III. 2. REVIEW OF A RECENT ARCTIC SOIL INVESTIGATION*

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(Summary)

Several isolated locations were investigated in the northern areas of Canada stretching from Cape Dyer, on Baffin Island, in the east to the Alaska coast in the west between latitudes 60°N and 70°N.

Mobilization in the arctic was done by staging out of Montreal and Edmonton and demobilization via Winnipeg in DC-4 aircraft. DC-3 aircraft were used for lateral flights in the east-west direction. As a result of this, medium-weight Longyear Junior drills with hydraulic heads were chosen for the investigation.

The investigations for each of these locations were carried out for various types of structures which include, warehouse, office quarters, and, in one instance, a water tower. In most cases, the foundation for each structure was investigated by at least three holes across the diagonal of the proposed area, two of which were carried to a depth of 25 feet and the middle hole to 50 feet provided no bedrock was encountered within these limits.

DRILLING TECHNIQUES

Throughout the investigation NXL series of drill equipment was used. Both carbaloid and diamond bits were supplied to the crews. Generally speaking, these bits were mostly of the bottom discharge type although ordinary standard bits were used with some success when the supply of bottom discharge bits ended. Both water and diesel oil were used throughout the investigation as bit coolants. Generally speaking, in the eastern portion of the investigated area diesel fuel was used continuously while in the west, where soil conditions differed, water was found to be quite adequate.

The coolant was circulated in a closed system. The returns from the hole collected in a settlement basin with a run-off to an additional basin from which the coolant was re-pumped down the hole. At no time during the investigation was refrigeration used.

PERFORMANCE OF DRILLING EQUIPMENT

The most successful diamond bit used in the performance of

* Additional information on this investigation can be obtained from the author.

this work was the broad-faced bottom discharge type. Other types of bits which have come to be known as permafrost bits were used. These bits, having a very sharp leading edge set with diamonds, are slanted down approximately 45° to the inside gauge. This particular type of bit was found to be inadequate in the regions of very dense bouldery soils in the eastern arctic because the cutting edge failed. The cut-out value on this type of bit, however, is relatively high. Carbaloid bits were also tried during this period of the investigation, but the standard type of carbaloid bit which has a simple vertical insert was found to be inadequate because the inserts dropped out in the bouldery material causing a complete burn-out of the bit after only a few feet of penetration. These bits were used quite successfully, however, in the easier drilling conditions encountered in the eastern end of the area investigated. Core recovery during the period of this investigation was usually about 100%. It was noticed, however, that a loss of 15% to 20% of core diameter occurred during coring. This loss is dependent upon the time taken for coring. In the dense bouldery soils, coring time is rather long and therefore the loss of diameter is greater than in the perennially frozen silts and clays where coring time is of the order of 5 to 10 minutes for a five foot run.

Another difficulty which was encountered during the drilling was the jamming of the casing when drilling with diesel fuel. The soil cuttings had no natural inclination to mix with the diesel fuel but tended to come up suspended in the diesel fuel filters through this artificially formed filter. This condition is not hard to detect because the engine begins to labour and eventually stalls. This difficulty is overcome by a simple operation of retracting the casing about 12 inches before further advance.

TYPES OF PERMAFROST ENCOUNTERED

The character of the permafrost was somewhat different at each location, but for the sake of clarity three typical types were described.

1. Large isolated lenses of frozen silt in the till were observed in the Cape Dyer region.
2. Overburden, 7 to 8 feet thick, perennially frozen overburden or overburden frozen throughout or containing patches of permafrost, was observed in the central part of the investigated region.
3. In the western part of the investigated region, particularly in Alaska, permafrost was found throughout the full 50 foot depth of each hole.

TYPES OF FOUNDATIONS UTILIZED FOR THE PERMAFROST CONDITIONS

1. In the areas of isolated lenses of permafrost in till, spread foundations enclosed in gravel pads were utilized to preserve the frozen state of the existing overburden.
2. In the areas of thin perennially frozen overburden and overburden containing patches of permafrost, spread foundations and gravel pads were utilized.
3. In the area where the permafrost existed just below the surface or at depths of 8 to 15 feet below the surface, piles drilled down to the permafrost were utilized for the foundations of structures. In one area, where the permafrost was about 12 inches below the existing ground surface, a gravel pad was considered as an alternative with a structural raft foundation for heavier foundations associated with the water tower.

