United States Patent [19]

Burt et al.

[11] **3,846,989**

[45] **Nov. 12, 1974**

[54] **INSULATED EMBANKMENT DESIGN TECHNIQUES**

[75] Inventors: **Glenn R. Burt,** Deer Park, Tex.; **Albert C. Condo,** Newton Sq., Pa.; **George R. Knight,** College, Alaska

[73] Assignee: **Atlantic Richfield Company,** New York, N.Y.

[22] Filed: **July 10, 1972**

[21] Appl. No.: **270,359**

[52] **U.S. Cl.** ..... **61/.5,** 61/36 A, 61/50

[51] **Int. Cl.** **E02d 3/00**

[58] **Field of Search** ..... 166/DIG. 1; 61/36 A, 50, 61/.5, 62/55

[56] **References Cited**

UNITED STATES PATENTS

3,768,547	10/1973	Best	166/DIG. 1
3,667,237	6/1972	Dougan	61/36 A
3,602,323	8/1971	Schuh	61/50
3,279,334	10/1966	Quartararo	404/31
3,135,097	6/1964	Scheinberg	61/36 A
3,524,320	8/1970	Turzillo	61/38

OTHER PUBLICATIONS

"Permafrost – " by S. M. Muller, p. 153, 177 J. W. Edwards, Inc. – Ann Arbor, Michigan, 1947.

"Arctic Construction" U.S. Army Engineer School CN–C.022–12, Oct. 1961.

Better Building Bulletin No. 5, "Permafrost and Buildings" Sept. 1955, National Research Council.

"Permafrost and Related Engineering Problems" Endeavour, Vol. XXIII No. 89, May 1964.

"Permafrost and Related Engineering Problems," Muller, pages 98–103, 123–126, T. W. Edwards, Inc. Ann Arbor, 1947.

Primary Examiner—Robert R. Mackey

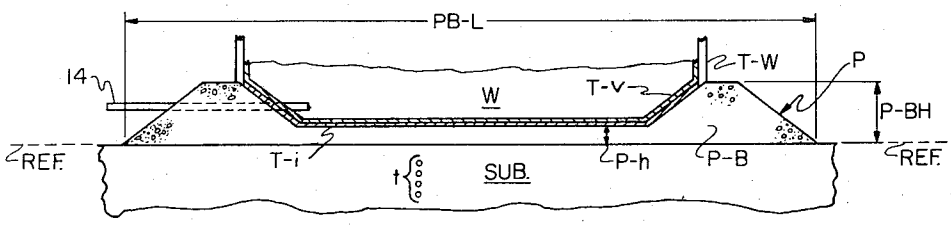
Assistant Examiner—Alex Grosz

Attorney, Agent, or Firm—Coleman R. Reap

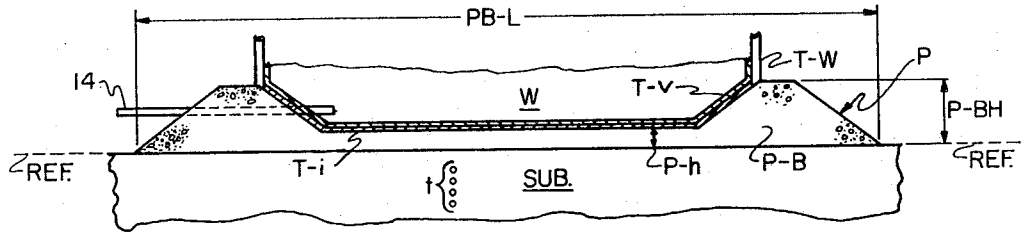
[57] **ABSTRACT**

Described are techniques and construction arrangements for providing insulated embankment foundation embodiments for liquid storage containers in "arctic temperature" environments; this including, in specific embodiments, techniques for determining optimum the thickness and other characteristics of associated insulation, as well as for subjacent gravel transition layers, plus other techniques such as pre-conditioning and refreeze schedules related to particular embankment design and service conditions.

12 Claims, 17 Drawing Figures



TYPICAL RESERVOIR CROSS SECTION



TYPICAL RESERVOIR CROSS SECTION
FIGURE 1

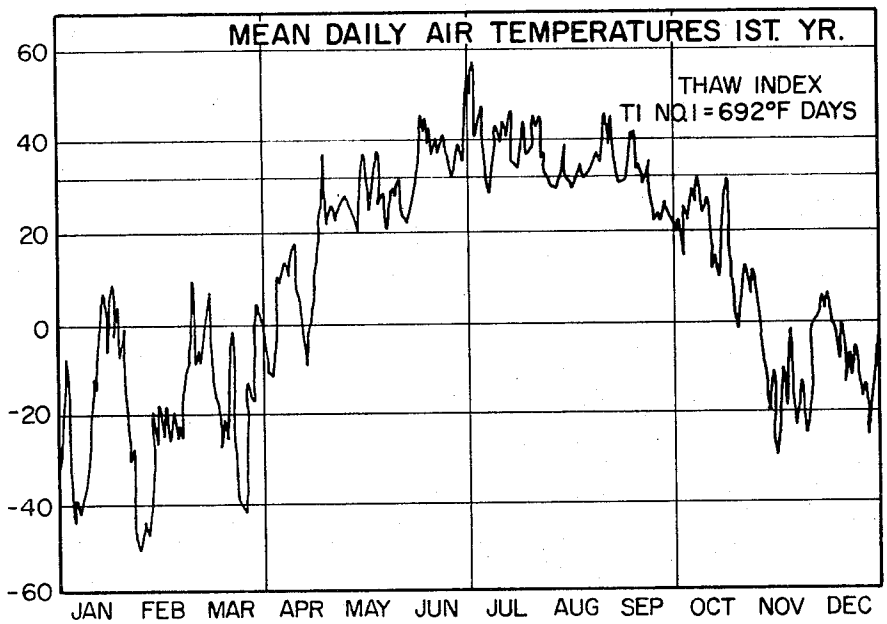


FIGURE 2

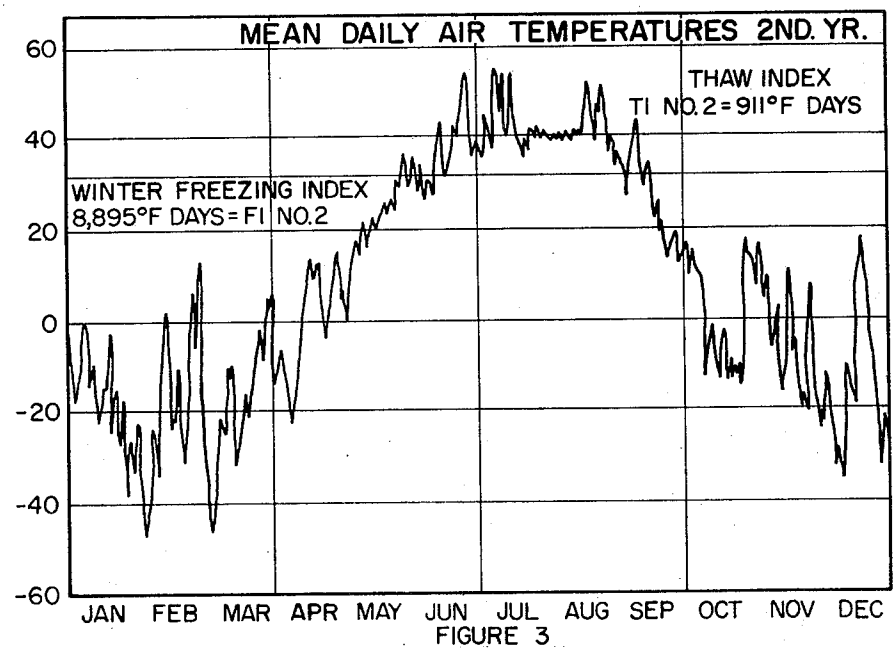
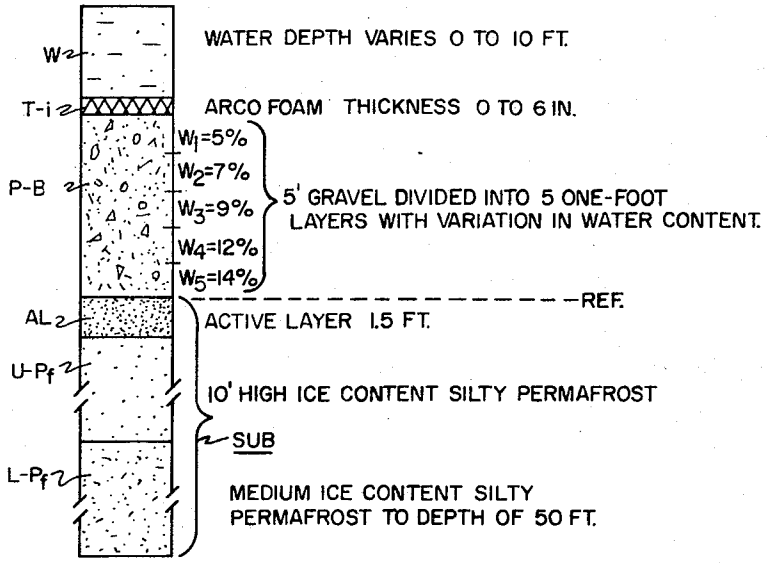


