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SEASONAL HEAT STORAGE IN UNDERGROUND WARM WATER PIT (DESIGN OF A 30.-50,000 m^3 STORAGE)

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Summary

Under contract ESA-S-162-DK(G) covering theoretical calculations and actual measurements during pilot operation with an underground 500 m^3 warm water store valuable experience and valuable agreement between theory and reality was obtained on which dimensioning and design of a 30-50.000 m^3 seasonal heat storage as an underground warm water store could be based. In order to take full advantage of the above mentioned research, the work on the present contract has been delayed three month. Thus final designs will not be available until October 1st, 1983.

The aim of the project is to design a 30-50.000 m^3 seasonal heat storage executed as a warm water pit, which is partly dug into the ground, partly constructed above the ground by placing the excavated dirt in embankments. The soil interfaces of the pit are assumed to be uninsulated in order to lower the construction cost. The lid on the pit is assumed to be floating and made from foam plastic insulation protected against the moisture from the pit and the climate in a suitable way.

In order to secure a realistic design a series of prospective users of such a pit has been contacted and a district heating system with a coupling to an electric power plant and a possible interest in seasonal storage of heat has been selected as supplier of the design data, from which the pit design can proceed. The district heating system selected has declared a serious interest in investigating a realization of the design when completed.

This paper deals with certain of the design considerations completed so far under this contract.

1. The pit geometry in relation to efficiency and economy.

In order to facilitate the design and location of a 30-50.000 m^3 warm water pit a thorough analysis of the geometry affecting the thermal efficiency and the cost of construction has been undertaken. The analysis included the hemisphere, the sphere-cap, the cylinder, the frustum of a pyramid and the frustum of a cone.

The characteristic dimensions called R was taken as the radius of the circular lid on all pits except the pyramid pits, where half of the length of the side of the lid was denominated R. For all the shapes studied the relation between the volume and the characteristic dimension was expressed denoting the depth of the pit as αR.

As the interface between the pit and the soil is assumed uninsulated, the heat loss from this interface is considerable compared to the loss through the lid. Consequently, the thermal efficiency for large pits is primarily determined by the ratio of the area of the interface with the soil and the volume of the pit.

Denoting this ratio ω this means

$$\omega = \frac{A}{V}$$

where A is the surface of the interface and V is the volume of the pit.

The hemisphere being the most economic shape has the surface coefficient ω varying from 0.18 at 10.000 m^3 to 0.08 at 100.000 m^3. R varies from 18 m to 37 m. Changing to the sphere-cap and using $\alpha = 0.3$ ω varies from 0.26 to 0.12 as the volume increases from 10.000 m^3 to 100.000 m^3 and R varies from 28 m to 59 m.

For the cylinder the minimum ω is obtained, where $\alpha = 1$. Here ω will vary from 0.205 to 0.095 as the volume increases from 10.000 m^3 to 100.000 m^3.

For the frustum of a cone with a slope of 1:2 and $\alpha = 0.3$ ω varies from 0.255 to 0.120 as the volume increases from 10.000 m^3 to 100.000 m^3. R is increased from 27 m to 59 m and the depth varies from 8.1 to 17.7 (see Fig. 1.). For a certain volume the figures relating to the frustum of a pyramid will be about 10% larger than figures relating to a frustum of a cone.

For the frustum of a cone the design for varying a and α which would equalize the amount of dirt excavated with the amount of dirt deposited in the embankments of the pit was studied. It was assumed that the crown of the embankment would remain 5 m and that the slope of outside of the embankment would remain 1:1.5.

If the slope of the pit walls are taken as a = 2.0 and $\alpha = 0.3$ the depth of excavation below ground level (Z) for the frustum of a cone will vary from 5.5 m to 10.8 m as the volume is increased from 10.000 m^3 to 100.000 m^3. (see Fig. 2.).

It should be noted that a change in a from 2.0 to 1.5 improves the ω by almost 10% and reduces R by about 10%. Similarly Z is reduced about 10%. The value of a can not be selected arbitrarily as will be further discussed in the following chapter.

It should finally be noted that for the frustum of cones and pyramids the coefficient ω is very close to the optimal value (α = 0.45) when α = 0.3 is selected. Thus, the depth of a pit will vary between 9 and 18 m as the volume varies between 10.000 m^3 and 100.000 m^3.

