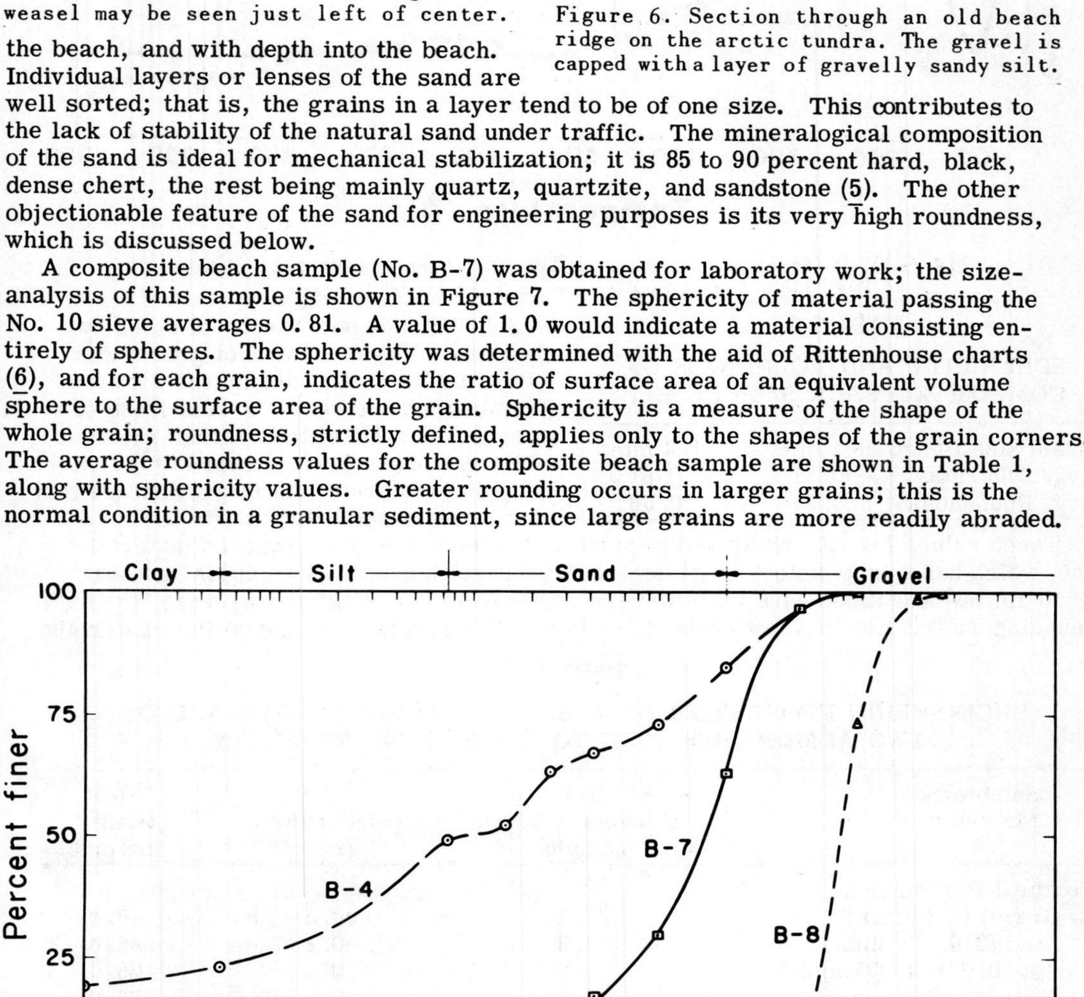

Figure 7. Particle size accumulating curves for three materials used in this study. B-7 is the natural beach sand; B-4 and B-8 are additives used to improve stability.