FIGURE 3



SOIL PROFILE (SITE NO. 1)
FIGURE 4

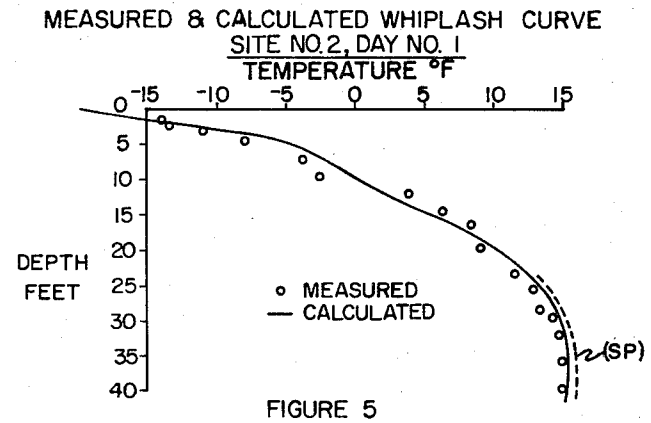


FIGURE 5

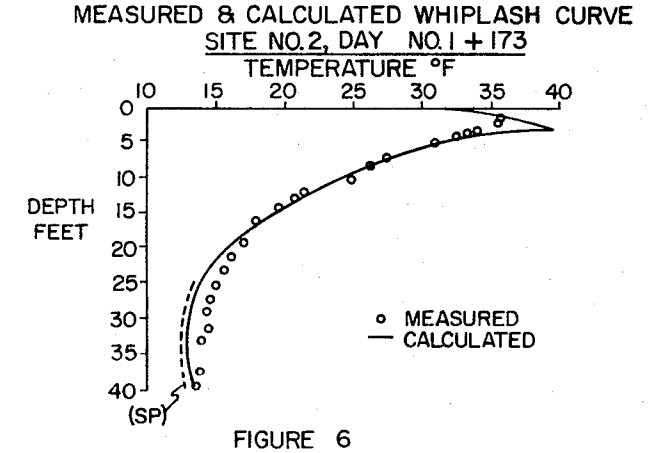


FIGURE 6

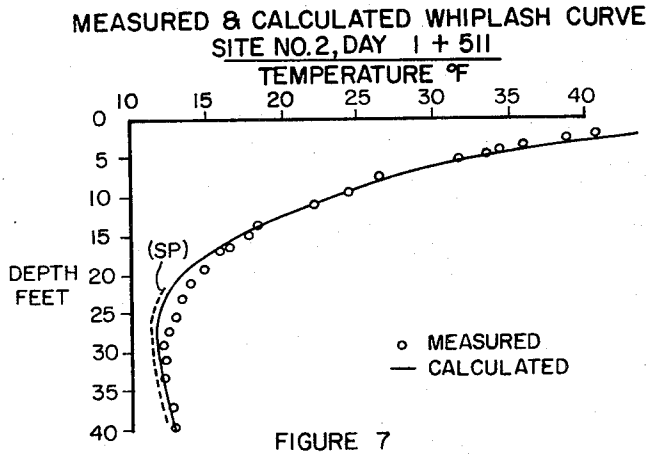
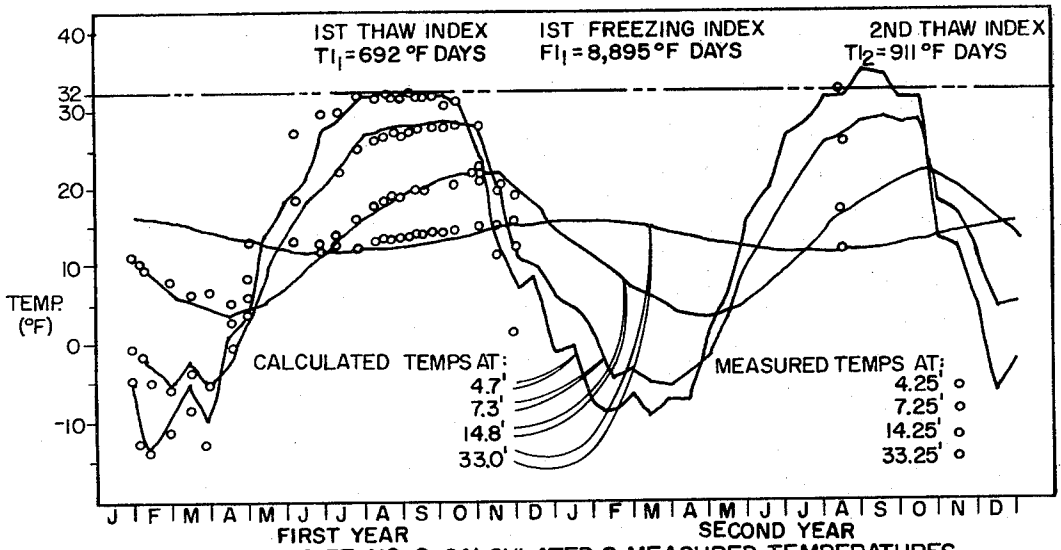


FIGURE 7



SITE NO. 2 CALCULATED & MEASURED TEMPERATURES

FIGURE 8

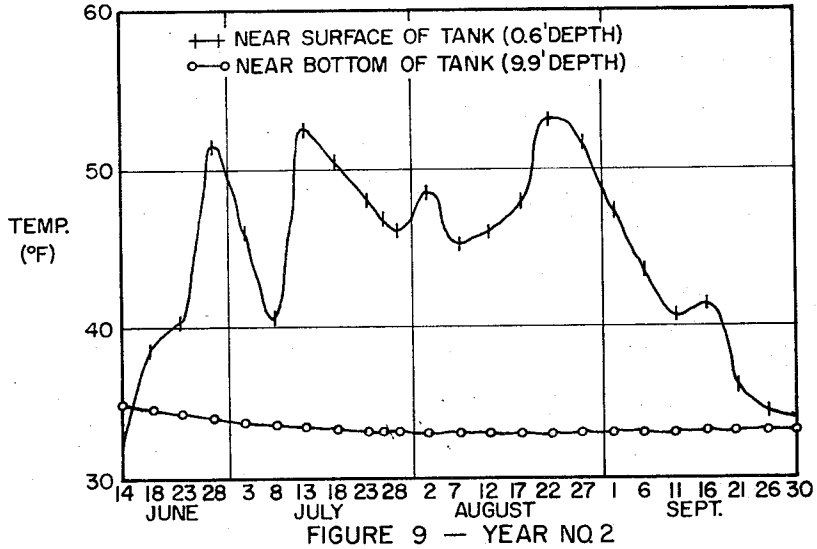


FIGURE 9 — YEAR NO. 2

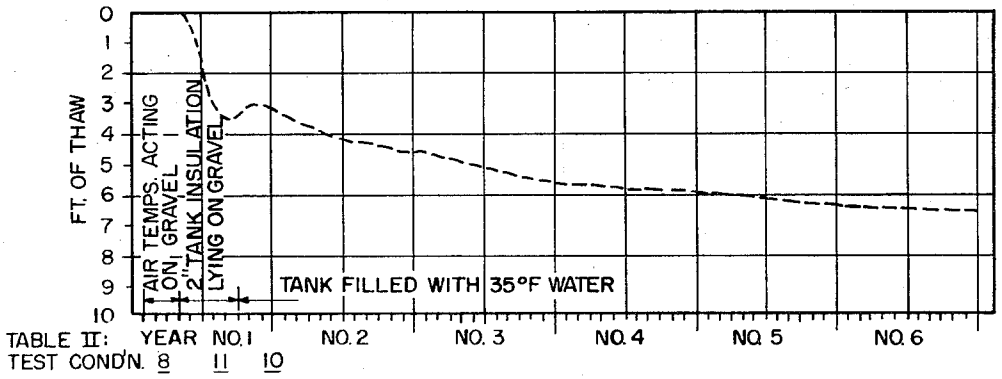
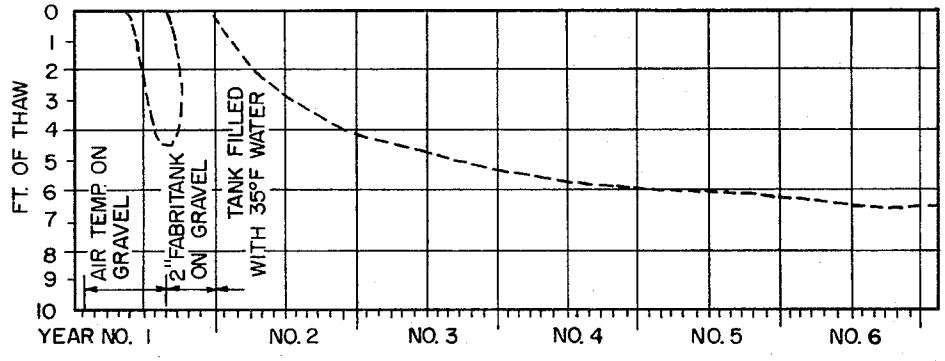
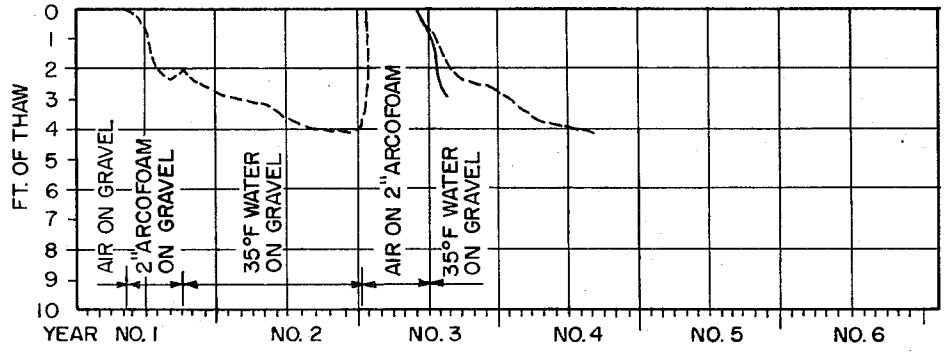


