TECHNIQUES FOR SETTING DRILL RIG PILING AND SURFACE CASING UNDER PERMAFROST CONDITIONS

J. S. Dier

During the years 1963 to 1965 Mobil Oil Canada Limited conducted an oil exploration programme in the Eagle Plains area of the Yukon Territory. The exploration leases consisted of 4,300,000 acres located approximately 250 miles northwest of Dawson, Y.T. and about the same distance southwest of Inuvik. The area straddled the Arctic Circle and the surface was bisected by the Porcupine River and its tributaries (Figure 1). The terrain was unglaciated but covered with moss and frozen organic and mineral soils to a depth in some instances of up to 150 feet. Fragmented shale and sandstone outcrops were fairly prevalent on hilltops and where river erosion permitted satisfactory drainage.

The drill rigs used in the area were in the intermediate size range capable of drilling to depths in excess of 7,500 feet and equipped with up to 850 horsepower diesel motors. The rig and associated equipment weighed in the order of 400 tons and were capable of exerting a pulling force of 500,000 pounds on the drill pipe. Because of the large quantity of materials required and the inaccessibility of the area during the summer, all of the lease preparations, rig moves and stocking were done during the winter months.

DRILL RIG FOUNDATION

Adverse terrain conditions restricted the selection of the drill rig site to a relatively small area. It was therefore seldom possible to select the most suitable ground conditions for erecting the equipment, and in most cases, special methods had to be used to obtain a firm working base. The most common method, but also the most time-consuming and costly, was to set the rig and associated equipment on a wooden platform completely supported by timber piles.

The piling design selected is shown in Figure 2. This design attempts to take into consideration the various combinations of static and live loads anticipated during the drilling operations. In order to simplify stocking and installation, the piling selection was limited to the following specifications:

10 inch diameter 16 foot piles set to a depth of 14 feet
8 inch diameter 10 foot piles set to a depth of 8 feet

The depths given here were the maximum required as the piles were set to a lesser depth if a resistant stratum was encountered. The size distribution of the piles was determined by the anticipated loading on the various portions of the structure.

Pile holes were drilled using a small seismic drill. Air was used as a circulating medium. The hole sizes were 12 1/4 inches for the 10 inch piles and 9 5/8 inches for the 8 inch piles. All holes were drilled using conventional tri-cone roller bits. Air volumes of 300 to 500 cubic feet per minute at a pressure of 100 psi was found to be adequate to lift the cuttings. After-coolers on the compressors were required to prevent thawing and subsequent freezing problems in the borehole. The ability of the drilling unit to move quickly from hole to hole was very important since the actual drilling time on each hole was less than 30 minutes. When the hole was completed a pile was set in place and frozen there by pouring 2 gallons of water into the annular space (1 foot of fill) every 4 hours. The limited volumes of water used on each pour ensured rapid freezing and prevented floating of the pile or heaving due to the pressure generated by ice crystallization. A total of 150 piles were required to complete the average structure. After the piles had set they were topped at the required elevation and capped as shown in Figure 1.

The second method of lease preparation was used on locations where it was known that the hole would be completed and the rig moved before Spring, or where the rig was located on a rock outcrop. In these instances a pad of gravel or fragmented shale was laid on top of the moss. This pad was built up to a minimum height of 2 feet above the original moss elevation using gravel from stream beds or broken shale and sandstone from the nearest outcrops. The fill was laid and compacted, and then covered with a double layer of polyethelene film to prevent water and drilling fluids from percolating through the pad and thawing the permafrost.

Both of the above methods proved to be workable and economic solutions to the problem of obtaining a stabilized platform for drilling operations.

Camp buildings and associated housing did not require elaborate foundations. It was determined that if they were set on 6 inch square timbers laid on top of the undisturbed moss, they would remain quite stable.

DRILLING THROUGH PERMAFROST

It was necessary to protect the frozen peat and unconsolidated overburden with casing as soon as possible after drilling to prevent excessive hole enlargement and unnecessary thawing. It is also very important that this casing be effectively bonded to the frozen material.

Previous operations in this type of terrain disclosed that if these conditions were not met, drilling fluids would continue to flow outside the casings causing hole enlargement sufficient to endanger the stability of the rig. It was also noted that subsequent attempts to bond the casing to the perennially frozen ground were singularly unsuccessful, and extremely costly in materials and time.