2. Soil mechanical problems.

The soil interface is supposed to be uninsulated. This could make it a desirable possibility, that the water tightness of the pit could be achieved without a liner. Leaving out the use of a liner will contribute to a lower construction cost but the elimination of the liner will place a need for increased attention on the solutions of the soil mechanical problems involved in construction of water tight embankments and dugouts.

The fluid loss through the interface with the soil must be limited to an amount which will make the corresponding heat loss acceptable. A loss of 1% per year would seem to be acceptable.

The fluid loss from an unlined water reservoir depends on:

- the hydraulic conductivity of the surrounding soil
- the viscosity of the fluid stored (temperature dependant)
- the level of the fluid in the reservoir
- the level of the ground water table in the area

Assuming that the ground water table is located far below the bottom of the pit the above mentioned max. yearly loss will lead to a coefficient of permeability of the soil (using a pit of 50.000 m^3 and pure 10°C water) $k_{10} \leqq 2x10^{-10}$m/sec. If the ground water table is close to the ground level the fluid loss can be determined by construction of a stream net (see Fig.3.). This lead to a required premeability of $k_{10} \leqq 4x10^{-9}$m/sec.

These investigations have been carried through by the Danish Geotechnical Institute (3). The conclusion is that the dugout part of the pit as well as the embankments must be constructed in clay. ($k_{10} < 10^{-10}$m/sec.). Clays fulfilling this requirement are quite common in Denmark. During the detailed design based on the chosen location further laboratory tests will help determine the slope of the sides of the pit, which will secure stability permanently during the heat storage operations. Thus, these test results will determine the final slope of the side walls of the frustum of a cone selected as the final design.

3. The remedy of interface imperfections.

Most clay deposits in Denmark can be expected to contain streaks of silty deposits. These weaknesses must be remedied during the

construction.

Pits for cold water as well as for waste of different kinds have been constructed in soils with insufficient impermeability. Using a liner in such structures the water tightness and the safety rest entirely on the quality of the liner applied and on the craftsmanship and production control applied during execution. The special requirements of the liners in warm water pits limit the choice of material considerably. At the moment membranes produced from high density polyethylene (HDPE) seem to show good durability under accelerated testing at temperatures clear up to 90°C.

Such a HDPE-liner was used in a thickness of 2.5 mm in the pilot plant of 500 m^3 forming the background for this design work.

Many pits for storage of waste have been made watertight by application of a volcanic clay to the soil interface. "Bentonite" is a sealant produced from a volcanic clay containing a special type of strongly swelling sodium montmorillonite. The unique molecular structure of this compound accounts for the extraordinary ability to absorbe many times its own weight of water.

When "Bentonite" is mixed into the top surface of the dugout and the embankments of the pit and watered and compacted all voids are filled and the surface is turned into a tough leather-like mastic impeding the flow of water through the soil interfaces.

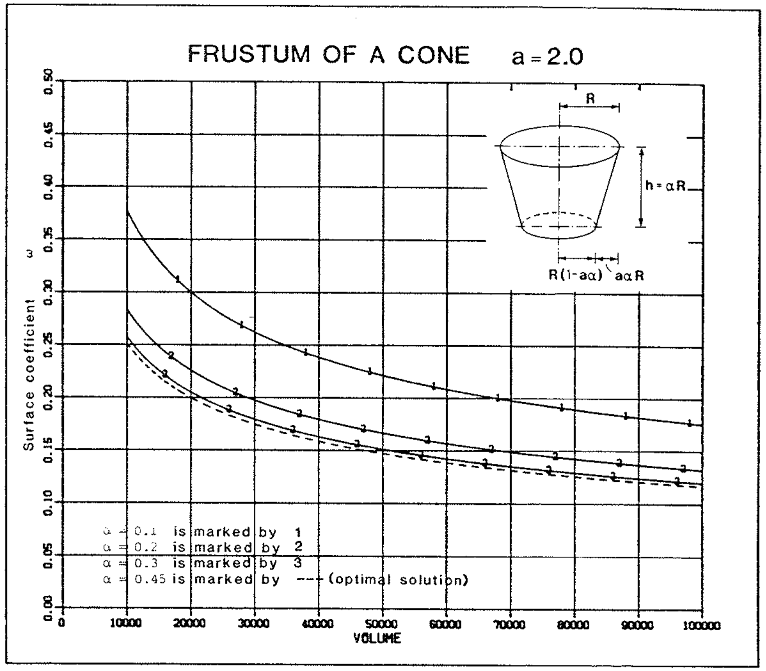
This technology is being further investigated, as it appears likely that water tightness can be achieved in this way at about half the price of the HDPE-liners.

