OIL STORAGE TANK FOUNDATIONS

By Irving E. Boberg, Chief Engineer

Too often the importance of foundations is underestimated. Since the flat bottomed oil tank is one of the simplest types of structure and has sufficient flexibility to accommodate appreciable changes in shape, the foundation on which it rests is frequently given little consideration.

With the advent of larger and higher tanks, the effects of poor foundations were multiplied. The larger tank not only imposes a heavier load and hence causes greater settlements, but the distortion caused by any given settlement is, in some measure, proportional to the size of the tank.

In addition, the floating roof user has become increasingly conscious of the importance of a shoe-to-shell fit that is as nearly perfect as possible. It must be obvious that perfection can best be attained if the tank shell is built circular and remains circular within reasonable limits.

If the grade is not level in the beginning, or if it later settles unevenly, the tank will inevitably have a distorted shell. Often the tank builder is blamed for a poor shell that should properly be charged to a poor foundation. In order to obtain good tanks, good foundations must be provided.

Proper grade preparation can also have an important bearing on bottom corrosion. Tanks erected on poorly drained grades, directly contacting corrosive soils or on heterogeneous mixtures of different types of soils, are all subject to electrolytic attack on the bottom side.

There is no rule of thumb that can be applied to all situations. Each case must be evaluated on the basis of conditions as they exist. Local conditions vary so widely that it would be impossible to anticipate them all. An attempt has been made in the material that follows to deal with the more common aspects of tank foundation design.

In selecting the proper type of foundation, the bearing power of the soil is the primary factor. Where no previous experience in the same area is available, soil borings to determine existing conditions are usually cheap insurance against future trouble. We have seen a number of instances where tank sites were judged solely from surface conditions only to have the empty tanks settle so seriously during construction that the water test could not be performed until the foundation was rectified. With the tanks already erected, this could only be accomplished at great expense.

We know of one instance where a tank settled under water test to such an extent that it collapsed.

While these are extremes, they serve to illustrate the importance of first knowing the nature of the foundation base. Knowledge of geological formation or experience with other heavy structures in the same vicinity will often suffice, but if such knowledge is absent, soil borings are the safest means of investigation. There are many firms over the country well skilled in the art of making such borings. Soil bearing tests are now generally conceded to have little value other than to evaluate conditions at the tested level. The depth to which an applied load will produce significant stresses is in some measure proportional to the size of the loaded area. A large tank fully loaded will probe out weaknesses never revealed by a test on 1 or 2 square feet.

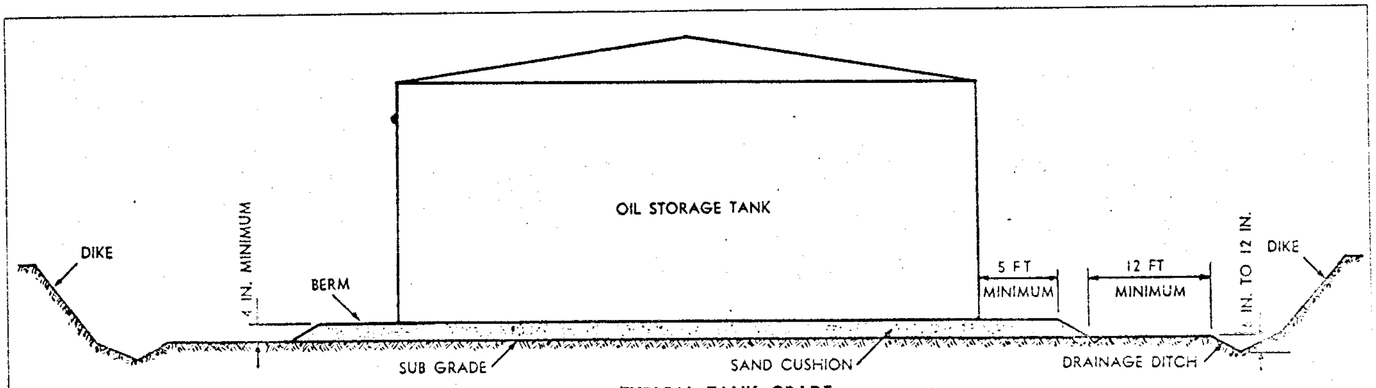
Frequently the result of borings will indicate the desirability of limiting tank height rather than the expense of costly foundations.