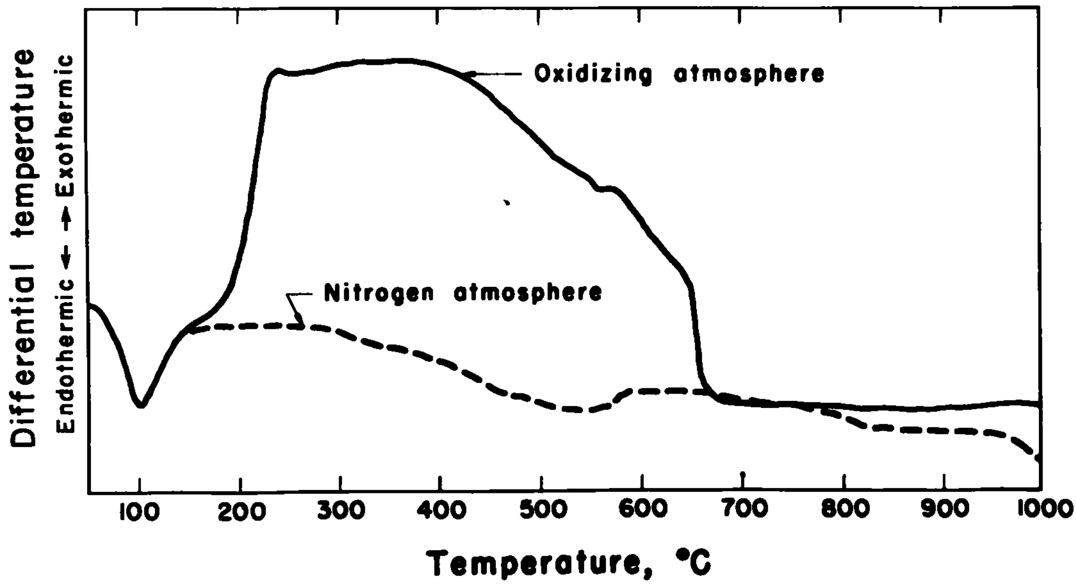

Figure 8. Differential thermal analyses of beach ridge silt sample B-4. Pre-test humidity controlled at 50 percent.

TABLE 1

SPHERICITY AND ROUNDNESS OF COMPOSITE BEACH SAMPLE B-7

Grain Size Range	<1 mm.	1-2 mm.
Avg. Sphericity	0.81	0.81
Avg. Roundness	0.53	0.58

Sphericity is not directly affected by abrasion. The roundness of grains was measured by visual comparison with the Krumbein charts (4). The roundness of a grain is the ratio of the average radius of curvature of the grain corners to the radius of curvature of the largest sphere that may be inscribed within a grain.

These values for sphericity and roundness do indicate a highly rounded material — one which has a long history of geological transportation and reworking by the sea. Geologic investigations have more or less confirmed this. Engineering-wise, the high rounding contributes to a low angle of friction in the material. Since no fine materials

TABLE 2

ENGINEERING PROPERTIES OF A BARROW BEACH SAMPLE AND OF TWO ADMIXTURES USED TO IMPROVE ITS STABILITY

Sample No.: Material:	B-7 Composite beach sample	B-8 Ice-rafted gravel	B-4 Binder material
Textural Percentages			
Gravel (>2mm.)	37.1	99.8	15.8
Sand (2-0.074 mm.)	62.3	0.2	35.6
Silt (0.074-0.005 mm.)	0.6	0	25.6
Clay (<0.005 mm.)	0	0	23.0
Textural Classification (BPR)	Gravelly sand	Gravel	Gravelly clay loam
Atterberg Limits			
Liquid limit, %	-	-	33.8
Plastic limit, %	-	-	21.7
Plasticity index	NP	NP	12.1
Engineering Classification (AASHO)	A-1-b	A-1-a	A-6(3)

TABLE 3

STRENGTH CHARACTERISTICS OF BARROW BEACH SAMPLE B-7

Standard Proctor Density	
Optimum moisture content	0%
Maximum dry density	121.4 pcf.
California Bearing Ratio [a]	
0.10-in. C.B.R. at optimum moisture	0.3%
Rebound, in.	0
0.10-in. C.B.R. after soaking 4 days	3.17%
Rebound, in.	0.002 in.
Swell	0%
Moisture content as compacted	0%
Average moisture content after soaking	10.6%

[a] Standard Proctor compaction used.

are present, the cohesion of the natural beach sand is zero. Laboratory tests indicate that the optimum moisture content of this material is zero, since water acts as a lubricant and permits continual shearing and displacement in the Proctor mold. The California Bearing Ratio at optimum moisture is 0.3; after four days soaking, it is 3.17. Additional data are given in Tables 2 and 3.