CONCLUSION

This paper was submitted in order that the experiences gained with drilling equipment could be presented. It is hoped that the difficulties experienced and comments may be of assistance to investigators and that this paper has indicated the necessity for the pooling of all information gained in this type of investigation in order that the techniques of drilling may be improved.

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Discussion

T. A. Harwood stated that the DEW Line sites were chosen under difficult conditions in late winter when the ground was snow covered. He asked whether the author noticed any foundation deflection in the three types of foundations used, i.e. piles, pads, foundations anchored to bedrock. The author replied that no movements were noticed. Gravel pads were used widely in the eastern arctic, for example in the Foxe Basin area where coarse-grained tills exist. Pile foundations were used in the western arctic where fine-grained soils are widespread.

A. Taylor reported on a visit to some of the DEW Line sites in the Committee Bay, N.W.T. area in 1958. The buildings were placed on thick fills on sharp bedrock ridges. The gravel pads were placed quickly with no subsequent compaction. Settlements of 18 inches developed in some of the buildings and shims were required to level the buildings. T. A. Harwood commented that in some cases the contractor changed the specifications.

G. Jacobsen asked what procedure was used when a boulder

was encountered in the drilling. The author's answer was that the hole was drilled through the boulder.

J. C. Osler wished to know the cost of the diamond bits. The author replied that about $1800 worth of diamonds were used.

J. C. Osler submitted the following discussion:
The purpose of this discussion is to present some parallel data to that presented by the author, based on several investigations performed in permafrost areas by Geocon Ltd. during the past two years.

During 1960, soils investigations were carried out at 11 sites, bounded by longitude 60°W to 150°W and latitude 65°N to 70°N. Another major investigation was carried out in the Fort Churchill area in November and December of 1961.

Equipment

The drilling was carried out using Longyear Junior Straitline drill rigs with "A" heads. Both hydraulic and screw feed heads were used. In general, the hydraulic head machine proved more satisfactory for permafrost drilling because of the greater variation in the rate of feed, but it is emphasized that the experience and technique of the operator is perhaps just as important as the type of equipment used.

All of the drilling was carried out in NX size. For the work in 1960, standard NX double tube core barrels were employed, both rigid and swivel types. In general, the swivel-type barrels, believed to be NXM series, were employed for drilling frozen soil while the rigid barrels were sometimes used for rock coring. In 1961, "L" series core barrels were employed. The NXL barrels produced superior core recoveries, particularly in unsaturated and poorly bonded granular soils.

Much of the work in 1960 was carried out between July and September, under summer conditions. During this period, the drilling fluid was cooled by a refrigerator. The other work reviewed in this discussion was carried out at different times between November and March and the drilling fluid was cooled by the atmosphere. The refrigerator used was custom-built to Geocon specifications by a Montreal firm. It was basically a three-ton commercial refrigeration unit powered by a 5 horse power air cooled gasoline motor. The unit measured about 4'-6" by 3'-3" by 4' high and weighed about 900 pounds. Freon was used as a refrigerant and the heat exchanger was an open system, which is believed to be superior for this type of work, since there is less chance of plugging of the heat exchanger by dirt in the circulating fluid. The specification given for the refrigerator was that it should cool 125 gallons of kerosene per hour from 40°F to 20°F; the unit provided had a capacity of 36,000 btu's per hour. The cost of the refrigerator was $1,550, not including the motor. The unit proved sufficiently rugged for this type of work, although one breakdown was experienced due to rough handling.

Diamond bits were employed for all the drilling in permafrost. Standard, bevel wall, surface set bits were generally used and the wear experienced ran usually between $1.00 and $2.00 per foot drilled. This type of bit did not prove satisfactory for drilling in strata of poorly bonded sand and gravel with a low degree of ice saturation. Much better results were obtained by using impregnated diamond bits when drilling in these strata. Whereas surface set bits were worn out in a few feet, a similar experience to that described by the author, the impregnated bits lasted from 20 to 40 feet.

Drilling Time

The time required to investigate 10 sites during the period July to September 1960 has been analyzed. The work was executed in 42 working days, comprising a total of 430 hours. In this period, 30 boreholes were drilled with a total footage of 700 feet. This time includes all time spent setting-up and moving at the individual sites but does not include time spent moving between sites. The time required to move between sites amounted to 59 days. Air transportation was used for all but one move where water transportation was employed.