Assuming that bearing conditions have been determined to be adequate, the simplest form of foundation is a sand pad laid directly on the earth. All loam or organic material should be removed and replaced with suitable material, well compacted. Often a satisfactory fill material is available at the site. If not, bank run gravel is excellent and is readily compacted.

The grade for the tank should preferably be elevated slightly above the surrounding terrain to insure drainage. Sufficient berm should be provided to prevent washing and weathering under the tank shell. The berm width should be at least 5 feet. Weathering can be minimized if the berm is subsequently protected with trap rock, gravel, or an asphaltic flashing.

It is customary to provide a crown of about 1 in. for each 10 ft. of radius. On large tanks, the crown is sometimes limited to 6 in.

The sand pad should be at least



TYPICAL TANK GRADE

Before placing sand cushion, all loam or other organic material should be removed from the original surface and replaced with well-rolled fill. Frequently the entire area is stripped and the strippings used in constructing the firewall. Berm should be protected against weather with trap rock, gravel or asphalt flashing.

4 in. deep. The sand should be clean and free from corrosive elements. Care should be taken to exclude clay or lumps of earth from coming into contact with the bottom. Frequently the difference in potential between two types of earth will set up an electrolytic cell with resultant pitting.

Sometimes crushed rock is substituted for sand, but sand is easier to grade and usually more available.

While there is some difference of opinion, it is considered desirable to oil a sand grade. It is not satisfactory to merely pour oil on the surface because it will not penetrate or mix with the sand. Subsequent laying of the bottom will be difficult and welding is likely to start a fire. Oil and sand should be thoroughly mixed either in a concrete mixer or by windrowing with a grader or by hand. Only sufficient oil should be used to thoroughly wet the sand. Excess free oil will make subsequent working on the grade both difficult and hazardous.

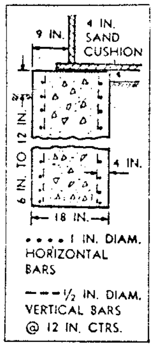
If the sand cushion is placed on top of crushed rock fill, the rock should be carefully graded from coarse at the bottom to fine at the top. If this is not done, the sand will percolate down through the voids in the coarser rock.

An excellent base can also be obtained by substituting about 1½ in. of asphalt road paving mix for the sand cushion. This material is available from ready mix plants in many sections of the country. There is one precaution that must be carefully watched. After the material has set up, it is difficult if not impossible for the tank builder to correct inaccuracies by taking down the high and filling in the low spots. It is, therefore, most important that a paved tank grade be levelled with extreme accuracy under the shell.

Drainage is important both from the standpoint of soil stability and bottom corrosion. Good drainage should be provided not only under the tank itself, but the general area should preferably be well drained. Where the terrain does not afford natural drainage, proper ditching around a group of tanks may help to correct the deficiency.

Where suitable bearing soil is not available at the surface, but is available a reasonable distance below the surface, a ring wall foundation is indicated. The purpose of the ring is to confine the soil and prevent lateral

Design of Ring Wall for 150 Ft. Diam. by 48 Ft. Floating Roof Tank Storing Gasoline



W = steel weight on wall = 1320 lbs. per ft.

H = height of shell = 48 ft.

h = height of ring wall = 5 ft. (assumed 4 ft. frost line and 1 ft. above grade)

q = weight of stored product = 45 lbs. per cu. ft.

$$T \text{ (thickness of wall)} = \frac{24W}{qH - 80h} = 18 \text{ in.}$$

Horizontal pressure on ring = 5 x 0.3 [(62.5 x 48) + (100 x 2.5)] = 4875 lb. per ft. of wall

Total hoop tension = PR = 4875 x 75 = 366000 lbs.

$$\text{Required area of hoop steel} = \frac{366000}{20000} = 18.3 \text{ sq. in.}$$

Use 24 bars 1 in. diam.

NOTES

Ring wall to be founded below frost line.

Note that weight of stored product was used in determining T, whereas weight of water was used in determining reinforcing steel. It is believed that settlement is a factor of time as well as loading, and that in most cases the long term loading is more significant than the temporary water load under test. On the other hand the hoop tension due to water test load must be taken into account to avoid cracking of wall.

Where the characteristics of the confined soil are known, the designer should use the correct ratio between vertical and horizontal pressures rather than the safe limit of 0.3 used above.

For the shallow wall illustrated, the hoop tension was assumed uniform from top to bottom of wall. For high walls, the increase in lateral pressure with depth would require closer steel spacing at the bottom than at the top.

movement. The ring wall is founded in the firm stratum and confines the weaker materials. Totally inadequate material should be removed and replaced with well compacted fill.