It appeared that possible methods for improving the C.B.R. of the beach sand would be: (1) to improve the gradation by adding coarse material, or (2) to improve the gradation and the cohesion by adding a cohesive binder, or (3) both. In 1954, coarse material was locally available on the beach where it had been carried in by ice cakes the previous winter. This material apparently freezes into the bottom of the cake immediately off shore; subsequent push carries it on to the beach where the next summer the ice melts, leaving the gravel. These ice-rafted materials are extremely variable in composition, and remain in place only until storm waves wash them away. The material sampled (B-8) is a gravel (Figure 7).

The problem of finding a cohesive binder is a difficult one at Point Barrow, for the Arctic climate limits chemical weathering and the formation of clay. Hence, most of the local "clays" turn out to be mixtures of silt and organic matter. A composite sample (B-4) of one of these materials was obtained from the thawed surface layer of the tundra. This sample was taken from the top of an abandoned beach ridge such as that in Figure 6 and is believed to represent a silt deposit containing sand and gravel admixture produced by ice-rafting during deposition or by late frost action. The particle size curve for this sample is shown in Figure 7. Differential thermal analysis revealed a large amount of organic matter in the sample, and even in a nitrogen atmosphere clay mineral reactions are not large (Figure 8). The low temperature at which hygroscopic water is lost suggests that much of the water may be loosely held in the peat fraction. The clay mineral may be illite; further tests are under way. The plasticity index of sample B-4 is 33.8 - 21.7 = 12.1, possibly helped by the organic matter. The abondoned-beach-ridge sources for material such as this are common in the Barrow area and are easily identified on aerial photos. This is the only binder material yet experimented with in the laboratory; other possible binders are discussed in the final section of this paper.

PROPORTIONING AND EVALUATION

The laboratory procedures for proportioning the three materials and evaluating the mixes were necessarily abbreviated because of the high cost of transporting large quantities back to Iowa. The AASHO Specification: M147-49 for soil-aggragate surface-course mixtures was selected as a starting point; these specifications condensed to textural classes are given in Table 4. Expressed in this way, the gradation specifications may be plotted on a triangular chart as in Figure 9. Materials to be mixed

TABLE 4

SPECIFICATIONS FOR GRADED SURFACE-COURSE MIXES EXPRESSED BY TEXTURAL CLASSES. ADAPTED FROM AASHO DESIGNATION: M147-49

Specification	Type I		Type II	
	C	D	E	E
Gravel, %	50-75	35-70	0-60	0-45
Sand, %	13-46	15-60	20-94	30-40
Silt and clay, %	8-12	8-15	8-20	8-25
Liquid limit	35 maximum			
Plasticity index	6 to 9			

are plotted on the same chart, and suitable proportions may be read directly.

Whereas rounding off of the specifications to grade limits does introduce approximations, when only two granular materials are to be used, there is actually little choice in obtaining an ideal grading. The advantage of the triangular chart, besides its simplicity, is that plasticity index requirements can be plotted on the same graph, and mix proportions selected where the two specifications overlap (Figure 10). The suggested plasticity index of the mixture determined on the fraction passing the No. 40 sieve is between 4 and 9. Plasticity indices of mixtures may be estimated by the use of the proportional equation given in Appendix. Figure 11 illustrates the changes in plasticity index brought about by varying the proportions of two materials.