To accomplish these two objectives, the surface drilling programme was divided into two stages. First, a 9 inch hole was drilled to 75 feet and reamed out in two stages to a diameter of 24 inches. The circulating media in all of these operations was compressed air. The use of air in this work had the dual advantage of giving more rapid drilling rates, and because of its much lower specific heat, caused less melting of the borehole than if water or drilling muds had been used. For these large diameter holes 5000 CfM of compressed air at 100 psi was available. This equipment was also used later in the drilling programme and was not brought in specifically for the surface drilling. After reaching a depth of 75 feet with this hole a string of 20 inch lightweight casing was run into the dry hole and cemented. The cementation consisted of circulating a Portland cement and water slurry down the casing and up the annulus as shown in Figure 3. After the cement had time to set and the permafrost to refreeze, drilling and reaming was continued until a 17 1/2 inch hole had been completed to about 750 feet. Here again air was used as the circulating medium. At this point a string of 13 3/8 inch OD casing was run and cemented using the same procedure as for the first string.

CEMENTS AND TECHNIQUES

Both of these strings were landed in the zone where the temperatures are below the normal freezing point. Since the hydration action of cement is essentially zero below 40°F it was necessary to have sufficient heat in the cement slurry to start the reaction. If properly accelerated cements were used, enough heat was generated through hydration to maintain the temperature and complete the setting reaction. After the reaction was completed, the cement cooled rapidly and the perennially frozen ground refroze to the set cement. While accurate measurements were not obtainable, it was determined that the near sur face permafrost temperature was in the 18° to 25°F range.

It is commonly agreed that all cements generate essentially the same quantity of heat of hydration (100 to 120 calories/gram). It became necessary therefore to select a cement formulation that would generate this amount of heat at a rate that would allow the cement slurry to maintain its original temperature. The three cement formulations normally available to the Oil Industry are "Normal Portland Cement", "High Early Strength Portland Cement" and "High Alumina Cements"

(Fondu). The relative rate of heat liberation for these three types of cement are shown in Figure 4. In comparison Figure 5 shows an actual well bore, time temperature profile in Normal Portland Cement accelerated by the use of 2% $CaCl_2$. It was decided to standardize on the High Early type of cement for the following reasons:

(a) This cement would have a rapid enough rate of heat release.
(b) It would be suitable for subsequent casing cementations thus only one stock item would be required.
(c) The yield of slurry per sack for the "High Early" is approximately 15% higher than for normal cements.

The High Alumina cements were not seriously considered at that time because of the high initial cost, normal slurry yielding characteristics and their sensitivity to contaminants. These cements have now, however, become more common and many operators are using it in their "Northern" operations.

As mentioned previously, the reaction of cement is essentially zero below 40°F. If a cement slurry is prepared using normal temperature water, and cement at temperatures as low as -60°F, the result will be a mass of ice crystals and dry cement. To prevent this, the mixing water must be heated to some extent. Figure 6 indicates the slurry temperatures obtained when mixing water and cement of varying temperatures. From this figure, a dry cement temperature of 0°F requires a mixing water temperature of about 85°F to give a slurry temperature of 60°F. In practice it is nearly impossible to determine the true temperature of the dry cement. It is advisable therefore to pilot test with hot water and a representative cement sample to determine the cement temperature. From this test the required water temperature may be determined from Figure 6. While cementing in the permafrost zone, it was decided that the minimum acceptable slurry temperature would be 60°F. It was found moreover that after the cement was placed, the casing should be filled with water at 60°F. By using the techniques described, some 20 casing strings were cemented through the permafrost zone without any indication of failure.

In summary, shale or gravel pads laid on top of the moss will serve as temporary bases for drilling equipment. More permanent installations require wooden piles frozen into drilled holes. In cementing through unconsolidated perennially frozen materials it is important to drill the hole as rapidly as possible, and the cements must be properly selected and heated to ensure proper bonding.

