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THE ADVISORY COMMISSION TO THE COUNCIL OF NATIONAL DEFENSE

FEDERAL RESERVE BUILDING

WASHINGTON, D. C.

November 26, 1940

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MEMORANDUM TO THE PRESIDENT

From: E. R. Stettinius, Jr.

Subject: UNDERGROUND STORAGE OF AVIATION GASOLINE

The Engineers' Committee from industry called together by this Division to advise the Army and Navy on the storage of aviation gasoline has submitted its report. Its recommendations bring together the combined experience of the industry, outside ideas from industry and the public, results of plant visitations with Army and Navy representatives, and consultations on current British experience.

Basis of recommendations:

Provision for storage of reserve stock at a reasonable cost near several alternative methods of transportation with protection against easy or complete destruction.

Storage adequate to supply peak demands and tie over the destruction of the source, as production facilities are open, subject to attack, and take long to replace.

Protection of storage only against incendiaries and bomb fragments, as complete bomb-proofing is too expensive and unnecessary.

Recommendations:

1. Simple cylindrical tank between 20 and 30 feet high designed for adaptability to diverse conditions - average capacity 25,000 barrels per tank, cost about $45,000, or $1.67 per barrel net capacity.

2. Tanks buried underground with 4 feet of earth over tank, that is enough to support vegetation and assure concealment, and a 9 inch concrete slab immediately on top of the tank itself.

3. Tanks arranged in farms with an irregular or circular layout to avoid destruction by a string of bombs - cost, a farm of eight (typical arrangement), completely equipped, $620,000, or $2.90 per barrel net capacity.

4. Each tank in group supplied with duplicate pipe lines with looped connections providing for transfer of gasoline no matter what single part of the system is damaged; also pumps, auxiliaries, and a protected electric power supply to assure continuous availability.

5. Separate ethyl blending plant located above ground for the safety of workers. Separation necessary since deterioration takes place after ethyl is mixed and allowed to stand in storage.

The report considered numerous alternative methods of storage such as: mines, caves, solid rock, canyons and cliffs, underwater, hillside, pipe line, drums, bomb deflectors and camouflage.

The report contains complete details and drawings of several types of tanks, including the design of tank farms with piping arrangements, pumps, power equipment, fire protection, and complete directions to assure lowest practical maintenance and operating cost.

The report has been submitted to the various interested military services. It can be turned over by them to the construction contractors for the erection of the suggested storage facilities at the points which the Army and Navy may indicate as desirable storage locations.

Service Action on Recommendations. The joint Army and Navy Aeronautical Board has approved the conclusions on type of storage for the use of the Services. The Army is awaiting approval of the gasoline purchasing program before selecting storage sites. Some preliminary Army site selection has been done in the western Pennsylvania area. An old mine and a limestone quarry have been tentatively selected as possible sites in which this type of storage is to be erected.

The Navy is planning to use this storage arrangement in its outlying bases and has given out these specifications to contractors who are to bid on the construction of the tanks at the outlying bases.

E. R. Stettinius, Jr.

PSF: Council of National Defense

19

REPORT

on

UNDERGROUND TANKAGE FOR AVIATION GASOLINE

from the

ENGINEERS' COMMITTEE ON OIL STORAGE

to the

PETROLEUM SECTION

ADVISORY COMMISSION TO THE COUNCIL OF NATIONAL DEFENSE

OCTOBER 1940.

REPORT

on

UNDERGROUND TANKAGE

FOR AVIATION GASOLINE

from the

ENGINEERS' COMMITTEE ON OIL STORAGE

October 1940

Table of Contents

	Page
Introduction and Summary	1
Cost of Tanks	2
Cost of Storage Center Complete	3
Detailed Design of Tankage	4
Assumptions Suggested to Committee	4
Assumptions made by Committee	5
Assistance Rendered by Manufacturers	7
Specifications Used for Comparative Purposes	8
Comparison of Designs	12
Shell Design	13
Vertical Bracing	13
Circular Girder Bracing	15
Specifications for Circular Girder Bracing	16
Girder and Beam Bracing	18
Arch and Stiffener Bracing (recommended)	19
Special Designs	21
Polyconic	21
Scalloped	22
Concrete	23
Roof Construction and Support	23
Conventional Design	24
Toothpick Design	25
Basket Design	26
Comparison of Advantages	27
Comparison of Advantages (Table)	29
Alternate Designs	30
Reservoir Type	30
Foreign Designs	32
Corrosion Protection	32
Conclusion from Design Study	35
Layout of Storage Centers	36
Pipe Lines	36
Valves	37
Alternate Piping Design Considered	39
Pumps and Tank Appurtenances	41
Pumps and Motors	41
Relief Valves	43
Gaging Facilities	44
Ethyl Blending Plant	45
Auxiliary Power Plant	46
Fire Protection	48