RESULTS

Mixture M (Figure 10) meets specifications D, E, and F, and has a calculated P.I. of 6. Results with this mix are given in Table 5. The standard Proctor density was increased about 10 pcf.; but due to lack of cohesion, the C.B.R. was not greatly affected. Apparently more binder was needed.

Mixes N, O, and P illustrate the effects of increasing the proportions of binder. Figure 12 indicates that an optimum mix is obtained with about 30 percent B-4, and when the calculated P.I. is about 8. Use of more binder than this gave a sticky, poorly workable mix.

The other possibility for improving the mix was to vary the proportions of ice-rafted gravel, sample B-8. This was done, and at the same time the calculated P.I. was maintained at the near-optimum of 7.5.

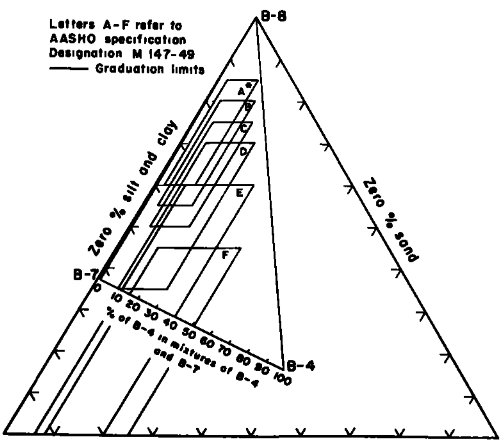

Figure 9. AASHO gradation specifications expressed by textural classes on a triangular chart. Compositions of three Barrow samples are also shown.

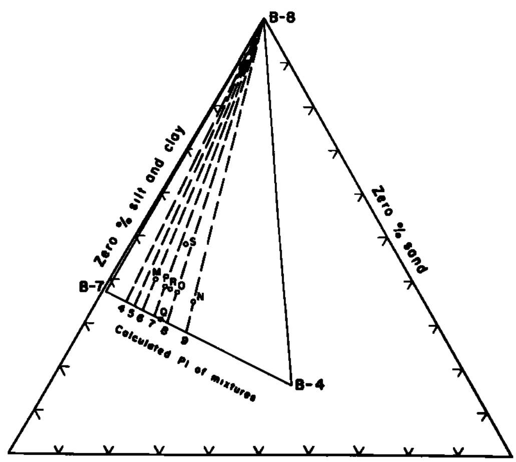

Figure 10. Plasticity index requirements plotted on a triangular chart. Graph was made by calculating the PI's of mixtures of B-4, B-7, and B-8. Trial mixes evaluated by CBR are indicated by letters.

Data for these mixes, Q, R, and S, are given in Table 6 and Figure 13. Data for mix R were interpolated from the other curves. The graphs indicate that additions of gravel B-8 up to 25 percent result in an increase in Proctor density, but amounts over 10 percent do not increase the C. B. R. From these data, it appears that the optimum mix is O, containing 30 percent binder silt B-4 and 10 percent ice-rafted gravel B-8.

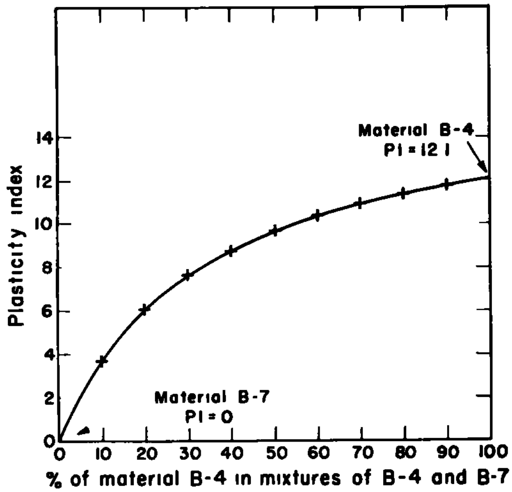

Figure 11. Calculated plasticity indices for mixtures of two materials.