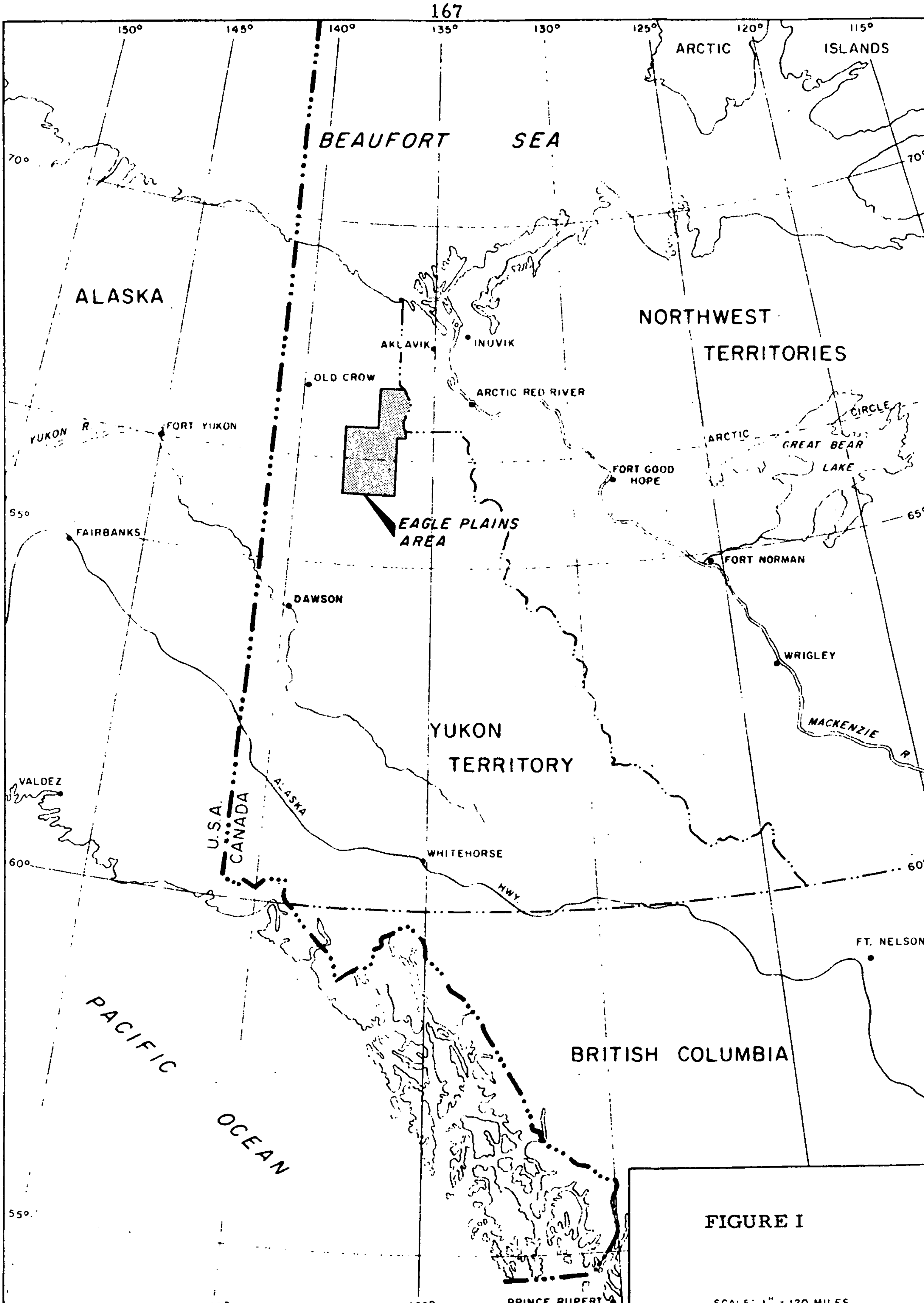

150°
145°
140°
135°
130°
125°
120°
115°
ARCTIC
ISLANDS
BEAUFORT SEA
70°
ALASKA
NORTHWEST
TERRITORIES
AKLAVIK
INUVIK
OLD CROW
ARCTIC RED RIVER
YUKON R
FORT YUKON
ARCTIC CIRCLE
GREAT BEAR LAKE
FORT GOOD HOPE
65°
FAIRBANKS
EAGLE PLAINS AREA
FORT NORMAN
DAWSON
WRIGLEY
MACKENZIE R
YUKON
TERRITORY
VALDEZ
U.S.A.
CANADA
ALASKA HWY
WHITEHORSE
60°
FT. NELSON
PACIFIC
OCEAN
BRITISH COLUMBIA
55°
140°
135°
PRINCE RUPERT
SCALE: 1" = 120 MILES