Considering that the work was carried out during the period when weather conditions are at their best in this region, the delays encountered on this job are considered significant. Of the 59 days spent moving, 15 were incurred by one crew waiting to move to a final scheduled eleventh site. Work at this site was ultimately cancelled. Even if this 15-day period is disregarded, some 44 days were required for moving between sites compared to 42 working days at the sites.

Core Recovery in Frozen Soil

Two typical borehole logs are presented which show core recoveries obtained in a wide variety of types of frozen soil and rock. Both holes were drilled with standard core barrels and so the recoveries are lower than would have been obtained using the "L" series core barrel. For example, at Fort Churchill, over 300 feet of core was drilled in poorly bonded frozen sand and gravel or siltstone bedrock using the "L" series barrel and the average core recovery was about 70 per cent.

The logs show the extent that crystalline ice can occur in permafrost. A knowledge of the existence of such unfavourable subsoil conditions is of major importance in foundation design in the Arctic and indicates the value of reliable soils information.

GEOCON

OFFICE REPORT ON SOIL EXPLORATION

CONTRACT S-2497 BORING # _____ DATUM LOCAL CASING NX
BORING DATE AUG. 18, 1960 REPORT DATE SEPT. 12, 1960 COMPILED BY J.W.A. CHECKED BY R.C.
SAMPLER HAMMER WT. 140 LBS. DROP 30 INCHES CASING HAMMER WT. _____ LBS. DROP _____ INCHES

SAMPLE CONDITION: DISTURBED; FAIR; GOOD; LOST

SAMPLE TYPES: A.S. - AUGER SAMPLE; S.T. - SLOTTED TUBE; W.S - WASHED SAMPLE; D.O. - DRIVE-OPEN; D.F. - DRIVE-FOOT VALVE; C.S. - CHUNK SAMPLE; F.S. - FOIL SAMPLE; S.O. - SLEEVE-OPEN; S.F. - SLEEVE-FOOT VALVE; T.O. - THIN WALLED OPEN; R.C. - ROCK CORE

ABBREVIATIONS: V - IN-SITU VANE TEST; M - MECHANICAL ANALYSIS; U - UNCONFINED COMPRESSION; Qc - TRIAXIAL CONSOLIDATED QUICK; Q - TRIAXIAL QUICK; S - DEGREE OF ICE SATURATION; γ_d - FROZEN UNIT WEIGHT; K - PERMEABILITY; C - CONSOLIDATION; γ_w - WET UNIT WEIGHT; WL - WATER LEVEL IN CASING; WT - WATER TABLE IN SOIL

ELEVN. / DEPTH	WATER CONDITIONS	SOIL DESCRIPTION	SYMBOL	ICE DESCRIPTION	STRAT. PLOT
12.7		GROUND		LEVEL	
0.0		LOOSE GREY-BROWN SAND & GRAVEL FILL	GP	UNFROZEN	
9.2		DARK BROWN SILTY PEAT HIGH DEGREE OF ICE SATURATION	PT ML II Vx	PROBABLY UNFROZEN; FROZEN, WHITE CLOUDY IRREGULAR ICE LENSES	
3.5					
8.7					
4.0					
7.5		10% TO 20%± - MOSTLY DARK BROWN PEAT INCLUSIONS INCLINED @ 45° TO 60°; SOME WOOD, OCCASIONAL GRAVEL	PT ICE	ICE, HARD, CLOUDY, ABOUT 80% TO 90% OF TOTAL VOLUME	
5.2					
1.7					
11.0		GREY SLIGHTLY SILTY FINE & MEDIUM SAND, OCCASIONAL GRAVEL, HIGH DEGREE OF ICE SATURATION	SM IC Ix	FROZEN, SAND WELL-BONDED, GRAVEL PARTICLES POORLY BONDED, ICE CRYSTALS	
-5.3					
18.0		PROBABLY GREY BROWN GRAVELLY SAND	SW	FROZEN, POORLY BONDED	
-6.0		END	OF	HOLE	
18.7					

WATER CONTENT W% _____ O NAT. □ w_w Δ P_w (20 / 40 / 60)
CASING PENETRATION ... BLOWS PER FOOT

ELEVATION SCALE: 14, 12, 10, 8, 6, 4, 2, 0, -2, -4, -6

OTHER TESTS — % CORE REC.