Properties of the Optimum Mix

Although the calculated P. I. of the optimum mixture, O, is 8, laboratory tests on the mix give a P. I. value of 9. 5. The C. B. R. at optimum moisture is 17. 0; it is 31. 0 after four days soaking. The effect of air-drying in the C. B. R. mold for five days was to increase the dry C. B. R. to 183 and the soaked C. B. R. to 35. Shrinking and swelling all cases were very low. Figure 15 compares the particle sizes in mixture O with those of various AASHO specification limits.

DISCUSSION

The data obtained for an optimum mix indicate that the mix specifications should be adjusted to allow for the unusual materials involved. The low clay mineral content of the binder apparently makes a greater amount of binder necessary. It will be noted that the P. I. of the optimum mix is 9. 5, but the maximum P. I. recommended (AASHO M147-49) is 9. Yet, even with this high P. I., shrinking and swelling are almost zero.

The other variable, that of adding ice-rafted gravel to increase the density, gives strange results, because highest densities do not give the highest C. B. R. Apparently

TABLE 5

STABILITY OF MIXES WITH VARYING PROPORTIONS OF BINDER B-4

Mix No.	M	P	O	N
Binder percentage (B-4)	18. 0	23. 2	29. 7	38. 8
Calculated P. I.	6	7	8	9
Experimental P. I.	4. 1	4. 9	9. 5	6. 3
Standard Proctor Density				
Optimum moisture, %	7. 30	6. 40	6. 25	7. 30
Max. dry density, pcf.	132. 4	136. 6	136. 9	132. 6
California Bearing Ratio [a]				
0. 10 in. C. B. R. at opt. moisture, %	2. 83	12. 0	17. 0	12. 8
Rebound, in.	0. 005	0. 017	0. 012	0. 043
0. 10 in. C. B. R. after soaking 4 days, %	4. 73	20. 2	31. 0	24. 3
Rebound, in.	0. 005	0. 025	0. 031	0. 048
Swell, %	0	0	0	0
0. 10 in. C. B. R. after air drying 5 days, %	-	-	183. 0	-

[a] Standard Proctor compaction used.