TABLE II:
TEST COND'N. 8 11 10

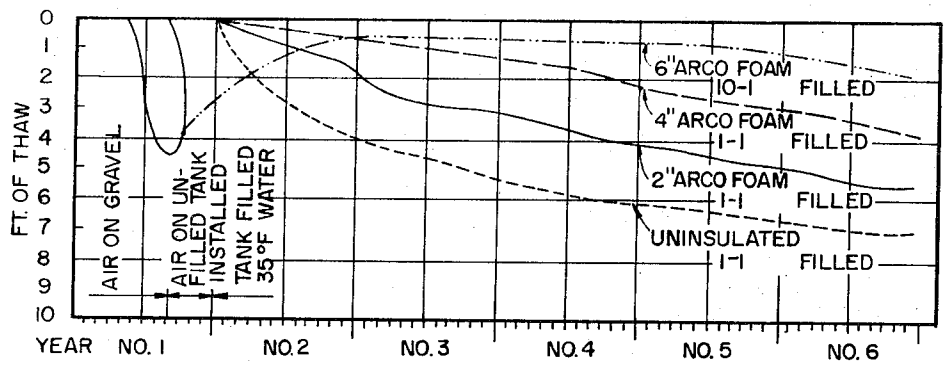
UNINSULATED SERVICE FACILITY-TANK FILLING I OCTOBER
FIGURE 10



UNINSULATED SERVICE FACILITY-TANK FILLING I JANUARY
FIGURE 11



ALTERNATING SOLUTIONS-UNINSULATED FACILITY
FIGURE 12



5 YEAR INSULATED FACILITY COMPARISON
FIGURE 13

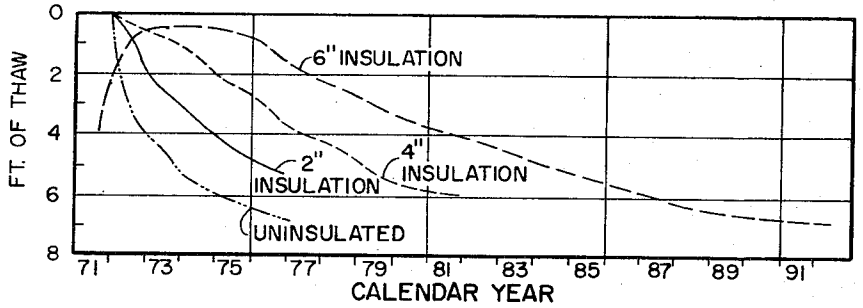


FIGURE 14

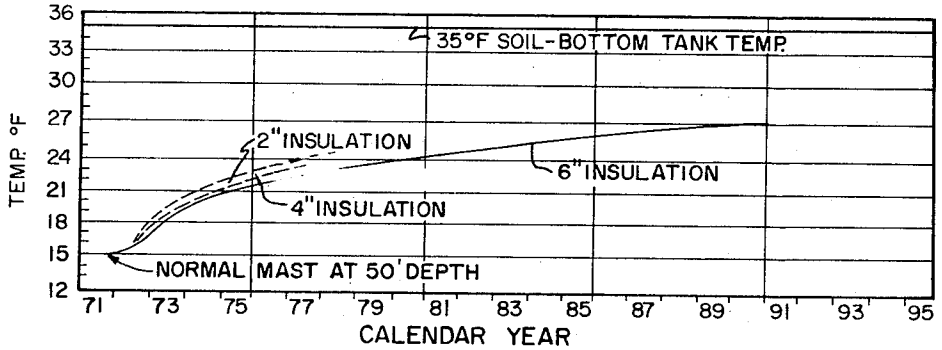


FIGURE 15

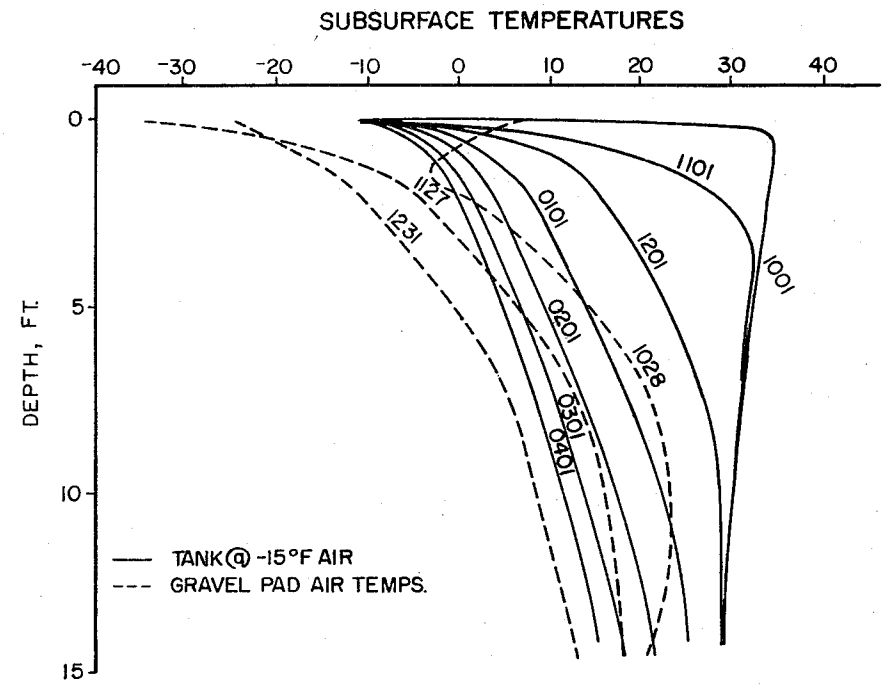


FIGURE 16

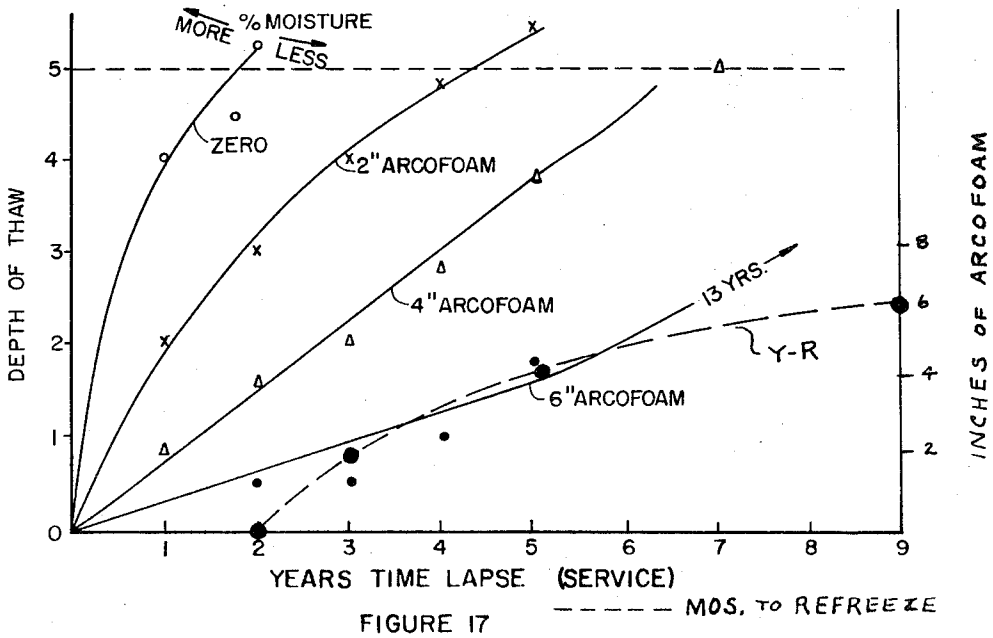


FIGURE 17

INSULATED EMBANKMENT DESIGN TECHNIQUES

BACKGROUND OF THE INVENTION

Workers in the art of cold weather construction are commonly confronted with the task of providing gravel embankments, or like foundations, for roadways, storage sites, building constructions and reservoir foundations, etc., in "arctic temperature" regions such as the Alaskan North Slope. A particularly vexing problem associated with such construction is how to provide an embankment foundation for a heated water reservoir. Such a storage facility may be contemplated for providing a continuous potable supply of water in an unfrozen liquid state to various man-support facilities, etc., in the arctic. The water must obviously be kept warm to avoid freezing and keep it liquid and available for human consumption, for chemical processing and especially for fire fighting purposes.

It was, at first, believed that if a worker analysed the interrelationship of temperature, soil depth and time for such a reservoir installation, it would be possible to apply a somewhat conventional, three-dimensional analysis and calculations and thereby evolve, for instance, a plot of temperature shift vs. driving thermal conditions — doing so on a time dependency basis for various points around the base of such a structure, — and to, at length, generate an ultimate "steady-state" solution (for infinite time). With such a technique a "thaw bulbs" could be delineated under a reservoir of the type mentioned, situated at varying depths thereunder and emanating from the center of the reservoir base to its corners (or generally to its outer periphery). Such a study will also suggest that the "thaw locus" (the subsurface location of the "thaw front" or 32°F. isotherm) will quickly drop under such a heated reservoir. For instance, in the case of a reservoir tank facility of particular kind (see Examples 1 and 2 described below) the thaw front will have dropped to about 5 feet below grade after approximately 200 days. Thawing would proceed further after 1 year to reach approximately 10 feet (upper 5 feet of permafrost completely thawed) and a depth of about 15 feet reached after about 700 days — with a relatively steady state or equilibrium taking place at approximately 20 feet below the center of the tank, assuming no settlement.

Such analysis, of course, would ignore latent heat factors, would assume that approximately 200 days after a "summer-filling" of this tank (or approximately in February) the active layer of tundra would be thawed (beneath the gravel embankment under the tank). The total thaw of the average active layer could be expected to result in approximately 4 to 6 inches of surface subsidence. After about 1 year or more, "ice wedges" melt and a surface settlement of 4 to 10 feet is possible where the wedge had existed; whereas in regions overlying the center of typical Arctic "polygons like" settlement would be somewhat less, perhaps 2 to 3 feet.

Now, obviously, such differential settlement is not acceptable; it can readily lead to degradation and destruction of the embankment and the tank facility and support equipment located thereon, with possible rupture of the tank, etc. Major maintenance and regrading operations would also be required following each summer of such service, entirely aside from the problem of how to deal with this "differential settlement."

The present invention is intended to provide a better solution to this and related problems. Accordingly and to meet the foregoing problems, we have developed techniques, according to various features of this invention, that involve such expedients as introducing a prescribed "artificial turf" under a heat-emitting facility (like this mentioned reservoir) — which, together with a superimposed layer of insulation, makes it possible to predict an extended, definite "service time" for the facility, together with a schedule for cooling the overall facility in a prescribed manner (before service and in some cases after service periods or during prescribed "refreeze" periods). Another feature involves indicating how prescribed measurable environmental factors such as the thermal history of the site and the moisture and other thermal parameters of embankment materials may be used according to novel calculation methods plus a novel design technique adopted to establish the parameters for such embankment construction. More particularly, this involves specifying prescribed embankment construction for supporting a given heated facility wherein the thickness of the aforementioned "artificial turf" is set in keeping with a prescribed "service life." In particular instances this also involves operating the tank facility according to a prescribed service refreeze schedule, whereby improved, continuous overall operation is achieved by alternating service time and refreeze time. Other features will be apparent to those skilled in the art from the following description of the particular embodiments of this invention.