FIGURE I

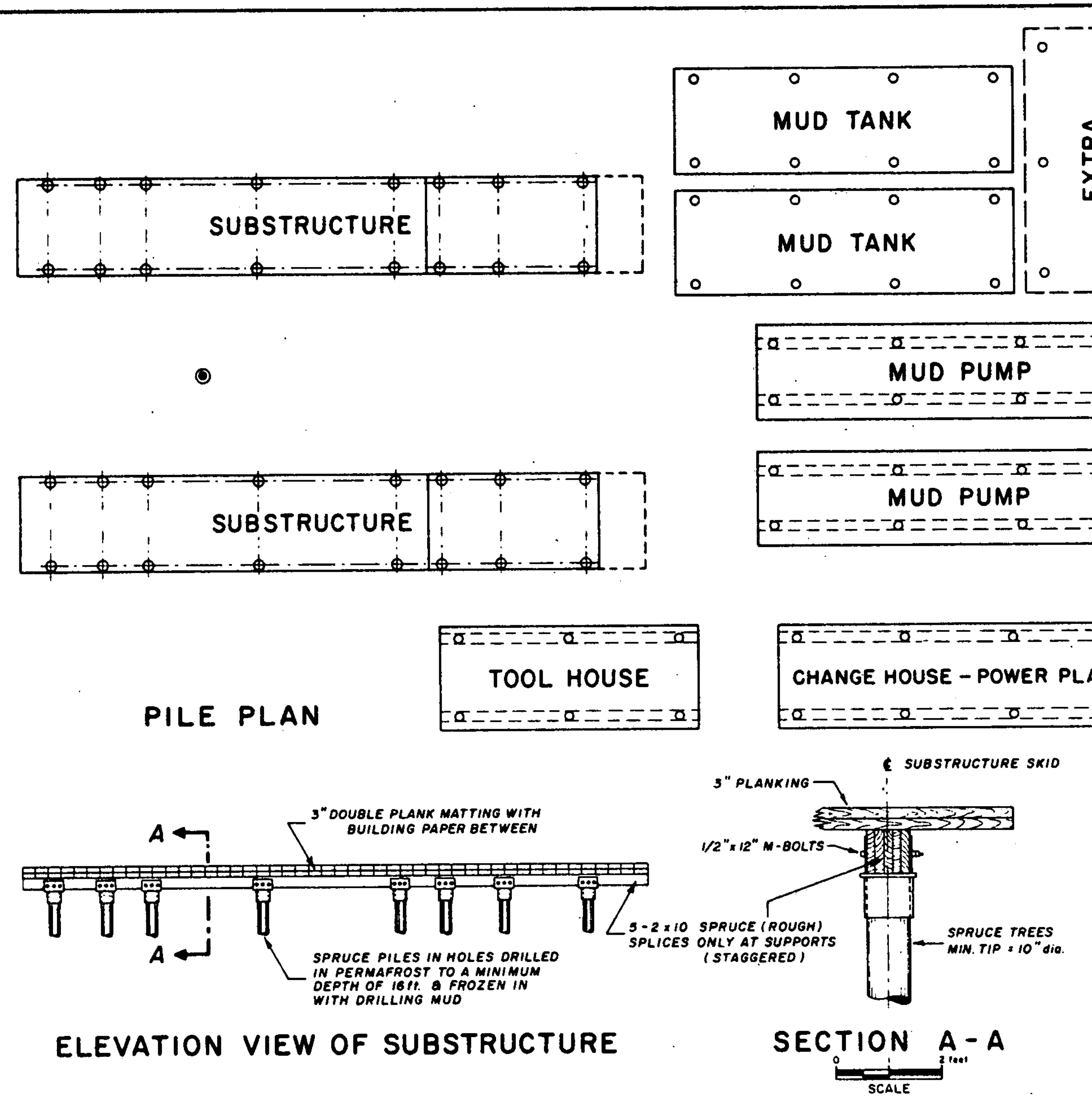


Figure 2
PILE FOUNDATION FOR DRILLING RIG

Figure 3

CEMENTING CASING USING TWO PLUG SYSTEM