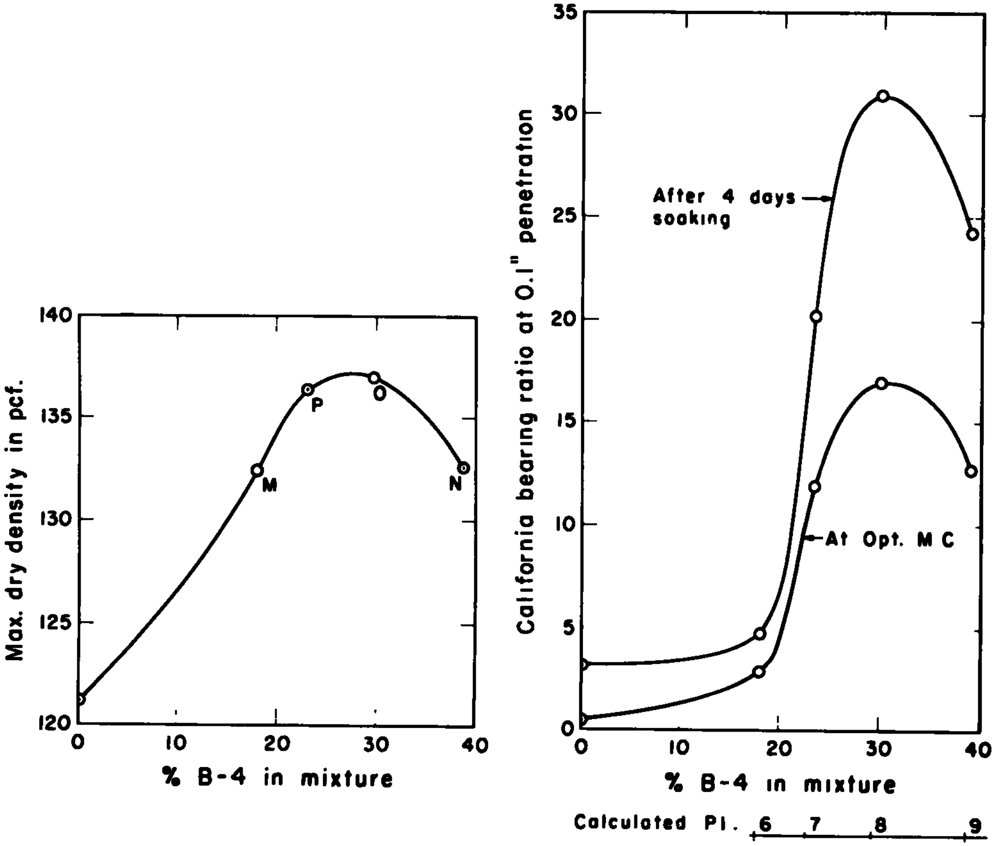

Figure 12. Effect of binder percentage on standard Proctor density (left) and on California Bearing Ratio (right). Plasticity indices are shown at the bottom.

TABLE 6

STABILITY OF MIXES WITH VARYING PROPORTIONS OF GRAVEL B-8

Mix No.	Q	R[a]	S
Gravel additive percentage (B-8)	0	10.0	25.0
Standard Proctor Density			
Optimum moisture, %	6.80	6.20	5.80
Max. dry density, pcf.	134.2	137.2	139.4
California Bearing Ratio[b]			
0.10 in. C.B.R. at opt. moisture, %	14.8	15.9	10.7
Rebound, in.	0.019		0.021
0.10 in. C.B.R. after soaking 4 days, %	23.7	27.8	27.2
Rebound, in.	0.031		0.024
Swell, %	0		0
M.C. as compacted, %	7.06		5.62
Avg. m.c. after soaking, %	6.13		5.44

[a] Values for hypothetical mix R were obtained from graphs of data in Table 5.
[b] Standard Proctor compaction used.

the addition of a highly rounded gravel to a highly rounded sand has a limited benefit on the bearing capacity.

FURTHER STUDY

Work in the Barrow area is being continued, and additional samples were obtained during the 1955 summer season. Laboratory evaluations of these materials have not yet been completed. Laboratory tests will be made, using several different binder materials, including a lake silt and an arctic-produced crude oil. Additional sources of coarse material were found during a comprehensive materials survey along the Barrow beach. From the present laboratory data, it appears probable that the most efficient use of these gravels would involve crushing. A source of plastic clay was found, but unfortunately it is highly saturated and is in permafrost. Further field studies of abandoned beach ridges have disclosed that these materials, having been infiltrated with silt, may in themselves possess an inherent stability. If this is true, these could be an extremely important source of materials for road building on the tundra.

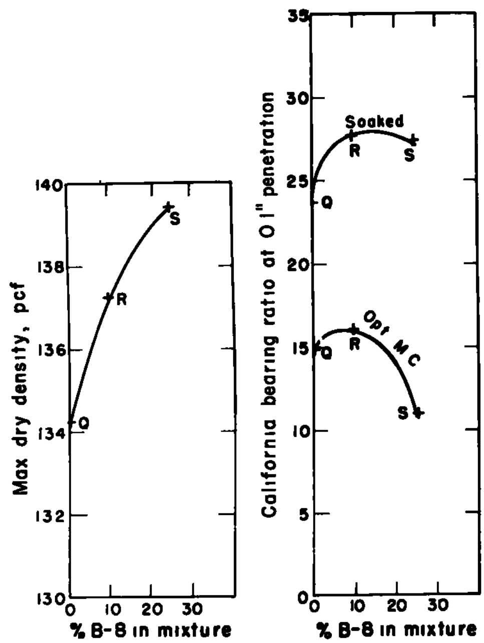

Figure 13. Effect of added gravel percentage on standard Proctor density (left) and on California Bearing Ratio. Note that the CBR comes down while the density goes on increasing.