Accordingly, it is an object of the invention to provide a solution to the aforementioned problems and in general to provide the features of novelty and advantage described herein. Another objective is to provide the foregoing in an arrangement including prescribed composite insulated embankments using prescribed techniques for construction and for determining the characteristics of the artificial turf material and its thickness. A related object is to provide the foregoing so as to afford a prescribed thermal impedance whereby to retard movement of the "thaw locus" associated with the facility for a prescribed extended period of time. Another object is to provide the foregoing in keeping with a prescribed schedule of cooling periods and service life. A further object is to provide the foregoing using a prescribed design technique based upon calculations from known, available environmental thermal parameters and material characteristics. Yet another object of this invention is to provide a design method for constructing insulated foundation pads on permafrost whereby to support a heated facility. (e.g., being kept at a constant service temperature, above freezing.) A still further object is to provide such design techniques wherein the facility operates at a constant temperature above freezing and yet will transfer its heat losses to the insulated pad at a predetermined reduced rate, such that the thaw-front will progress down through the pad (toward, but short of, the "artificial turf") at a predetermined rate; this rate being arranged such that the associated "transit time" corresponds to, and defines, a prescribed "service period" for the facility. Yet a further object is to provide in this design a means by which the aforementioned pad is cooled and thermally restored to its original heat budget by providing a refreeze period which elevates the thaw front up from the artificial turf well into the insulated pad. A further object is to provide, within such design meth-

ods, the means by which such thermal restoration and dissipation of geothermal heat plus other heat accumulated in the pad during service is removed at a predetermined rate, dependent on design constraints. The time lapse from elevation of the thaw front (from the active layer tundra surface to its original position "as constructed") to "just-prior" to being placed in service is referred to as the refreeze period. This refreeze period is a non-productive period during which the facility is not operative (as a reservoir). Still another object is to provide, within such design constraints, a structural facility which so minimizes the length of this refreeze period as to maximize the ratio of service time to refreeze time.

The invention and means by which the objects of this invention are accomplished will become clear in the Examples to be hereafter described. Also, the various objects and advantages of the invention will be fully understood from reference to the following detailed description of the preferred embodiments of the invention when taken in light of the accompanying drawings, wherein is indicated a typical embankment construction for a cold environment together with various modes of construction and associated curves indicating the effects thereof.

IN THE DRAWINGS:

FIG. **1** is an idealized elevational section of such an embankment embodiment designed as a foundation for a heated reservoir tank situated upon a site characterized by permafrost with certain items being only fragmentarily and/or schematically indicated for simplicity;

FIGS. **2** and **3** are curves indicating air temperatures representative of this site over 2 successive years, respectively;

FIG. **4** is a schematic thickness profile of certain subsurface strata below the subject reservoir of FIG. **1**;

FIGS. **5, 6,** and **7** are curves indicating subsurface temperatures (calculated and measured) vs. depth at a second site, similar to that of FIG. **1,** as of a certain date, then 6 months, and 18 months thereafter, respectively;

FIG. **8** comprises curves indicating temperature fluctuations (calculated and measured) at various subsurface depths on the site of FIG. **1** over a 2 year period;

FIG. **9** shows curves plotting temperature fluctuations with time at two locations in the reservoir tank of FIG. **1**;

FIG. **10** is a plot of the locus of the thaw front with time in an embodiment like that of FIG. **1** in the face of certain different test conditions, including placement of tank, then filling with heated water; while FIG. **11** is a similar plot, with site cooling and a tank filling taking place over different seasonal periods however; while FIG. **12** is a like plot for other site conditions; and FIG. **13** is a like plot for further, more representative site conditions as a function of foam insulation thickness.

FIG. **14** shows the shift in thaw locus in time for various insulation thicknesses in an embodiment like that of FIG. **1**;

FIG. **15** indicates the rate of temperature rise over extended time 50 feet below the embodiment of FIG. **1** for various insulation thicknesses;

FIG. **16** shows two families of curves; each family indicates how the profile of subsurface temperatures relative to embodiments as in FIG. **1** shifts with "cooling time", one family with insulation; the other without it; and

FIG. **17** shows plots of thaw depth vs. "service time" for embodiments as in FIG. **1** having various thicknesses of insulation; together with a plot (Y–R in phantom) of insulation thickness vs. "refreeze time".

Reference will first be made to the construction of FIG. **1** to indicate the context of a typical (cf.EXAMPLE I, however it being understood that no insulation T—i is employed) problem circumstance and as a means of developing, explaining and applying various improvement features of novelty.

EXAMPLE 1 - The Problem

A service foundation pad P, as seen in FIG. **1,** was constructed atop the tundra-subsoil substrate (terrain "sub") at a location (site No. 1) on the arctic plain. This was done by compacting river bank gravel hauled from a river borrow pit nearby. The gravel thickness (P–*h*) above the tundra was 5 feet. Pad P is surrounded on all four sides by a gravel berm PB to a maximum height (P-BH) of 18 feet and with a "3 on 1" shoulder and an overall (PB-L) of 201 feet from toe to toe (as shown in the cross-sectional view in FIG. **1**). The space between berms, and above the 5 foot base forms an inverted trapezoid which defines a space for coating a one million gallon capacity water storage tank T, only the walls T–W thereof being shown and including an inner layer of fiber reinforced vinyl T–v. The top side surface of the water tank may preferably include a thermal insulation cap, such as a 2 inch layer flexible polyurethane foam (not shown), which retards the loss of heat from the waterfall W to the cold ambient air. The stored water (fill W) in the reservoir tank is recirculated thru a heat exchanger (not shown; coventional) thru an outlet system (only one conduit of which, **14,** being shown, and this fragmentarily) at a rate to maintain a constant temperature of 35°F., at the exchanger. Thermistors connected to data aquisition equipment (neither shown) were installed at various "test depths" (e.g., see test sites *t*) down to 15.5 feet at the center, beneath outlet **14,** and beneath the berm. The facility was constructed in the fall, allowed to freeze, and subsequently filled the next January. Shortly thereafter, the reservoir failed due to thaw beneath an outlet conduit (e.g. **14**) and consequent subsidence (of the melting permafrost underneath) and collapse of the conduit.

EXAMPLE 2 - Deriving SST Curves - FIGS. **5–8**

A set of thermistors were installed in the 5 foot gravel embankment over the tundra at site No. 1 to several embankment-sampling depths of 4.25, 7.25, 14,25 and 33.25 feet below the gravel surface (i.e. all except the 4.25 foot site lying under the top surface of the terrain -- i.e., below reference grade REF in FIGS. **1** and **4**). During two successive 12 month periods, ambient air temperatures were recorded daily and the mean daily air temperatures (simple arithmetic mean calculated) were plotted versus time (see FIGS. **2** and **3,** respectively). The soil profile for this site (S–1) was determined from various soils samples and averaged. The averaged soils profile for site No. 1 is shown in FIG. **4,** were heated water fill W, embankment cross-section

P-B including layers having water content W_1–W_5 (varying from 5 at top to 14 percent at bottom), ground surface locus REF and subsurface strata SUB are as indicated for FIG. **1.** "ARCO foam" insulation layer T–*i* will for the present be ignored and assumed nonexistent. Subsurface strata SUB comprises a top "Active Layer" (aforementioned) averaging about 18 inches of vegetation, rocks, silt and like tunda-soil material. Layer AL will be subject to thaw under native ambient conditions, at least occasionally (to fill depth). Under layer AL is a layer U–P_f of high moisture (ice) content, silty soil; assumed perpetually frozen (permafrost) under native ambient conditions; with a second permafrost layer L-P_f under layer U–P_f, however being typically thicker (about 50 vs. about 10 feet) and of lower moisture content. Table I is a tabulation of the properties to be assumed for the materials indicated for the soils profile of FIG. **4.**

The above-freezing ambient air temperatures indicated in FIGS. **2** and **3** reflect the "heat-engine" or driving force applying heat at a certain rate to any soil surface which in turn acts to transfer the heat flow to subsurface depths.

Ambient air temperature fluctuations can be translated into soil-surface temperatures fluctuations and to sub-soil temperatures at various depths. Mathematical techniques have been developed which provide a means for effecting this translation; however, these are limited to a somewhat-idealized mean annual sinusoidal air temperature fluctuation and to simplified soil strate conditions; and accordingly deviate somewhat from actual temperature measurements taken at various test-depths in the soil.

TABLE I

PROPERTIES OF MATERIALS IN SOILS PROFILE OF FIG. 4

	Dry Density pcf	Moisture Content %	Thermal Conductivity BTU/fthr°F.	Vol.Heat Capacity BTU/cuft°F	Latent Heat of Fusion BTU/cuft	Thermal Diffusivity sq ft/day
ARCO-FOAM	2.0	0.0	0.0125	1.0	0.0	0.003
Gravel	120.0	5.0	1.08	24.9	864.0	1.04
Gravel	120.0	7.0	1.30	26.8	1210.0	1.17
Gravel	120.0	9.0	1.50	38.5	1555.0	1.26
Gravel	120.0	12.0	1.78	31.2	2074.0	1.37
Gravel	120.0	14.0	1.96	33.0	2419.0	1.43
Act Layer	90.0	30.0	0.97	35.5	3888.0	0.66
Silt	35.0	142.0	1.28	30.6	7100.0	1.00
Silt	56.0	72.0	1.28	30.2	5930.0	1.02
Water	62.4	100.0	0.35	62.4	8990.0	0.14
Ice	57.0	100.0	1.28			0.98

A "finite differencing" computation technique will be described whereby the soil composition and thermal properties for any subject strata are employed along with (reported) actual daily temperature data to establish resultant subsoil temperature profiles verified by establishing a direct correlation between theoretical and measured values of sub-soil temperature (driven by ambient air temperatures) -- these profiles shifting of course with seasonal thermal changes.

First, it is desirable to measure ground temperature, at various selected depths beneath the 5 foot gravel pad, these being recorded (or computed) to be plotted as a function of ground surface temperature conditions on a selected starting day (Day No. 1). Ambient air temperatures are also recorded for Day No. 1 and "N-factored" to establish the mean daily soil surface temperature. A "whiplash" curve showing the variation of temperature with subsoil depth is thus derived.