	Page
Appendix	A1
Storage in Mines and Caves	A1
Storage in Drums	A1
Underwater Storage	A3
Storage in Solid Rock	A5
Pipe Line Storage	A5
Hillside Storage	A5
Cliffs and Canyons	A6
Bomb Deflectors and Camouflage	A6
Drawings	Dwg. No.
Load Diagrams for Underground Tank	1
Underground Tank for Aviation Gasoline	2
Alternate Shell Designs	3
Fig. 1 - Vertical Bracing	
Fig. 2 - One Type of Combined Bracing	
Alternate Shell Designs	4
Fig. 3 - Ring Girder Bracing	
Fig. 4 - Another Design of Ring Bracing	
Alternate Shell Designs	5
Fig. 5 - Scallop Design	
Fig. 6 - Polyconic Design	
Alternate Shell Design	5-A
Fig. 7 - Ring Girder and Beam Design	
Steel Lined Circular Underground Concrete Tank	6
Steel Lined Underground Reservoir	7
Alternate Types of Column Design	8
Fig. 8 - Toothpick Columns	
Fig. 9 - Basket Columns	
Diagrammatic Layout for Four Underground Tanks	9
Diagrammatic Layout for Eight Underground Tanks	10
Diagram of typical Cathodic Protection for 8 underground tanks	11

DESIGN OF UNDERGROUND STORAGE FOR AVIATION GASOLINE

This report covers the design of reserve tankage to be constructed by the Government for storing aviation gasoline underground, and the general layout of storage centers. It does not cover small tanks such as those used at airports for fueling airplanes, but one or more tanks of the type considered might be located near an airport and used for refilling the working tankage.

The tank designs considered are based on a comparatively light cover suitable for concealment and protection from light incendiary bombs and bomb fragments, but not for protection against direct hits by heavy bombs. The same type of construction could, however, be made suitable for deeper cover up to at least twenty-five feet by using more steel. The detailed studies that have been made are based on tanks having a capacity of approximately 25,000 barrels, but the same type of design would be suitable for tanks having any capacity between 10,000 and 50,000 barrels, a range that should cover most of the needs now in sight.

Some other types of tankage are very briefly discussed in the appendix.

SUMMARIZED CONCLUSIONS

Tanks

There are several kinds of tanks that would be suitable for storing gasoline underground, and within reasonable limits they all require about the same amount of steel and do not differ much in cost. The most practical and economical design, however, is believed to be the one having the form of a vertical cylinder between 20 and 30 feet in depth with a plain steel shell, capable of taking internal pressure, and braced against collapse from external earth pressure by a combination of horizontal and vertical stiffening members. Such a tank is shown in drawing No. 2. The roof is flat, and the bottom is slightly sloped toward the center.

The roof is supported by a column structure and is covered by a concrete slab. The bottom rests on a concrete slab, and with the design shown, is anchored to it at intervals. The column and roof structure shown is conventional and recommended for immediate use. An alternate type of construction, however, has been suggested for test and, if approved, offers some economies in construction, especially where high ground water prevails. The alternate column construction would permit either or both concrete slabs to be eliminated under favorable soil conditions.

Concrete tanks, unless lined with steel, are not recommended for gasoline service.

The cost of a 27,000 barrel tank of the type recommended is roughly estimated as follows:

Excavation 11,210 cu.yd. @ 50¢	$5,600.00
Botton slab 291 cu.yd.@ $20.	5,800.00
Steel tank structure	23,400.00
Top slab 218 cu.yd.@ $20.	4,400.00
Protective coating	1,300.00
Backfilling,cleaning up and landscaping	4,500.00
	$45,000.00

or about $1.67 per barrel net capacity.

Layout of storage centers.

Diagrammatic layouts of storage centers are shown in drawings No.9 and No. 10.

It is recommended that the tanks be arranged in a generally circular plan, the circle of course being broken or varied to suit local conditions. Duplicate pipe lines with looped connections provide for transferring gasoline, no matter what single part of the system is damaged.