CONDITION	TYPE	NUMBER	PENETRATION RESISTANCE BLOWS/FT.	OTHER TESTS / % CORE REC.
	NX RC	1	—	28%
	2" DO	2	35/6"	S=39.5% γ_d=64 pcf
	NX RC	3	—	58%
	NX RC	4	—	91%
	NX RC	5	—	32%
	NX RC	6	—	M γ_d=105 pcf 30%
	NX RC	7	—	0%
	2" DO	8	50/5"	
	2" DO	9	—	S=100% γ_d=81 pcf

WC=15% WC=18.6%

GEOCON

OFFICE REPORT ON SOIL EXPLORATION

CONTRACT S-2497 BORING # _____ DATUM LOCAL CASING NX
BORING DATE SEPT. 2, 1960 REPORT DATE SEPT. 27, 1960 COMPILED BY J.W.A. CHECKED BY R.A.S.
SAMPLER HAMMER WT. 140 LBS. DROP 29 INCHES CASING HAMMER WT. _____ LBS. DROP _____ INCHES

SAMPLE CONDITION: DISTURBED; FAIR; GOOD; LOST

SAMPLE TYPES: A.S. - AUGER SAMPLE; S.T. - SLOTTED TUBE; W.S. - WASHED SAMPLE; D.O. - DRIVE-OPEN; D.F. - DRIVE-FOOT VALVE; C.S. - CHUNK SAMPLE; F.S. - FOIL SAMPLE; S.O. - SLEEVE-OPEN; S.F. - SLEEVE-FOOT VALVE; T.O. - THIN WALLED OPEN; R.C. - ROCK CORE

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ELEVN. / DEPTH	WATER CONDITIONS	SOIL DESCRIPTION	SYMBOL	ICE DESCRIPTION	STRAT. PLOT
2157.1 / 0.0		GROUND		LEVEL	
		COMPACT BROWN POORLY GRADED SANDY GRAVEL	GP GM	UNFROZEN	
2154.6 / 2.5		BROWN SILTY SAND	SM II	FROZEN, IRREGULARLY ORIENTED LENSES & MASSES ¼" TO ½" THICK ¼ TO ½" SPACING. ICE 25%± BY VOL.	
2153.6 / 3.5		BROWN SILTY SAND INCLUSIONS	SM ICE	MASSIVE ICE 70%± BY VOL. ICE HARD, CLEAR COLOURLESS	
2151.9 / 5.2		WEATHERED BEDROCK		FROZEN	
2151.5 / 5.6		INCLUSION: SILTY SAND	SM ICE	MASSIVE ICE: 70%± BY VOL.	
2151.0 / 6.1		WEATHERED GREY BASIC VESICULAR LAVA BEDROCK	IS	FROZEN, 1 ICE LENS ½" THICK 1 ICE LENS 2" THICK	
2147.3 / 9.8			ICE	MASSIVE ICE: 40%± BY VOL.	
2146.8 / 10.3			IS	FROZEN, 5 ICE LENSES ¼" THICK 1 ICE LENS ⅛" THICK	
2144.3 / 12.8		SOUND GREY BASIC VESICULAR LAVA BEDROCK		FROZEN	
2140.5 / 16.6		END OF		HOLE	

ELEVATION SCALE: 2158, 2156, 2154, 2152, 2150, 2148, 2146, 2144, 2142, 2140

WATER CONTENT W% 20 40 60 — ○ NAT. □ Lw △ Pw
CASING PENETRATION ---- BLOWS PER FOOT

OTHER TESTS — % CORE REC.

SAMPLES: CONDITION | TYPE | NUMBER | PENETRATION RESISTANCE BLOWS FT.

OTHER TESTS	CONDITION	TYPE	NUMBER	PENETRATION RESISTANCE BLOWS FT.
		2" DO	1	20
M γ_f=92pcf S=89%		NX RC	2	—
WC=12.5% 91%				
γ_f=67pcf S=99% WC=27.5%		NX RC	3	—
95%				
81%		NX RC	4	—
γ_f=131pcf				
100%		NX RC	5	—
94%		NX RC	6	—