FIG. **5** shows such a whiplash curve for Day No. 1 taken at site No. 2 removed a distance from site No. 1 but similar thereto for the present purposes. FIG. **6** shows the same curve taken about 6 months later and FIG. **7** shows the same curve for conditions about 18 months later. The "spine" (SP) of these curves (below 30 feet) will be seen to remain relatively the same (vertical), indicating constant temperature (close to 15°F.), while the upper "soil" or "whip" sections oscillate back and forth, indicating that the temperatures so oscillate with the seasons, changing more radically the closer to the surface one gets (the whip-action). Referring to FIGS. **5, 6** and **7** it has been seen in practice that the theoretical sub-soil temperatures which were calculated at 0, 6 and 18 months (after Day No. 1, using the referenced "finite differencing" program and ambient air temperature driving conditions from air temperature records for that day) correlate well with measured values. That is, actual thermocouple measurements of temperature at these depths over the same period yields curves that "fit" closely to the indicated theoretical curves. The validity and accuracy of this Finite Differencing technique are undoubted now. FIG. **8** shows the sinusoidal temperature fluctuations over a 2 year period as measured and as calculated for several depths in and below a 5 foot embankment. This continuous 2-year set of subsurface soil temperatures (SSTs) as influenced by air temperature correlates well with the curves of FIGS. **5, 6** and **7.**

On the basis of the foregoing, and as further explained, it will be seen that the "finite differencing" calculation method can be employed to calculate subsurface temperatures for any locale in the Arctic or sub-Arctic where a relatively one-dimensional heat flow can be anticipated with reasonably level terrain and at a point not significantly influenced by an adjacent lake, stream or like thermal anomaly.

The input ambient air temperature data will be correlated with the air temperature reports from the nearest weather station that provides such on a current basis. A conversion factor (the "N-factor") computations can thus be developed to convert such "baseline" (reference) weather data for the (nearby) site in question.

Appropriate soil conditions for the specific site must of course be determined, establishing the site and composition of sub-soil layers and their properties. If ground surface temperature data is not available, it may be derived by known calculations as a function of the sinusoidal air temperature fluctuations at the site. This will constitute the (quasi-steady-state) heat in-flow to the subsoil.

With this initial data and calculations, one can employ conventional weather information over the prior 5–20 years and thus derive a general approximation of weather data for the coming 2–20 years, including responsive fluctuations in ground temperatures. This, in turn, will help to provide the necessary information required for forming the subject novel design for embankments over permafrost. More especially, a probability basis will be determined to indicate the extent and frequency of deviations from given mean temperatures. Further particulars will appear from the following Examples.

EXAMPLE 3 - Heated Tank; Optimize Fill-Time (FIG. 9)

The tank facility of Example 1 is analyzed to establish tank water temperature, and to determine an optimum time of year for filling the tank. Analysis of the facility and ambient thermal factors indicates that, assuming the thaw conditions of year No. 2 (FIGS. **3** and **8**) and a tank maintained reasonably full through the summer period and assuming 10 feet of uncirculating water and no heating (see FIG. **9**), a large temperature gradient from top to bottom of the tank will result. FIG. **9** shows that at the bottom of the tank, water temperature was relatively constant, 35°F. Such a "bottom temperature" is acceptable; being accompanied by an "upper tank" temperature of 50°F. and more. If circulation is maintained during the four month summers, the tank water would have a mean temperature of 39°F. (throughout), resulting in a larger bottom-of-tank thaw index (TI_b). This clearly indicates that water circulation is not advisable during summer. Accordingly, it is preferred that the circulation system be selectively controlled by a relay system that permits circulation during the summer only when bottom-water is at, or below, 34°F.

The best time to fill the tank in reference to the summer period can be arrived at by a thawing index comparison. A tank filled in the spring of the year and allowed to remain quiescent so that the temperature does not exceed 35°F. will produce a bottom thaw index on the gravel of approximately 700°F-days (see below). This compares with an air thaw index approximately twice as great. The foregoing was arrived at by comparative analysis of the following tank conditions:

I. Tank filled on the first of May and water temperature inside of tank held at 35°F.

II. Tank left empty after the first of May with a 2-inch flexible foam insulation lying on the gravel surface.

Analysis of the empty tank (Case I) showed approximately 3 feet of thaw into the gravel beneath the tank by October 1st; whereas the tank filled on May 1st (Case II) would have only 2 feet of thaw into the gravel. These analyses (elaborated below re Example 5) clearly indicate that filling should take place as early as practical in the spring, if not before (preferably fall or winter; and after "refreeze" in any event).

Now, in brief recapitulation, workers in this art will recognize the following novel features as derived and exemplified above. Gravel thickness P–*h* in Examples 1–3 (FIGS. **1** and **4**) is, in reality, arranged to provide a prescribed "artificial active layer" (or "pseudo turf") under the heat-emitting tank facility which, together with a superimposed layer of insulation, can so retard the thaw front (under specified ambient conditions), to allow a prescribed "service time" to be scheduled, together with a following recuperative cooling period if needed. Using prescribed measurable environmental factors, such as the thermal history of the site and the moisture and other thermal parameters of construction materials, workers in the art may avail themselves of a novel improved design and techniques for embankment construction.

EXAMPLE 4–A

Assuming the facility of Example **1** and applying the teachings of Examples 2 and 3, one may establish different operating limits depending on whether the gravel is uninsulated or insulated under tank T. Here, as in Example 1, the basic soils profile of FIG. **4** and the properties of each stratum tabulated in Table I will be assumed; however, with inclusion of insulation layer T–*i*.

The cross-sectional view of the insulated foundation P for the heated tank facility shown in FIG. **1** indicates the 18 foot berms, P-B, the 5 foot gravel pad, P–*h*, heated water reservoir, W, in relation to each other and also to a layer of thermal insulation T–*i* (not assumed in prior Examples). Insulation T–*i* preferably comprises an ARCOFOAM-*1* polyurethane system constituted and installed as described in copending commonly-assigned U.S. Pat. application 227,664, filed Feb. 18, 1972, entitled "Stabilizing Arctic Ground Cover," by Albert C. Condo and Joseph E. Neubauer.

This ARCOFOAM-1 system (including isocyanate ISO–1A plus polyol OL–1B) is spray-applied on the gravel pad as indicated in FIG. **1.** Its properties and characteristics will be as summarized in Table I-A as follows:

TABLE I-A

"ARCOFOAM-1" PROPERTIES

Compression strength (psi) at yield	43–50
Compression at yield	3.5–5.0
Density (pcf)	2.7–2.8
K-factor	0.11
Closed Cells (%)	89.5
Open Cells (%)	6.8
Cell Walls (%)	3.7

ARCOFOAM 1 foam provides a high ratio of compression strength to density.

Preferably, a moisture barrier precoat (subcoat) is used with ARCOFOAM 1 (thereunder) such as "Arcote Weathercote" as described in the referenced application.

The aforementioned Finite Differencing method is best understood and explained in terms of known initial conditions and known subsurface properties. To this end, various test conditions were postulated for the facility of Ex. 1 for selected "test periods" and in various sequences. (Table II below). To determine (calculate) their thermal effects as represented by the resultant position of the "thaw-front," in or beneath the gravel embankment (FIGS. **10–13** as follows); the plot of "thaw locus" thus derived indicated (expectedly) that the effect of each test condition was (somewhat) dependent upon the effects of the prior test condition. Here it

should be assumed that all test conditions relate back to the described inadequacies of the service facility of Example 1. Also, the Finite Differencing used will be understood as allowing for a normal variation in moisture gradient within the gravel and for normal variations in the properties of the foundation soils.

The test conditions invoked are summarized in Table II below. Analysis was run on these and the aforementioned sets of subsoil temperatures were generated over the indicated time and seasons for the site.

TABLE II

1. Air temperature on 5 feet gravel (moisture content, w:14 percent).
2. Air temperatures on 8 inches ARCOFOAM over 5 feet gravel (w:14%).
3. 35°F. on 6 inches ARCOFOAM over 5 feet gravel (w:variable).
4. Air temperatures on 6 inches ARCOFOAM over 5 feet gravel (w:14%).

350°F. on 4 inches ARCOFOAM over 5 feet gravel (w:14%).

6. Air temperatures on 2 inches ARCOFOAM over 5 feet gravel (w:14%).

35°F. on 5 feet gravel (w:14%).

8. Air temperatures on 5 feet gravel (w:variable).
9. Air temperatures on 2 inches ARCOFOAM over 5 feet gravel (w:variable).
10. 35°F. on 5 feet gravel (w:variable).
11. Air temperatures on 2 inches flexible foam over 5 feet gravel (w:variable).
12. Air temperatures on 6 inches ARCOFOAM over 5 feet gravel (w:variable).
13. 35°F. on 4 inches ARCOFOAM over 5 feet gravel (w:variable).
14. Air temperatures on 4 inches ARCOFOAM over 5 feet gravel (w:variable).
15. 35°F. on 2 inches ARCOFOAM over 5 feet gravel (w:variable).
16. Air temperatures on 2 inches flexible foam, 10 feet water, 2 inches ARCOFOAM over 5 feet gravel (w:variable).
17. −15°F. on 2 inches flexible foam, 2 inches ARCOFOAM over 5 feet gravel (w:variable).

By way of further explaining the calculation sequences (runs) of Table II, application of Test Conditions Nos. 1, 2 and 3 will now be described, these being invoked, successively, for certain respective time periods. The pad P of FIG. 1 is initially assumed to be affected only by ambient air temperatures acting on the 5 foot gravel thickness with an average moisture content of 14 percent during the period starting on the first of February and ending the first of August. This is followed by test-condition No. 2 wherein 6 inches of ARCOFOAM and 2 inches of flexible foam over 5 feet of gravel with 14 percent moisture content is left in situ until the first of October; this, in turn, was followed by test condition No. 3 whereby tank T with 35°F. water is assumed placed upon 6 inches of ARCOFOAM, overlying the 5 feet of gravel (variable moisture content) for an additional 5 years. The results of this (No 1, 2, 3) sequence indicated specific subsoil temperature profile sets, varying with time, along with the average temperature degree which, of course, varied seasonably from the site. This was used to plot "thaw front" location; for example, in FIG. 13, treated below; the "thaw iso-therm" location is picked out of each such profile set and plotted with time for various insulation thickness as well as for "zero thickness."

FIG. 10 indicates the effects of different successive test conditions on a test embankment facility as a function of "thaw locus;" i.e., how seasonal weather (thermal) changes at the test site (site No. 1) and certain service conditions (tank installation, then filling with heated water, kept at 35°F.) can affect the location of the "thaw-front" (i.e., lowermost location of 32° isotherm). Here, conditions 8, 11 and (a modification of) No. 10, obtain for the indicated seasonal periods. The facility of Example 1 will be assumed as employed here, with a 5 foot pad (outer tank, on frozen substrate -- same gravel type, having variable moisture content per FIG. 4) on which is situated a collapsible-inflatible "pillow tank" having walls of 2 inch flexible foam insulation and a "vinyl insert" outside, later being substantially filled with water kept at 35°F.