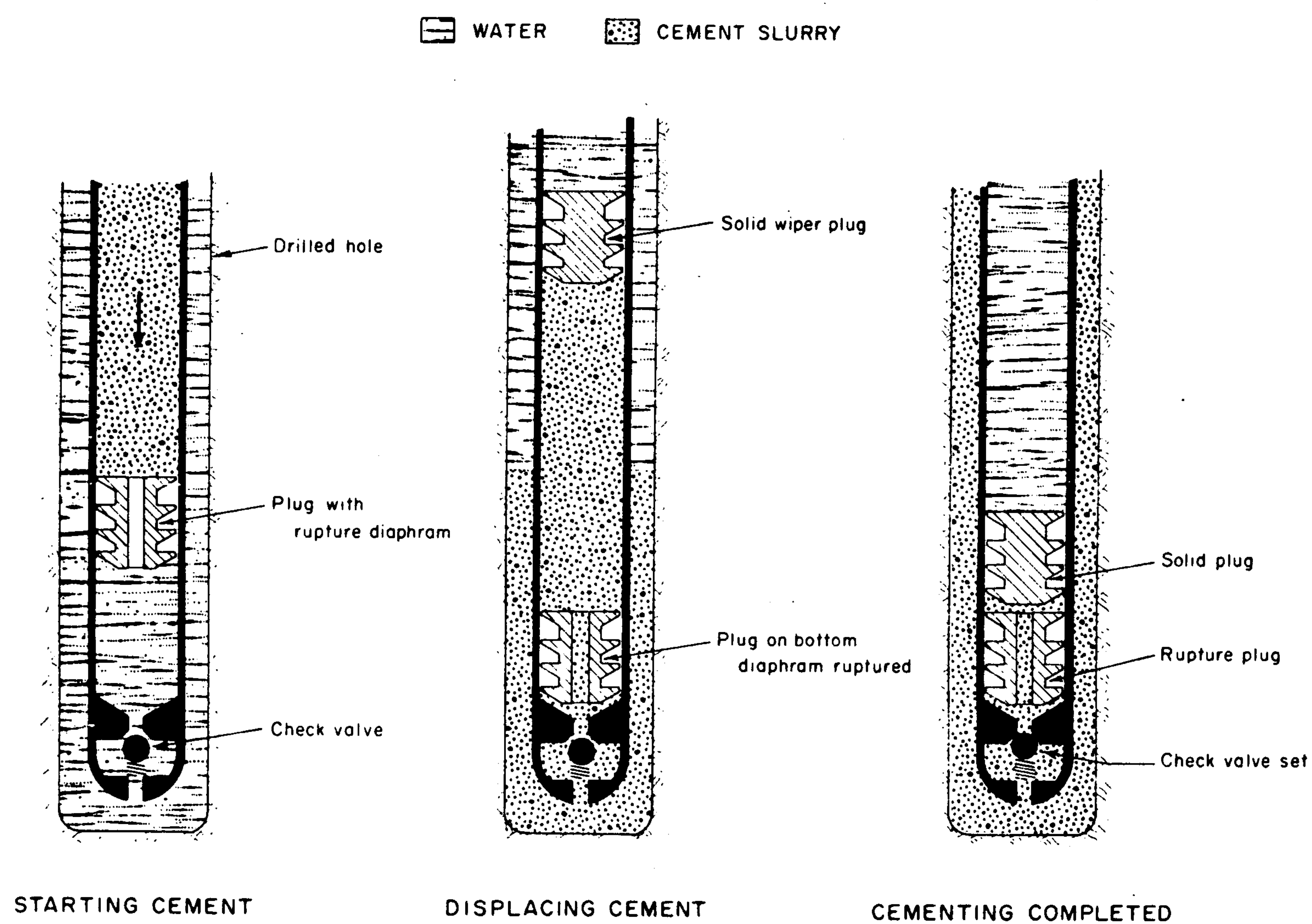


Figure 4

RATE OF LIBERATION OF HEAT BY CEMENTS

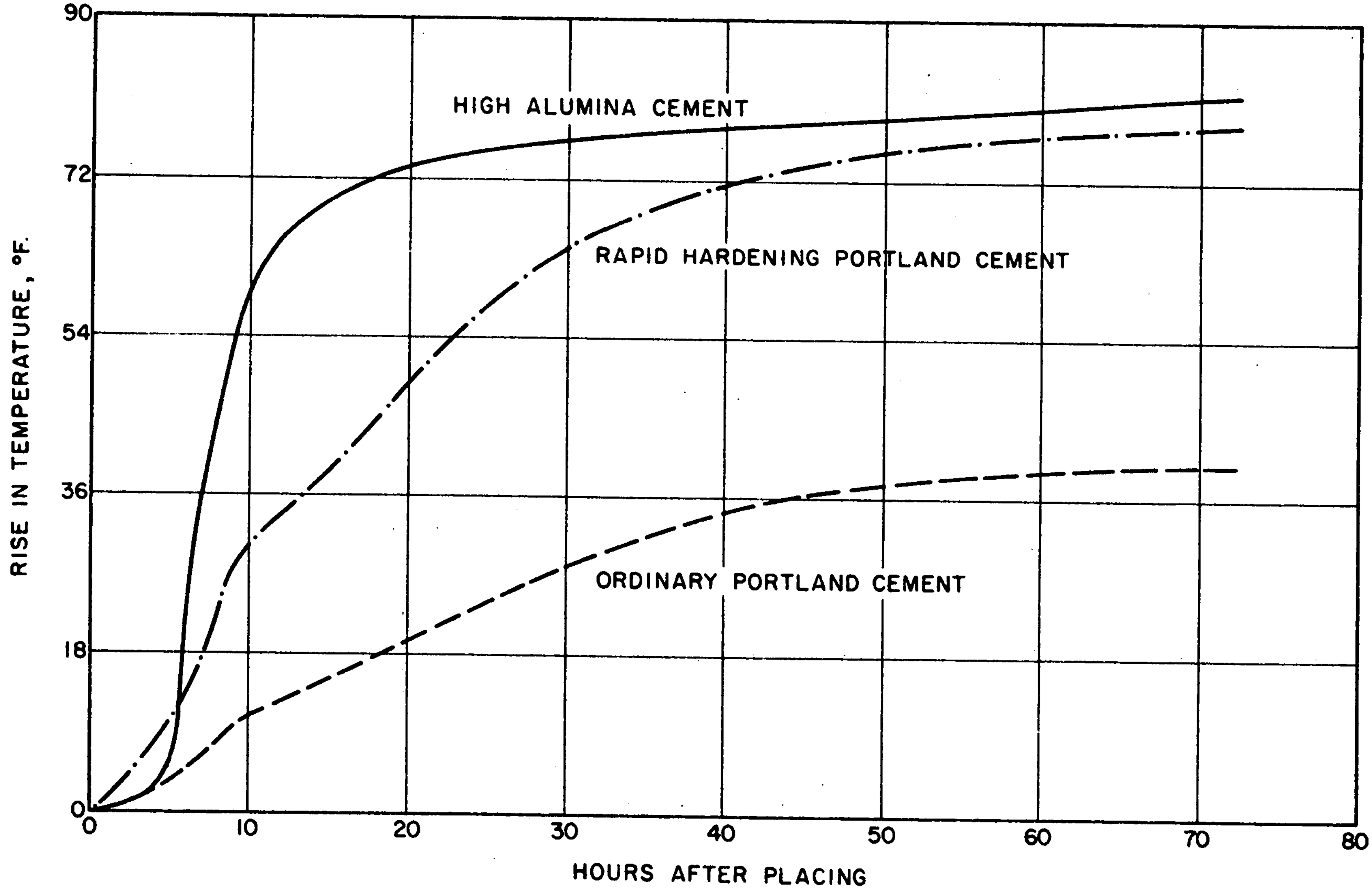


Figure 5

EFFECT OF HEAT OF HYDRATION

Slurry 15.4 lb/gal. Normal Portland cement 2% $CaCl_2$

Mix water temperature 74° F, formation temperature 65° F.

MOBIL OIL CARSON CREEK WHITECOURT 7-28

Survey depth: 550' K.B.