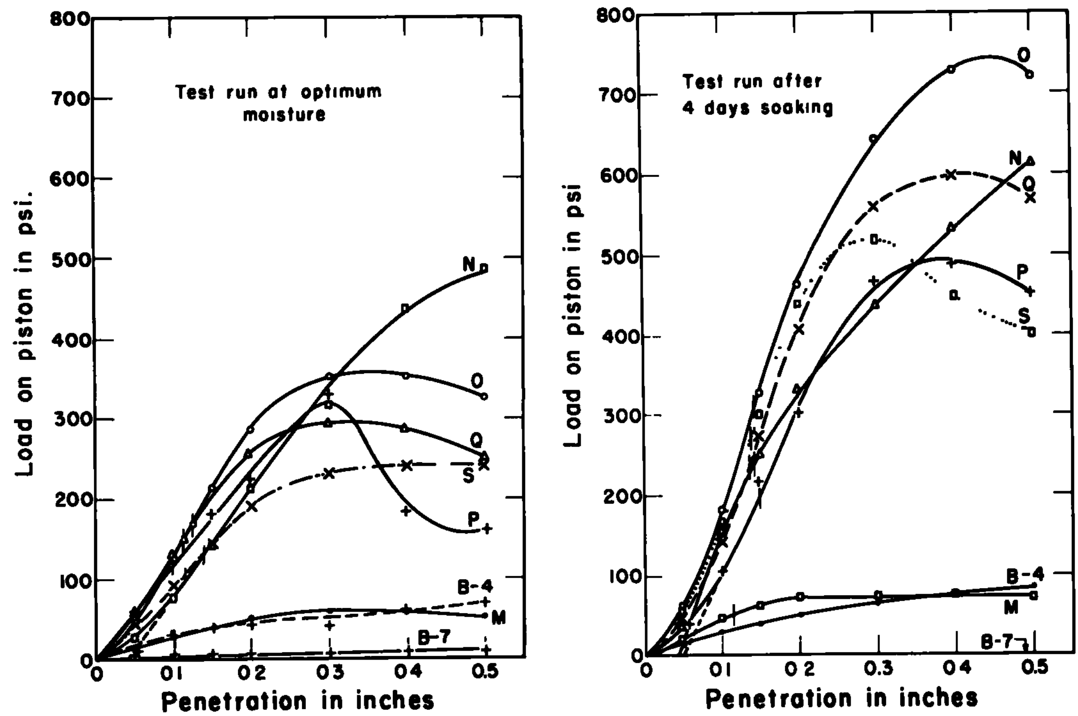

Figure 14. Stress penetration curves obtained from the CBR test. During soaking all mixtures gained strength, whereas the natural beach sand B-7 lost strength.