FIG. 11 assumes the same test situation except that a longer and different "air-only" period obtains (vs. condition No. 8), a different "empty-tank" period obtains (vs. condition No. 11) and tank filling (start-of-service) occurs 3 months later (on January 1). The prolonged effect is that, as a result of a cooler, more-effective "pre-condition period" (analogous to a more effective refreeze period), the curve ("thaw-locus") is kept up ("higher" on the embankment) for a longer period (e.g., takes about 3 months longer to reach 5 feet depth).

As aforementioned, FIG. 12, like FIGS. 10, and 11, plots the shift in "thaw-locus" with different test conditions (cf Table II) and in various respective seasonal periods -- doing so for a pad which is effectively non-insulated.

FIG. 13 plots the same thing for a more specific and practical set of test conditions (tank of FIGS. 10, 11 used here also), simulating the preconditioning and use of the facility as in Example 2 etc. with various thicknesses of foam insulation (and "zero foam" as a "baseline" reference). Consideration of FIG. 13 shows that application of 2 or 4 inches of foam gives a marked, surprising improvement (e.g., extending thaw-time) over the "zero-insulation" case; and that going to yet thicker insulation (6 inch foam) brings one closer to a point of "diminishing returns" as well as inducing a surprisingly-long "initial cooldown" time. The latter suggests that the "rectitherm effect" aforementioned is at work and that a consequent loss of refreeze effectiveness will result (further discussed below, see FIG. 18 and discussion).

EXAMPLE 4–B

A careful appraisal was made to establish the operating limitations of the tank as affected by the uninsulated 5 feet of gravel with 35°F. water as in Examples 1 and 4–A. This appraisal was made to determine how the existing tank of Example 1 could be returned to service. Here it is assumed that the tank is to be repaired and placed on the embankment ready for filling on (September 1 of filling year No. 1, then being filled the next month (on October 1) -- this compared with filling on January 1 of the next year. The outputs from the Finite Difference analysis of Example 4 showed that 18–24 months (see FIG. 13; no insulation, 4–5 feet thaw; also FIG. 11) would be required in the case of the January filling for thaw to take place through the gravel

to a point where addition thawing would create excessive settlement.

If the embankment supporting the tank is to be operated without insulation, it thus appears that the tank must be left empty to cool-down for a reasonable time each winter (1–3 months) sufficient to refreeze the embankment. The analysis of the necessary refreeze period assumed that the average mean temperature from November 1 through April 1 will be less than −15°F., (based on previously given known winter data for this site No. 1). This appraisal showed that allowing the tank to remain in place, and cooling without any water in it for approximately 3 months would result in the subjacent temperature returning very close to that of the "native condition" (i.e., where no such reservoir operation exists to affect it).

EXAMPLE 4–C

The specific location of an insulation layer within the service embankment causes slight variations in the thermal design. For the specific case of the reservoir of Examples 1 and 4, it was assumed an insulation layer would be placed directly on the gravel and up the side slopes as per FIG. **1.** Analyses were performed on the assumption of 2, 4 and 6 inches of ARCOFOAM in Example 4–A to establish the time rate of thaw beneath the insulation. These analyses assumed that the insulation and tank would be placed in refreeze condition September 1 (RD-Dry + zero). The analyses are based on fillings on Oct. 1 or January 1 (FIGS. **10, 11** respectively). The studies assume maintenance of the 35°F. temperature for the number of years to result in a maximum permissible thaw through the gravel.

The Finite Difference appraisals given in FIG. **14** are premised upon a year 1971 repair and modification of the existing storage unit. All curves in the figure are premised on air temperatures acting on the gravel up until September 1. It is assumed as of that date, the tank and the insulation will begin to naturally cool under the influence of the ambient thermal condition (i.e., to refreeze). With the exception of the "6 inch insulation" case, it will be understood that "filling" (when reservoir service begins -- or "S-Day plus zero") will take place the following January 1, thus allowing for a refreeze period. Analysis of the "6 inch" case is based upon an earlier (October 1) filling. FIG. **16** shows how, after 20 years the mean Annual Soil Temperature (MAST) at a depth of 50 feet beneath the center of the tank is raised by insulation (e.g., as much as 10°F).

In summary, the foregoing curves clearly demonstate that for such tank facilities (including modifications), the following effects may be predicted, assuming the described conditions:

1. If no insulation is utilized: the reservoir (tank) will have to be left empty for about 3 months each winter to permit refreeze.
2. If 2 inches of ARCOFOAM are utilized: the reservoir may be maintained, full of water, for about 4 to 5 years before it must be emptied and cooled for about 3 months (of normal winter) to effect refreeze.
3. If 4 inches of ARCOFOAM are utilized: the reservoir may be continuously kept full of water about 7 to 9 years before it must be "refrozen" i.e., empty for about 4 to 6 months of normal winter.
4. If 6 inches of ARCOFOAM are utilized: the reservoir may be kept full of water for approximately 12 to 14 years before "refreeze;" for which it will be left empty for about 9 to 12 months for normal winter.
5. It also appears reasonable to assume that if on the order of 10 to 12 inches of ARCOFOAM were utilized, one would derive on the order of 20 continuous years of reservoir operation before thaw would have traveled down all the way through the gravel; however, the associated refreeze time could be upwards of 2 to 3 years -- a prohibitively long time for most cases.

Here, it is surprizing to note the extent to which thicker insulations will heat up sub-surface strata at considerable depths; e.g., the 10° rise 50 feet down after 20 years (FIG. **15**). One may conclude that, given the considerable heat-input which effects such a substrate heating over such a long period, a correspondingly long cooling period will be required to dissipate its effects -- the inferance being that a very considerable "thermal inertia" is provided by such frozen substrata.

EXAMPLE 5

To appraise the time requirement for refreeze in the "2 inch insulation" case, two analyses were run for a 5-year test period (see FIG. **16**) assuming a gravel embankment having the same soil properties as the embankment of Example 1 (see FIG. **4**). The first analysis run was for a "zero insulation" case to establish a baseline or "normal" temperature regime after 5 years. The second analysis was run for the same operating structure and conditions, however, assuming 2 inches of insulation in place beneath the tank. At the end of 5 years, the tank was assumed to be emptied and left in place over the 2 inch insulation. The solid-line "whiplash curves" of FIG. **16** indicate that after a cooling of about 3 to 4 months (October 1 to January 1), the subsurface heat-budget was reasonably well restored (e.g., vs. a normal, "empty" pad of the same type -- of dotted-line curves from October 28 to December 31).

In recapitulation, the foregoing description and features of novelty indicate some conclusions regarding "service time" and "refreeze":

I. The existing tank of Example 1 (if repaired and intake-outlet modifications made) can be operated better if a "refreeze period" is scheduled; with the original "thermal regime" restored by leaving the tank empty under ambient cooling for 3 months each winter (while also free of snow, preferably). With this modified operation and assuming a relatively normal year (e.g., no extraordinarily high thaw-index or extraordinarily low freeze-index), the thaw periods (summer time) should not cause significant permafrost melt or embankment subsidence.

II. The tank installation should be filled as early as possible before late spring (thaw) to minimize subsurface melt in a summer. This will hold true whether the tank is insulated or not.

III. 2 inches (effective) of ARCOFOAM, or equivalent insulation, placed beneath the tank and atop a 5 foot gravel embankment (as in Example 4–A) and allowed to refreeze will so retard the thaw front as to give about 5 years stable service (keep thaw above permafrost level—assuming reasonably "normal" winter weather). After this 5 year "service", the tank

will be left empty for about three (normal winter) months to permit appropriate cooling of the gravel and substrata under the insulation.

IV. 6 inches of ARCOFOAM (under the conditions of Example 4) will keep the "thaw front" within the 5-foot gravel thickness ("transit-zone") for about 13 years.

EXAMPLE 6

As a result of the foregoing analysis and explanation, it will become apparent that one can, using the features of novelty of the subject invention, develop a technique for composite foundation pad design and for determining insulation thickness as a function of optimum "service time" and "refreeze time" for a given heat-emitting facility to be supported on the pad. Accordingly, one may determine an optimum insulation thickness as a function of the contemplated service (melting) and "refreeze" periods -- assuming the installation constraints and the environmental factors indicated above for Examples 1 and 2; also assuming that service is initiated at the onset of the Arctic winter (about October 1); and, further assuming that the installation will be removed from service during a prescribed optimum "refreeze period."

Attention is next directed to FIG. **17**, where thaw depth is plotted versus "service time" (solid lines only) for the subject heated-tank installation of Example 1 using various thickness of ARCOFOAM insulation. FIG. **17** also shows a related plot of insulation thickness versus "refreeze time" (dotted-line curve Y–R). In both cases the melting time and refreeze time will be understood as referenced to and based upon maintainance of the (top of the) underlying permafrost formation in a frozen state (that is, the bottom of the 5 foot gravel layer) and datum REF of FIG. **1** should never rise above 32°F.

TABLE III

THAW VS. REFREEZE (cf FIG. 17)

ARCOFOAM (inches)	0	2	4	6
Thaw Time (years)	1.8	4.3	7	13
Refreeze Time (months)	2	3	5	10.5 (curve Y-R)
Delta (% difference)	−10%	+133%	+140%	+122%

A tabulation comparing these thaw and refreeze curves indicates that, since a typical arctic winter (e.g., at Site No. 1) gives only about 8 (±1) full, normal winter months of useful refreeze (approximating the conditions assumed in curve Y–R -- although "Freeze Index" is a better measure), one cannot use more than about 4–6 inch ARCOFOAM insulation here without taking the subject installation out of service for about 2 full winters (possibly more) -- an extreme penalty! Note also that, compared with "zero insulation," the incremental cost in added refreeze time is only about 1 month with 2 inches of ARCOFOAM (vs. about 3 added months with 4 inches ARCOFOAM). Now, the 5-month total refreeze time with 4 inches is rather "marginal," and might not be satisfied in one rather warm winter. Accordingly, the 2 inch foam thickness is preferred here (in related cases 4 inches may instead be preferable). With 2 inches, the extra expense (vs. using no foam at all) involved in accepting one extra month or refreeze time and in applying the 2 inches of ARCOFOAM should be weighed against the value of the added "service time" (2.5 years) this produces. Similarly, a second 2 inches of ARCOFOAM (the 4 inch case) plus the extra 2 months refreeze time it costs can be weighed against the value of extra serice time (2.5 years) it provides.