To avoid suction troubles and eliminate deep tunnels for pipe lines, which are both expensive and hazardous, individual submerged vertical pumps are recommended for each tank. A duplicate electric power supply is necessary. One source may be a utility service, but the other should be an installation of small generators driven by gasoline engines.

On account of the hazard involved in placing an Ethyl blending plant underground, it is recommended that such plants, if possible, be placed above ground and well hidden or camouflaged.

The cost of a storage center of eight tanks totalling 216,000 barrels, similar to the one shown on drawing No.10 is roughly estimated as follows:

Land, 72 acres	$14,000.00
Tanks 8 @ $45,000.	380,000.00
Pumps and tank appurtenances	20,000.00
Piping system complete	40,000.00
Electric power wiring	20,000.00
Auxiliary power plant	15,000.00
Cathodic protection system	8,000.00
Ethyl blending plant	18,000.00
Planting and camouflage	10,000.00
Water supply, etc.	15,000.00
Dock or loading facilities	30,000.00
Contingencies and miscellaneous	50,000.00
	$ 620,000.00

Approximate cost per barrel $2.90.

DETAILED DESIGN OF TANKAGE

In arriving at the general requirements for gasoline storage we have been guided, first, by the opinions and suggestions offered by the Army and Navy officers and other experts in various conferences, and second, by our own experience and analyses. Our memorandum of September 18th outlined several requirements developed from the comments of the Army and Navy officers with whom we had conferred. The requirements were:

1. All Government reserve aviation gasoline tankage should be underground.
2. Bomb-proof tankage would require an impractical amount of cover; therefore, concealment and protection from light incendiary bombs and bomb fragments are all that can be reasonably provided for.
3. A cover of approximately four feet of earth over a 9" concrete slab will serve to give this concealment and protection and will be sufficient to support vegetation over the tanks without discoloration that would reveal their position.
4. A maximum tank diameter of approximately 100 feet is desirable to keep the size of the target to a practical minimum.
5. Capacities of tanks should range from 10,000 barrels to 50,000 barrels. (All barrels considered here are of 42 U. S. gallons or 5.615 cubic feet.)
6. Tanks should be spaced in an irregular pattern with a minimum distance from shell to shell of 200 feet.

Since September 18th we have had the opportunity of learning something about the experience with gasoline tankage in Europe. In general this further information serves to confirm the assumptions just outlined. However, we have been informed that some of the European tankage has been effectively concealed with only 2½ feet of earth cover over a 6" concrete slab. The difference in cost would amount to approximately 11¢ per barrel, and the Services may therefore want to consider this modification, although the additional depth is very convenient if not essential for concealing the pump and piping.

Various discussions have brought out a consensus of the committee regarding the following additional conditions for design and construction.

1. Concrete tankage unless completely steel lined is unsuitable for gasoline storage. Concrete is always subject to cracks due to unequal settlement and is not resistant to concussion. Gasoline will easily penetrate small cracks. This conclusion has been reached after consideration of the possibilities of the so-called pre-stressed design and of the effect of supposedly gasoline-resistant paints and dopes for sealing off small shrinkage cracks.
2. While the hydraulic system may have many advantages for small tanks such as those used for fueling planes at airports, it cannot be recommended for reserve storage, except perhaps in special circumstances. It will result in a considerable increase in cost, largely owing to the necessity of providing for a higher internal working pressure and for a suitable and duplicate supply of water, as well as for duplicate water lines. It offers virtually nothing in the way of added fire protection nor protection of the gasoline from deterioration, and there is even some suspicion that it may,

over a long period of time, react unfavorably with Ethyl fluid or inhibitors. Its advantage in delivering clean, dry gasoline may be paramount in airport fueling systems, but is of only secondary importance for reserve storage. Though generally understood, it may be pointed out that the vapor-air mixture above the gasoline in underground storage will be too rich to explode or take fire except on rare occasions and only while a tank is being emptied rapidly. Evaporation loss in underground tankage, except during filling, will be virtually nil in any case. Owing to the excellent insulation inherently provided there will be very little temperature change to cause breathing, and breathing will in fact be prevented by designing the tank to take a small internal pressure.

3. The tanks should preferably be round in horizontal cross section to obtain greatest economy of material and best resistance to earth pressure and concussion.
4. The tanks should be welded throughout. For easy welding, plate steel of A.S.T.M. specification A-10 is recommended.
5. In general, the tanks should be built in an open excavation. The spoil may be disposed of according to local conditions, but the backfill must be so made as to leave the surface of the ground in its original appearance.