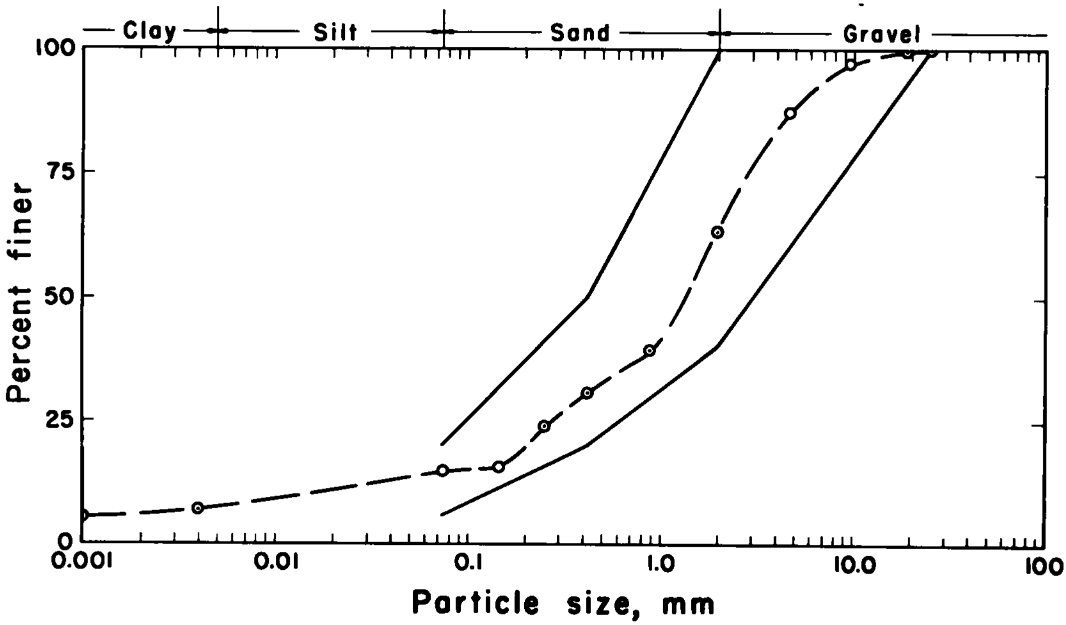

Figure 15. Particle size accumulation curve for optimum mix O. AASHO specification limits for grading D (Type I) are also shown.

CONCLUSIONS

1. The engineering performance of a gravelly beach sand such as that at Point Barrow may be greatly improved by mechanical stabilization, using locally available materials.

2. California Bearing Ratio data indicate that stabilization of the Barrow beach sand with local gravel and silt increases the wet stability approximately tenfold. However, the stabilized C. B. R. of 31 probably still is not adequate for permanent base or surface course construction. Laboratory work using other locally available materials is to be continued, and the effect of modified Proctor compaction on the C. B. R. will be investigated.

3. The highly rounded nature of the Barrow beach sands and gravels and the scarcity of clay minerals in Arctic soils point to the need for special considerations in designing a suitable mix. As yet only the trial-and-error method is available.

ACKNOWLEDGMENTS

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Appendix

Plasticity Index of Mixtures

The common textbook formula for estimating the plasticity index of mixtures is:

$$P.I. = \frac{A'ax + B'by + C'cz}{A'a + B'b + C'c}, \text{ where}$$

A', B', C' = respective percentages of materials A, B, and C in the mixture;

a, b, c = respective percentages of A, B, and C passing the No. 40 sieve;

x, y, z = respective plasticity indexes of materials A, B, and C (determined on the respective fractions passing the No. 40 sieve).

The equation is essentially one of proportion and may be developed as follows: Since A' is the percent material A in the mixture, A'a is the percent of the mixture passing the No. 40 sieve and supplied by A. The same is true respectively for B'b and C'c. The total percent of the mixture passing the No. 40 sieve is the sum of these, or

$$M_{40} = A'a + B'b + C'c \qquad (1)$$

If x is the plasticity index of material A, A'x represents the contribution of A to the plasticity index of the mix. However, the plasticity index is determined from material passing the No. 40 sieve, so A'ax is the contribution of fines in A to the plasticity index of fines in the mix. If the mix consists entirely of A,

$$P.I. = \frac{A'ax}{A'a} = x$$

If B and C are inert, adding them to the mix will dilute A and reduce the plasticity index proportionately,

$$P.I. = \frac{A'ax}{A'a + B'b + C'c}$$

If B and C are not inert, B'by and C'cz will be the respective contributions to the plasticity index of fines in the mix. Since the contributions are assumed to be additive,

$$P.I. = \frac{A'ax}{A'a + B'b + C'c} + \frac{B'by}{A'a + B'b + C'c} + \frac{C'cz}{A'a + B'b + C'c}$$

$$P.I. = \frac{A'ax + B'by + C'cz}{A'a + B'b + C'c} \qquad (2)$$

Recommendations vary for application of the formula should the plasticity index of one of the materials be zero. Different recommendations are that values of 0, 1, or 3 be used when the P.I. is actually zero. In this study, the true value of zero was used. While experimental results did not agree with those predicted from the equation, the direction of the difference was not consistent. The formula is intended as an approximation, and should be used only as a guide.