Comparing these cost/benefit considerations with current economic factors, it is usually most advantageous to use at least 2 inches of ARCOFOAM (or equivalent) insulation. Also, in light of the aforementioned desirability of beginning service approximately in October and beginning refreeze in January, it will be apparent that foam insulation on the order of 2 inches is a very practical working solution -- other cases are not so well suited to this schedule. For instance, if service had begun on Oct. 1, 1970 using the 2 inch foam insulation, one would expect to take the installation out of service about Jan. 30, 1975 (4.3 years later), and then begin a three-month refreeze, ending about Apr. 1, 1975. The second service cycle could then begin (during Apr. of 1975) and extend for a similar 4.3 years, ending in the fall of 1979, at which time a second refreeze period could begin (-- etc., etc.).

Workers in the art will, of course, appreciate that the foregoing conditions and associated refreeze times and service times are to be taken as a statistical approximation and will vary with changes in gravel moisture, in weather at the site (e.g., abnormal FI or TI for site) and other conditions. They are given primarily for propaedutic reasons and serve to illustrate how one can employ certain features taught. For instance, although the time of service is given in years, for simplicity, it is (as workers will understand) more properly a function of the total degree days of thaw (thaw index TI) for a given season at the site -- and this can, of course, vary widely. Of course, the cumulative TI is a linear function with time because the facility is subject to a constant heat source. Similarly, although the refreeze time is given about in months, it should more properly be expressed as a function of total "nominal" degree days of freeze (Freeze Index FI). Also, if one assumes that a selected refreeze period extends into a thaw period, then a net (effective) FI, or the Total FI, less TI, should properly speaking be determined and used. The thermal driving forces influencing refreeze time are dependent upon climactic conditions which, of course, vary cyclically (e.g., diurnal temperature fluctuations) -- as opposed to a constant heat source. Therefore, the total cumulative degree days of refreeze is going to be a non-linear function with time, and it will vary with the time of year as well as with annual temperature variations from the selected "basis." Therefore, the period of 3 months nominal refreeze time given for the "2 inches of ARCOFOAM" case, must be understood as primarily illustrative of a January to April period during thermal conditions that approximate those used as a "basis" for the site. Accordingly, it will be evident that any given refreeze time may have similar deviations depending upon when (i.e., what season of the year) refreeze is initiated and upon what deviations in ambient temperature conditions should be expected from the "basis" used.

EXAMPLE 7

The arrangement of Examples 1 and 2 is modified by providing a second tank facility identical to that afore-

described and constructed to also supply heated water to the same "use-station" except, of course, that conduits (inlet/outlet) and associated facilities are appropriately modified (e.g., duplicated). This second facility will be arranged and controlled (by conventional means -- none of this being illustrated) in conjunction with the first so that one tank may be selectively drawn-upon (i.e., in service) when the other is taken out of service (e.g., during its refreeze period) and so avoid interrupting the supply of water to the common use-station. Preferably, this "multible reservoir" arrangement involves two or more tanks, each situated upon its own embankment pad, this being constructed according to the embodiment of Example 1 using 2 inch ARCOFOAM insulation over 5 feet of gravel, with appropriate interconnections for exchange of liquid between tanks, etc. Preferably, this second tank facility will be situated a prescribed minimum distance away from the first, at least enough so that any "thaw-bulb" developed under one pad would be substantially unaffected by the adjacent pad. A minimum spacing of the order of several dozen yards will suffice in the subject case. Of course, third, fourth, etc. duplicate facilities may likewise be provided to be alternatively used and cooled in the same manner.

Workers in the art will recognize advantages derived from the foregoing dual (or multiple) systems; for instance, refreeze time may now be invoked in the optimum, coldest season (e.g., beginning in January for sites 1 or No. 2), and maintained for a longer time, without concern over interrupting the liquid supply to use-stations. (e.g., see Table III; if four "2 inch" facilities are provided, only one need be "cooling" at one given time).

EXAMPLE 8

The arrangement of Examples 1 and 2 is constructed with 2 inch ARCOFOAM as before, except that, here, "cooling-shunt" means are interjected above the 5-foot gravel layer to cover it entirely, thus being disposed below the insulation (i.e., just below layer T–*i* in FIG. 1). An example of such a "shunt" is described in copending, commonly-assigned U.S. Pat. application Ser. No. 207,379 filed Dec. 13, 1971 now U.S. Pat. No. 3,791,443 Richard Odsather, Kay E. Eliason and Albert C. Condo, and entitled "Foundation for Construction on Frozen Substrata." This will form, in effect, a "rectitherm" embankment system as explained below.

As a further modification of the foregoing "cooling shunt" construction, insulation layer T–*i* is modified to comprise a pair of like 1–2 inch ARCOFOAM layers separated by "spacer means" adapted to introduce an air space therebetween. Preferably this is accomplished by supporting each foam layer on a rigid structural platform (wood is satisfactory for ordinary tank loading), the pair of platforms being spaced apart at least a few inches by structural spacer members thereby form a double platform supporting the superposed tank structure, this being entirely encapsulated in insulation with 1 to 2 inch ARCOFOAM extending entirely across each platform and covering all side areas extending between the platforms as well. Preferably, the sides defining this inter-platform "air space" are covered with foam blankets and preferably portions of these blankets are rendered removable or "displaceable" at opposite sides of the air space to allow selective introduction of ambient air cross-circulation (when the blanket sections are so displaced). The sides are preferably insulated in the same manner as the platforms with 1 to 2 inches of ACROFOAM on suitable supporting means. More particularly, it is preferred that "hatches" or swinging circulation ports, are provided for this purpose, being adapted to be swung open for cold air circulation during "cooling weather," -- such circulation intended, of course, to accelerate dissipation of heat from the gravel and permafrost beneath. Such an expedient will thermally " shunt" the overlying insulation layer and tank facility, allowing heat escaping therefrom to bypass the thermal impedance associated therewith. The hatches will be closed during warm (thaw) weather to thermally isolate (stagnate) the airspace and, taking advantage of its insulating properties, helping to impede heat input to the substratum.

Workers in the art will appreciate many advantages to this feature. For instance, such a "cooling-shunt" means will be appreciated as providing a new and useful system for helping to retard heat-input to a permafrost substrate (e.g., from a heated structure on an embankment pad; as well as from warm ambient air) as well as to, selectively (e.g., during cold weather), accelerate heat-output from this substrate; e.g., as an aid to minimize "refreeze time." Stated otherwise, the system can provide improved insulation during warm weather together with improved heat dissipation during cold weather. Such a system could thus be characterized as a "unidirectional" or assymetric conductor (or heat -- i.e., a one-way heat valve); or, to analogize to electrical conductors (cf. rectifiers which are unidirectional conductors of electric current), a "rectitherm" system as it were. However, without the use of such "rectitherm" means, most users of the subject embankment construction features will tend to derive such "rectitherm" effects anyway, using other expedients. For instance, the aforedescribed technique of employing minimal insulation thickness and have maximum "winter cooling" while still providing an acceptable mean thaw during warm weather -- itself exhibits a certain "rectitherm" effect. That is, if only a mean thickness of insulation is used, such as to barely provide the least acceptable protection against thaw, as has been explained, this will optimize the cooling and restoration of the embankment heat budget during cool weather. According to this teaching of "minimal insulation" techniques, it is critical, yet not obvious, that the greater the insulation thickness, the more one will impede substrate cooling (e.g., dissipation during a prescribed refreeze period of geothermal and other heat taken up by permafrost which can, over an extended period, degrade the usefulness of the facility supported). This is a rather surprising teaching, contrary to the heretofore accepted NORM: that is, workers have to the present accepted that "the thicker the insulation, the better" (aside from increased material costs, of course).

EXAMPLE 9

The arrangement of Example 8 is constructed as above except that "phase conversion means" is incorporated into the embankment system to enhance heat dissipation. More particularly, the air-space between the described insulated platforms is employed to receive a resilient "pillow tank" of inflatable plastic (or the like) and this tank is partly filled with freezable "phase-conversion" means in the form of water, leav-

ing only sufficient space therein to allow for freeze-expansion without rupture. The water will freeze during typical cold weather service conditions and, as ice, will drastically retard the improvement of any thaw-front therepassed. Workers in the art will readily recognize that a substantial ice mass like this will present enormous thermal impedients to passage of a thaw-front in that the front must first give up enormous quantities of heat (latent heat of fusion) and convert all ice to water before it passes beyond the mass. Preferably, this pillow-tank will extend over and intersect substantially all of the cross-section of the air-space (but only part of its height) so as to interrupt all heat flow through the pad. This modification may be used supplementarily with the above-described "icing-in" of the subjacent gravel or as a substitute therefor. Obviously, unlike "icing-in," it will involve no risk of liquid loss, run-off or resulting subsidence.

Of course, workers in the art will perceive equivalent "phase conversion" means (or "fusible fillers") to use instead of water, such as an aqueous glycol solution, brine (e.g., using sea water), etc.; or other liquids that will freeze at the ambient service temperatures, expected and will have a reasonably large, useful latent heat of fusion (preferably comparable to water or better). Of course, if such a filler has a higher melting temperature (as solidified) than water, it will offer even more protection for the permafrost substrate since it will melt much sooner.

Workers will also contemplate other analogous container means for such "fusible fillers". For instance, plastic (vinyl chloride polymers) bags will be feasible for certain applications; an example of such a bag given in U.S. Pat. Nos. 3,381,441 to Condo et al., 3,501,433 to Condo and 3,419,511 to Condo et al. Such bags are relatively small, inexpensive and readily available and this will often provide a superior "container module" (or "water bag") adaptable to a wide variety of "fusible filler" applications -- for instance offering a volume-module adapted for occupying a wide variety of spaces (size, shape). Similar bags may be made of like elastomeric material -- preferably being resilient enough to accommodate freeze-expansion. Likewise, certain rigid containers may be employed, such as "tin cans", "fibre foil" containers, glass or plastic bottles, oil drums or the like -- as long as they are adapted to accommodate the freeze-expansion of the liquid fill (e.g., by leaving adequate expansion space therein) and, of course, are arranged so as to effectively retain the liquid (e.g., by sealing the drums, capping the bottles or cans, etc.). Employment of such containers would not only solve a disposal problem but provide containers which are longer-lived and more stable (e.g., resistant to corrosion, leakage) than the aforedescribed pillow-tank or plastic bags. A related advantage is that such containers may be "second-hand," somewhat dirty, etc. and thus inexpensive; their use may also help alleviate waste disposal problems (e.g., used oil drums, discarded bottles, cans).