Many tank owners use ring wall construction as standard even when soil conditions do not indicate its use. There are a number of advantages in this practice that may well compensate for the added cost. The incidental advantages of the ring wall are neat appearance, an excellent foundation for the tank shell, the elimination of washing and weathering of berms, and the exclusion of surface water running into the grade.

We recommend that ring walls be so proportioned that the unit soil bearing at the level of the bottom of the wall is the same under the concrete as under the confined soil. This can be accomplished and will encourage uniform settlement of the foundation as a whole.

Assuming the tank shell to be centered on the wall, and earth to weigh 100 lbs. and concrete 140 lbs. per cubic foot, the thickness of the concrete wall may be determined from the following formula:

$$\text{Thickness of wall in inches} = \frac{24W}{qH - 80h}$$

Where W = weight of metal in shell and roof supported on the ring wall in lbs. per ft. of circumference.
H = height of tank shell in ft.
h = height of ring wall in ft.
q = weight of stored product lbs. per cu. ft.

In no case should the ring wall be less than 8 in. thick.

On tanks of relatively small diameter, the formula will result in ring walls less than 8 in. thick, in which case the 8 in. minimum should be used as the closest approach to the desired ideal.

Where a ring wall is used, it should be reinforced circumferentially to resist the hoop stress resulting from lateral pressure of the confined earth. Because soil conditions are rarely known in advance, it is our practice to design such walls on the basis of a lateral pressure equal to 0.3 of the combined liquid and earth vertical pressure. For shallow rings the vertical load contributed by the earth is small, but on deep walls it can become important.

If there are openings in the wall, the reinforcing must be carried around such openings to preserve the continuity of the hoop action. Nominal vertical steel is normally provided primarily for convenience in placing hoop steel.

Through the years there has been considerable discussion of the merits of placing the tank shell on the concrete versus placing the tank entirely within the ring wall. For many years we contended that the tank should not rest on the wall. It was feared that if settlement was greater within the wall than under the wall, failure of the bottom could occur.

On a carelessly prepared grade, this could happen and has happened. It has been our observation, however, that hundreds, if not thousands, of tanks have been successfully erected on ring walls. There are distinct advantages to so doing. It gives the erector a better base on which to build and there is less danger of subsequent shell settlement and distortion. The ring wall is not only founded on better soil than exists near the surface, but there is no danger of erosion under the shell.

We have, therefore, changed our opinion and now recommend ring wall construction with the tank shell resting on the wall, provided the following precautions are taken:

1. Proportion the ring wall so that soil pressures under the entire tank and wall are equal at the level of the wall base. The base of the wall should be below frost line.

2. Pour the ring wall against undisturbed earth without forms if possible. If this is not possible, see to it that backfill both inside and outside of the wall is thoroughly tamped in place. This is particularly important during cold weather when fill material may be frozen. If this is not conscientiously done inside the wall, serious settlement along the wall can damage the bottom.

3. The top of the ring wall must be level. This point is frequently overlooked. It is not generally realized what large shell deformations can arise from relatively small differences in ring wall elevation. If the wall is out of level, the erector has no choice other than to erect on shims which involves the placing and maintenance of grout. Experience has shown that it is possible to insist on and obtain accurately levelled walls. A desirable criterion is that the wall shall be level within 1/4 in. (plus or minus 1/8 in.) in one plate length (about 34 ft.), and that no two points on the wall shall differ in elevation by more than 1/2 in. (plus or minus 1/4 in.). This may sound unduly restrictive, but it can be attained and will pay dividends.

In some cases, several layers of heavy asphalt felt roofing are placed on top of the ring wall under the edge of the tank. This practice has merit in that it seals off the periphery The bottom joint breakdowns or backup strips settle into the felt and thus the effect of point bearing at bottom joints is minimized.

There are, of course, many pitfalls to be avoided in grade construction. If possible, always avoid situations where a tank rests partly on cut and partly on fill. If it cannot be avoided, see to it that the fill is of a readily compactible material and that it is well compacted. Be sure the fill is retained against lateral movement either by an adequate berm or a concrete ring.

The same caution applies to locations where rock occurs near the surface. Be sure the rock is under the entire tank and that the earth overburden is reasonably uniform in depth. Frequently rock strata will end abruptly and a good criterion is to locate tanks so they are entirely over rock, or entirely off of rock.

Where soil conditions are such that none of the simpler foundation types are adaptable, piled foundations or other special types will require individual consideration for each case.