Amerada temperature element range 50 – 150°F

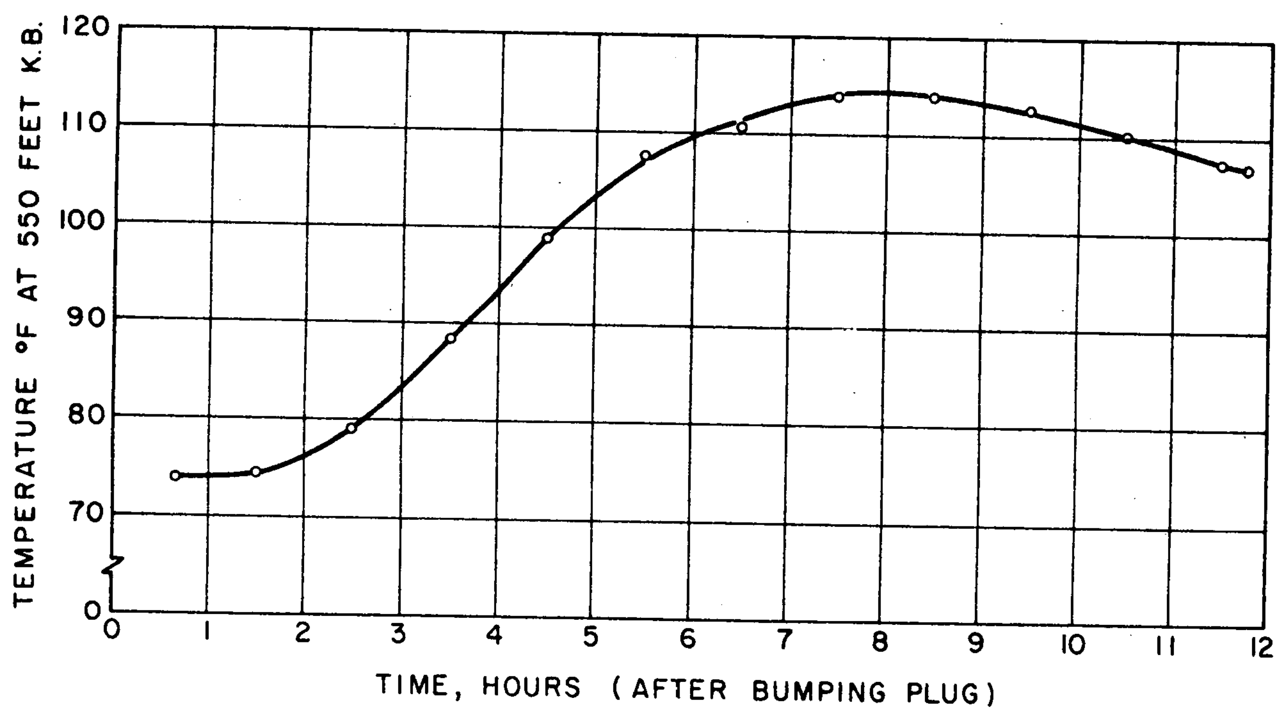
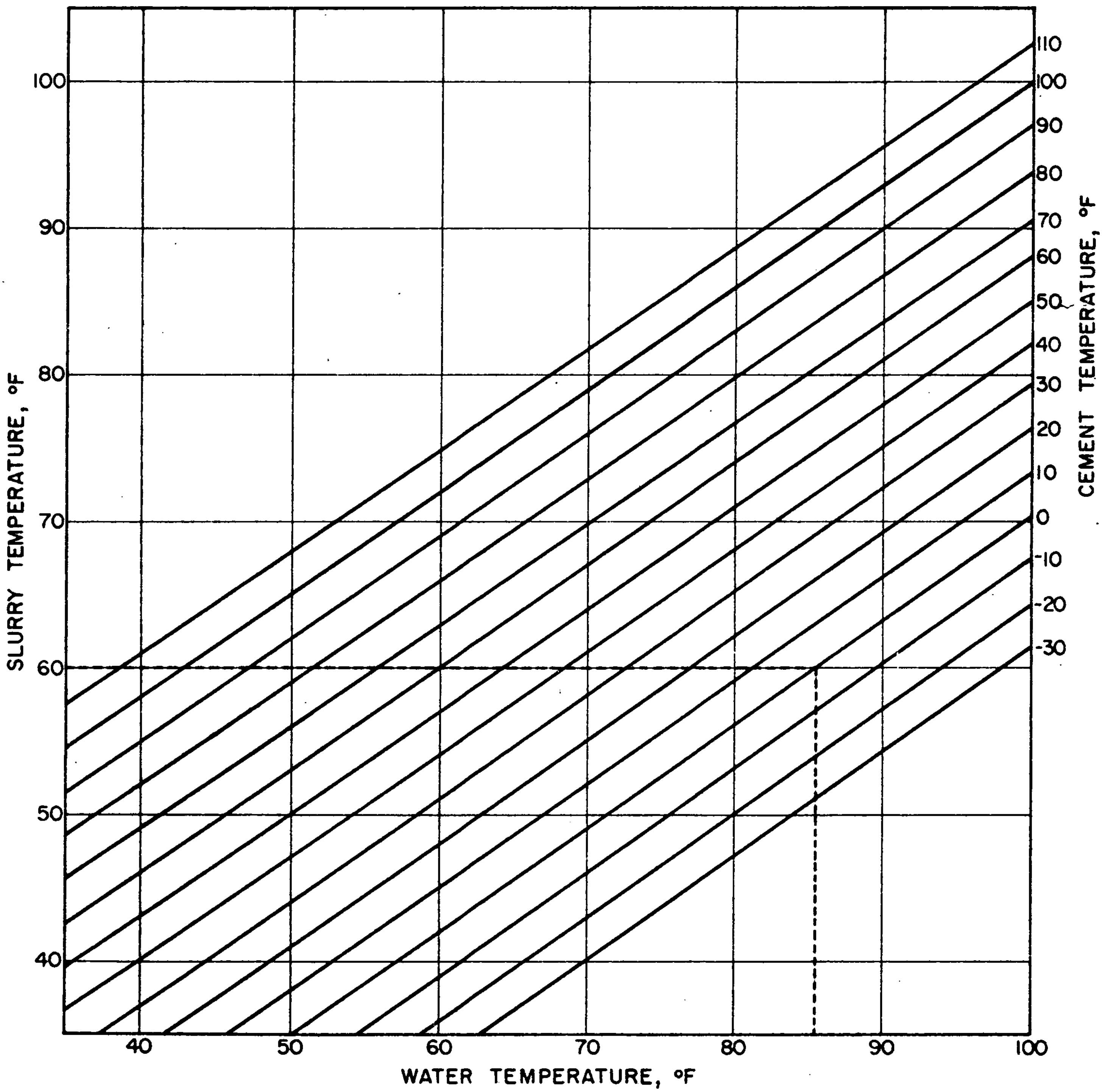