The phase-conversion containers may, in many instances, be otherwise housed also. For example, as opposed to placing the described pillow-tank inside the described inter-platform airspace (which, of course, relieves the tank of any top-loading from the facility above and eliminates the risk of pillow-tank rupture, leakage and resultant embankment subsidence), the circumstances of service may permit direct structural coupling of the "pillow" to the embankment and superstructure, so long as the slight rise and fall of the tank (with freeze/thaw) and of the entire embankment and facility it supports can be tolerated -- in which case the platforms would be eliminated with the pillow-tank replacing (or supplementing?) the entire "cooling shunt" structure. Here, the risk of rupture is, of course, accepted; however, if the full-tank thickness is only an inch or so (e.g., and a freeze-plug is used), the risk may be tolerable --especially where a plurality of such "thin" pillow-tanks is piled-up to provide the overall liquid volume contemplated. However, direct loading of smaller resilient containers like the recited bags will be less desirable since it will present the added risk of differential settlement. However, the described rigid containers may also be loaded directly, such as by burying sealed oil drums (partly-filled with water) in an embankment. Of course, the small plastic bags (or like resilient containers) may be housed in other various facility-supporting structures; for instance, the plastic bags may be nested within a honeycomb matrix of structural cellular plastic (e.g., rigid urethane, styrene foam or water-resistant fibre) fashioned to receive them and able to support the top-loading structures. More particularly, the bottom of the water-storage tank T–W of FIG. 1 may be provided with a base of rigid urethane foam (under the vinyl liner T–*v*) comprising a solid flat urethane sheet with bag-receiving pockets on the underside thereof and the recited water-bags nested therein. Alternatively, a simple metal grid (open-mesh surrounding bags conductively while supporting a continuous-sheet upper load such as a sheet of rigid urethane) may be used under a rigid support means. Other forms of such "phase-conversion" means and accessories therefore will be contemplated.

EXAMPLE 10

The arrangement of Examples 1 to 2 is constructed as described except that, while the gravel pad is being laid, it is so "wetted" with water and so compacted (or kept compacted -- with a minimum percent void) as to coat and wet at least a substantial percentage of the gravel particles with ice around the surface thereof, and so as to also fill a substantial portion of the interstitial spaces therebetween and thereby form a composite "ice-particulate" pad (assuming ambient conditions adequate to freeze the water film). This "wetting" must, however, not substantially "swell" the gravel layer and thus will not supply sufficient excess interstitial liquid to substantially move or separate the compacted particles mechanically -- the process thus constituting a "stable wetting" technique, which, after freezing and later thaw, will not yield any detrimental lift or subsidence effects. Thus, the particle size, and degree of compaction must be kept within limits (high "effective-density"; with low "percent-void") to provide adequate stability and liquid-retention capacity to the compacted-gravel pad (at least until "freeze-up" sets in). This is generally determinable according to the amount of the (initially) applied water retained in the gravel mass, after a certain time to allow for run-off of free, non-adsorbed liquid. Compaction (overall pad density or percent void) will not be so high as to prevent liquid from effectively percolating through the particle interstices and from "wetting" most of the particle surfaces. Once some, or all, of the 5-foot gravel pad is so "wetted" and then freezes (the particles thus

being coated with a thin film of ice -- or "rimed") with insulation superposed, the tank facility being placed thereon, etc.), it will be evident that a substantial heat-absorbing capacity is added to the foundation pad whereby, as the "thaw-front" proceeds down through the gravel so "rimed", it encounters a thermal impedance which is greatly amplified, since it must convert ice to water, replace the latent heat of fusion as it proceeds, and its progress is accordingly very greatly retarded. The result, of course, is a much extended "service time"; often enough to dispense with any need to refreeze. Of course, the "fusible filler" (where employed) will be melted thewhile and subject to loss (run-off, evaporation, etc.) unless "packaged" as above indicated. Thus, it will often be preferred to avoid any such packaged phase-conversion means and use only the described "riming" technique for introducing ice as a thaw front barrier (thermal impedance).

The enhancement of the warm-weather stability of embankments constructed as described will obviously be enormous though surprising in light of the simple means used. Moreover, workers will appreciate that, using the "rimed-gravel" technique, (even aside from whether the "wetting" moisture converts to ice) will provide a new and eminently useful embankment (gravel) material which has a prescribed, predictable homogeneous moisture content ("a wetted-gravel"). Using such can render particulate pads unlike any heretofore used in such circumstances, being not only "pre-moistened", but moistened to an unusually uniform degree to thus impart much more uniform, predictable thermal properties (e.g., compare a homogeneous moisture content of about 14 percent throughout the three-dimensions of gravel bank P–B in FIG. 1 with one which exhibits the indicated typical ranges of 5–14 percent moisture as in FIG. 4).

The attendant advantages are tremendous. Now, a "pad designer" can free himself from concern over varying moisture content when using virtually any kind of native gravel (e.g., he can ignore the moisture factors of the gravel regardless of "source" or its "shelf-time" and associated evaporative losses), and is liberated from the consequent variations in reliability and stability. Instead, he can calculate from a constant reliable "reference moisture" as though the pad gravel were artificially manufactured to his specifications.

Workers will also perceive various refinements of this "wetted embankment" construction. For instance, in some cases, a suitable interstitial moisture-absorber such as sawdust, may also be incorporated with the gravel particles. Moreover, in some cases, the "wetting" may be renewed after melting ("end-of-service"). This will at times be effected by removing overlying structures and re-moistening the gravel to the proper wetness, where feasible; or by incorporating a moisture-delivery duct system throughout the gravel thickness and introducing moisture through this at appropriate times. One may even employ an airduct system of the type described in the aforementioned Application where feasible, enabling the ducts thereof to perform a "re-moistening" function in addition to circulating coolant air. Also, in cases where gravel or other soil particulates are not desired as embankment material, other material may be substituted in certain cases, such as perforate mats of plastic webs, chipped non-degradable fines or other materials adopted to exhibit the necessary structural qualities and the designated moisture-penetration.

Likewise, the described phase conversion means may be employed, and/or modified, with or without the other described features or, in other, equivalent ways. Also, for cold weather facilities like those described it will be apparent that workers may, according to this teaching, employ other thermal impedance means and/or heat dissipation means to yield the described "rectitherm" effect, for instance, using just sufficient insulation to keep the frozen substrate from melting and NO MORE, lest the cooling thereof be impaired; and/or "cooling-shunt" means for this purpose; and/or the described "Finite Differencing Technique" for improved embankment design; and/or insulated embankment, the construction and material, of which are designated as a function of "service life", site ambient temperature history (especially deviations from the "norm" for the site), facility temperature and heat-input, geothermal heat, soil composition (especially moisture content), subsurface soil temperature profiles, or a combination of these, as well as other factors such as the initial thermal regime; and/or the cooling (refreeze) mode for the given embankment at the given site; and/or the provision of a particulate soil "transition-zone" under the facility designed to accommodate a prescribed "thaw-transit" (i.e., travel of "thaw-locus" as driven by environment heat-input); and/or the provision of artificial (e.g., urethane foam) insulation above this "transition-zone"; and/or the scheduling of prescribed times for service initiation or for refreeze or a prescribed insulation thickness corresponding thereto for the given facility and service conditions; and/or the provision, otherwise, of an "artificial active layer" (or "pseudo-turf") beneath such facilities, and/or the provision of an ice layer thereunder; and/or the alternation of a plurality of such facilities to take at least one thereof out of service for such cooling. In particular, workers may, according to features taught, employ a correlation of surface and subsurface temperatures for the site (soil) with conventional thermal data, for extended time periods (function of service life contemplated) to determine the amount of insulation (as optimized); and/or to determine the likely service time and/or refreeze time, this being recognized as widely advantageous, especially for a cost/benefit comparison of insulation thicknesses.

The foregoing features of invention will be understood as described only in exemplary emobidments and obviously applicable with other equivalent means and for analogous purposes, the scope of protection pertaining hereto being limited only by the appended claims. This is, it is obvious that various modifications of the structures and/or techniques taught herein may be made without departing from the spirit of the invention as defined in the appended claims. For example, equivalent elements and steps may be substituted for those described, parts may be reversed and various features may be used independently of other features, all without departing from the spirit of the invention.

What is claimed is:

1. A method which permits the long term continuous use of a heated liquid storage reservoir in permafrost regions said reservoir being supported by frozen terrain and being thermally insulated from said terrain by a thermal barrier comprised of a layer of synthetic thermal insulation, said method comprising the steps of:

a. Storing heated liquid in the reservoir until the thaw front resulting from the transmission of heat from the heated liquid downwardly through the frozen terrain extends to a predetermined depth,

b. Removing substantially all of the heated liquid from the reservoir, and

c. Permitting the terrain beneath the reservoir to refreeze.

2. The method of claim **1** wherein the layer of synthetic thermal insulation is sufficiently thick to permit the reservoir to be continuously used for several years without the necessity of refreezing the underlying terrain.

3. The method of claim **1** wherein the heated liquid is water.

4. The method of claim **1** wherein said thermal barrier includes a layer of gravel.

5. The method of claim **4** wherein the constitution and thickness of said thermal barrier is such as to provide a reservoir use period of 4 to 9 years and a refreeze period of 3 to 6 winter months.

6. The method of claim **4** wherein said gravel layer is 4 to 6 feet thick.

7. The method of claim **6** wherein said layer of synthetic insulation is 2 to 4 inches thick.

8. The method of claim **1** wherein said synthetic thermal insulation is foamed polyurethane.

9. The method of claim **1** wherein two or more storage reservoirs are employed together and cycled such that at least one reservoir is in use when another is out of service for refreezing the terrain lying thereunder.

10. The method of claim **1** wherein said thermal barrier includes a heat dissipating means.

11. The method of claim **10** wherein said heat dissipating means comprises a cooling shunt means.

12. A method which permits the long term continuous use of a heat emitting liquid storage system comprised of a plurality of liquid storage reservoirs supported upon frozen terrain in polar regions without excessively melting and thereby destroying the support for the reservoirs, said reservoirs being thermally insulated from said frozen terrain by a thermal barrier comprised of a layer of gravel and a layer of synthetic thermal insulation, said method comprising using each reservoir on a given cycle comprised of an in service period and a refreeze period the cycles being such that when one of the reservoirs is on the refreeze period another is on the in service period so that the system as a whole provides continuous service.

* * * * *