The "Bentonite" solution can be compared to solutions where the bottom and the walls are constructed by redeposited compacted clays excavated on site. This will of course assume that the pit is located in an area with suitable clays.

In Denmark many deposits of glacial clays make such a solution possible.

It should be noted that large warm water pits will be less in risk of failure, if the water tightness and the stability of the structure is based on a suitably constructed clay pit. Thus, a clay solution may be sought even for structures, where HDPE-liner is applied to increase the safety of the structure.

Applications of large warm water pits in large district heating systems for seasonal storage of waste heat as well as for rational operations of heating plants may demand the use of a liner in order to secure chemical stability of the water circulating in the district heating system. A liner with the prime purpose of securing the water quality may be much thinner and thus less expensive, if the safety of the structure is secured by clays. The problems are being studied further in the detailing of the design.



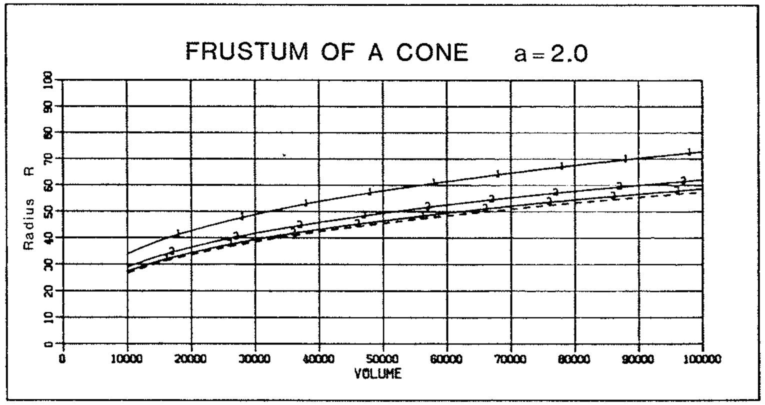
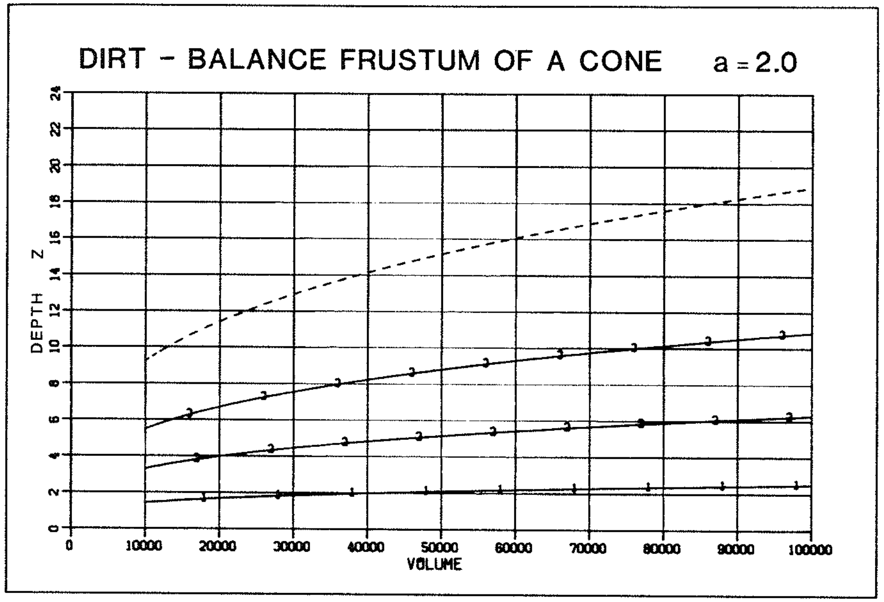


Figure 1a and 1b.

Figure 1a shows the surface coefficient ω while figure 1b shows the characteristic parameter R, both as a function of volume. The slope is chosen as a=2.