Figure 6

SLURRY TEMPERATURE FOR VARIOUS TEMPERATURES OF WATER & CEMENT

BASED ON 46% WATER BY WEIGHT OF CEMENT



Discussion

Dr. H.R. Peyton asked how Mobil Oil has coped with the problem of the permafrost thawing out radially from the hole during drilling due to above freezing temperatures of the drilling fluid. Secondly, he wished to know what sort of structural strength was used in the casing and the cement on the outside of the casing after production when the hot oil is being conducted upwards. The author replied that drilling took place on some holes for as long as 4 1/2 months and there was no indication of thawing of the permafrost near the surface. The basic hole size was approximately 24 inches and drilling took place inside 9 5/8 inch casing so there was considerable insulation present. The second question could not be answered because no oil was discovered.

Mr. K. Hinchey requested more information on Fondu cements. He said that his company was not familiar with them and he asked whether they are used extensively in Canadian drilling programmes. The author replied that the term "Fondu" is a trade name for high alumina content cements. They are being used on the Alaskan North Slope by at least two operators, Mobil Oil and Atlantic Richfield. The Dowell representative in Canada could furnish information on the properties of "Fondu" cement. Mr. Hinchey noted that the author mentioned using "High Early Strength Portland Cement", which yielded 15 per cent more slurry than normal cements and that it could be used for the other operations for which cement is required. He asked whether this applies also to "Fondu" cement. The author replied that "Fondu" is basically a cold temperature cement whereas Portland cement will not begin to react until its temperature is several degrees above 40°F and it does not become effective until approximately 50°F. The "Fondu" has a normal reaction rate at freezing temperatures which is a big advantage. It can be mixed at a 32°F slurry and a solid cement bond can be obtained. Mr. Hinchey asked whether he understood Mr. Dier to say that he was not familiar with using other additives than cement in insulating the starting casing or surface casing where the permafrost would thaw away from the casing, or did he state that his company did not have any experience in this problem? The author replied that they had not yet carried out any experimental investigations. They used a normal Portland water cement slurry, about 14 1/2 to 15 pounds per gallon which performed satisfactorily.