   The tanks should be filled with water for test and the water ahduld be kept under a head of seven feet above the tank tops while backfilling. The top soil should be segregated and the remainder of the backfill material selected and mixed to get the most desirable uniform material against the tank shell from top to bottom. This material should be carefully deposited in layers about twelve inches thick dampened, and well compacted. The use of cinders, ashes or soil containing vegetable matter should be avoided. The fill against the tank steel should be free from large stones to avoid breaking the protective coating on the shell.

6. Special schemes for storage, many of which have been suggested to the Advisory Commission, are for the most part of value, if at all, only in particularly favorable circumstances. A partial list of these schemes with comments on their utility is included in the appendix.

With these assumptions and conditions as a basis we have worked out typical specifications which appear suitable for conditions ordinarily to be expected, and have asked a number of tank manufacturers and contractors to submit designs and preliminary cost figures. In accepting this assistance we have made it clear to all parties that the final placing of contracts would in all probability be made on the basis of Army and Navy specifications, and that no supplier would be prejudiced in any way either by failing to submit designs or by the relative merit of any design submitted. Manufacturers offering designs include:

Bethlehem Steel Company
Chicago Bridge & Iron Company
Graver Tank and Manufacturing Company
Hammond Iron Works
Petroleum Iron Works Company
Pittsburgh Des Moines Steel Company
Raymond Concrete Pile Company
Southwestern Engineering Company

In addition to the designs submitted by these firms we have also reviewed such foreign designs as have been available.

We are appreciative of the assistance so kindly rendered by these companies and have no wish to draw any comparisons that might appear to the disadvantage of any. Because of this, and because in several cases the same design features were submitted by more than one manufacturer we shall refer to the features by number or description rather than by company name.

For the purpose of making a design study it has been necessary to assume certain governing conditions and specifications in addition to the general conditions previously outlined. These are:

1. The depth of the tank will be 20 feet. (Under most conditions this depth, if not ideal, at least lies in the bracket of reasonably economical proportions. However, if soil conditions are favorable and if ground water is negligible, it will be economical to increase it, perhaps to an upper limit of 35 feet.) With the 100 feet diameter previously assumed as a desirable maximum, a height of 20 feet gives a gross capacity of 27,980 barrels and a net working capacity of about 27,000 barrels.
2. The maximum height of ground water will be 5 feet above tank bottom. (This is a purely hypothetical assumption, and in case of higher water it will be necessary to make simple changes in design. In extreme cases it may be advisable to reduce the depth, or to incase a portion or even the entire tank with concrete, and perhaps either to increase the amount of cover or to adopt the hydraulic system to prevent flotation.)
3. The dead load on the tank roof (4 feet of earth and 9" of concrete)

will be 515 lbs. per sq. ft. The live load, to provide for passage of motor trucks and construction equipment, will be 100 lbs. per sq. ft., giving a total of 615 lbs. per sq. ft. The dead load indicated will be sufficient to prevent any tendency of the empty tank to float until the ground water reaches a level 8-½ feet above the tank bottom, without allowing for the weight of the bottom slab or steel structure, or 10-½ feet with all allowances considered.

4. In order to facilitate welding, provide corrosion protection, and insure a uniformly sloped bottom, a concrete base slab will be used. The thickness and reinforcement will depend on the requirements for distributing the column loads. The steel bottom will be anchored to the slab between columns at frequent enough intervals to prevent failure due to water pressure between the slab and the steel bottom.

5. The thickness of the bottom will be 5/16", the minimum thickness of the top will be ¼", and 1/16" will be added to the minimum thickness calculated for the shell as a corrosion allowance. Exterior corrosion can be minimized by the use of inexpensive coatings and by the application of cathodic protection where required.

6. The shell will be designed to withstand the hydrostatic pressure due to a water contents, in accordance with American Petroleum Institute standards 12-C of April, 1940, and in addition 3 lbs. per sq. inch vapor pressure at the liquid surface, without

allowance for any support from the earth. With the temperature range to be expected an internal pressure of $1\frac{1}{2}$ lbs. above the liquid surface will be sufficient to prevent breathing losses. While there is no probability that the tanks will be filled with water except during testing and backfilling, it does not appear feasible to effect any savings in shell construction by using lower requirements for calculating hoop strength and the necessity of providing for external earth pressure makes it necessary to increase these minimum thicknesses in the most practical designs.