α = 0,1 is marked by 1
α = 0,2 is marked by 2
α = 0,3 is marked by 3
α = 0,45 is marked by ---
(optimal solution)

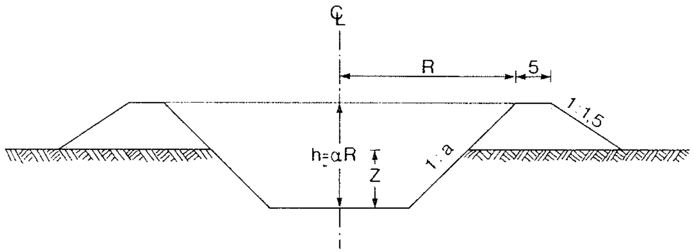


Figure 2. The depth Z as a function of the volume giving dirt balance with a conical geometry. The slope is chosen as a = 2.

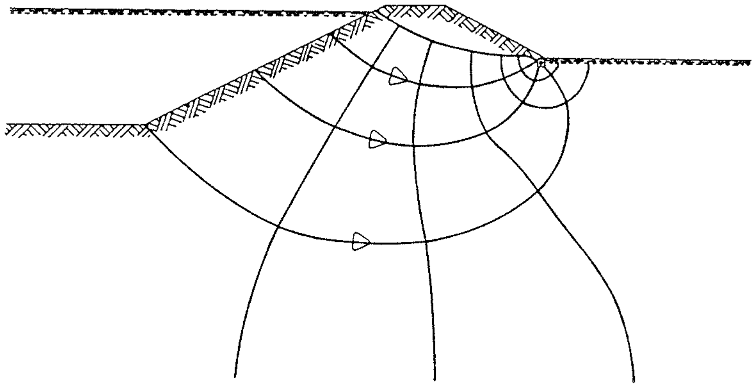


Figure 3. For a ground water level at the ground level the fluid loss is determined by constructing a stream net.

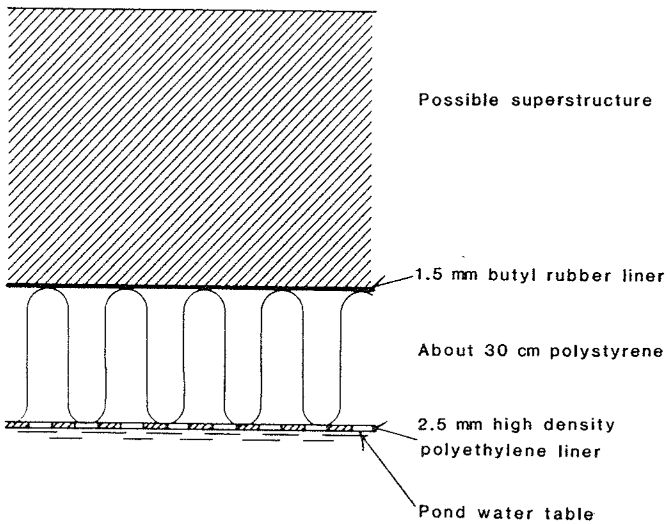


Figure 4. The principle in the floating lid.

4. Design considerations concerning the floating lid.

Fig. 4 shows the construction principle for the floating lid. The lid is heat insulated by about 0.3 m of polystyrene foam. This foam is protected against vapor from the pit by the use of a bottom sheet of high density polyethylene (HDPE-plastic) liner. The topside of the heat insulation is protected against the outside climate by the use of a 1.5 mm butyl rubber liner. On top of the foam clay may be deposited to safeguard against oxygen diffusion towards the pit water. On top of the clay a layer of topsoil placed on a layer of gravel for drainage may be arranged thus making the appearance of the lid acceptable from the point of view of the townplanner.

The vapor resistance of the HDPE liner must greatly exceed the vapor resistance of the rubber topliner in order to safeguard against moisture accumulation in the insulation.

5. Concluding remarks concerning certain design considerations completed so far.

The design considerations dealt with above are only a part of the design considerations needed in this project. Problems relating to geotechnical stability of embankments in relation to temperatures, to the embedment of the bottom liner of the lid in the pit edge, to the airfree circulation of the pit water, as well as the problems relating to the adaption of the structure to the volume change with temperature changes as well as the problems related to the loading and unloading of the storage with hot water, will be dealt with during the completion of the project.

6. Literature.

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