7. The unit stresses in steel will, with the exception of column proportions, be taken from the A.P.I. standards 12-C dated April, 1940, which are, except for shell stresses, essentially the same as the 1934 specifications of the American Institute of Steel Construction and Navy Department Standards No. 12 Yb, as follows:

Tension on shell plate (load calculated 12" above bottom of each ring)	21,000 lbs per sq. in.
Efficiency of double welded butt joints	.85
Tension in rolled steel other than shell plate	18,000 lbs. per sq. in.
Compression on short lengths	18,000 lbs. per sq. in.
Compression on gross section of columns	$\dfrac{18{,}000}{1 + \dfrac{L^2}{18{,}000\ r^2}}$
with a maximum of	15,000.
The ratio of $\frac{L}{R}$ for main compression members shall be limited to	120.
(The A.P.I. permits 180)	
Maximum $\frac{L}{R}$ for secondary members	200.
Bending, on extreme fibers of rolled sections	18,000.

8. The unit stresses and elastic properties of concrete and reinforcing steel will be taken from Navy Department standards No. 3 Yb, November 15, 1929, the principal values being as follows:

Flexural compressive stress in extreme fibers of 2000 lb. concrete	700 lbs. /sq. in.
Shear in beams	40 " " "
Bond of deformed bars	100 " " "
Tensile stress in intermediate grade reinforcement	18,000 " " "
Young's modulus for steel	30,000,000 " " "
Young's modulus for 2000 lb. concrete	2,000,000 " " "

Where a concrete slab is poured over the steel roof of the tank the lower reinforcement bars may lie on and be adequately welded at intervals to the steel roof plate. For ease of welding square bars are preferred.

9. Earth pressures will, for the purpose of this general study, be assumed in accordance with the diagram shown on drawing No. 1. This diagram is necessarily arbitrary, in that no special site has been considered, but an attempt has been made to make it representative. It is calculated by the old Rankine-Coulomb method with the assumption of an earth density of 100 lbs. per cu. ft., an angle of repose of 33° 41' and with ground water level 5 feet. The angle of repose is taken the same below the water as above, on the assumption that the backfill will be properly selected and placed. With a circular tank this method of calculating earth pressures is very conservative; for, as long as the tank is in reasonably good ground, a tendency to contract in one direction will be resisted by additional earth pressure at

right angles. The load diagram on drawing 1 applies to all designs but the shear and moment diagram applies only to one form of shell bracing; that with vertical beams.

10. It is recommended that the "Qualification of Welding Procedure and Testing of Welding Operators" of the American Welding Society govern the welding process used in fabricating the tanks.

11. There will be no openings in the shell plates nor bottom. Openings for access and pipe connection will be provided in the roof as required. For the present purpose the details of openings have been omitted, their number and size depending upon the pump and piping layouts. It is, however, believed that individual submerged pumps supported at the top of each tank near the shell will provide the most practical, certain, and economical equipment layout eliminating suction difficulties or the necessity of constructing deep tunnels for pipe lines.

12. The bottom of the tank will be sloped to the center one inch in 10 feet. The center plate will be dished to a depth of 8 inches to provide a water collection sump and facilitate cleaning. All internal structural members will be arranged or pierced for free drainage to the sump.

COMPARISON OF DESIGNS

The specific designs presented to the committee will now be discussed. In considering them it appears convenient to separate the shell design from the column, roof, and bottom design. The form of the shell selected has little, if any, bearing on the design of the roof, bottom, or column structure. On the other hand the design and spacing of the columns does materially affect the roof and bottom.

SHELL DESIGN

The shell of a tank which has a generally round horizontal cross-section may be made of plain rolled plate and reinforced against buckling from earth pressure by added stiffening and strength members, or it may be made of plate rolled to special forms to give it greater inherent collapsing resistance. The plain braced cylindrical design has obvious advantages in unquestioned stability under the internal loading and in permitting construction by conventional methods, and does not compare very unfavorably with other designs as regards weight, so, it will be discussed first.

A plain shell may be braced against earth pressure by vertical stiffeners, horizontal stiffeners, or a combination of the two, and plans involving all three schemes have been submitted by various builders. A comparative study indicates that the lightest and most practical bracing consists of a combination of horizontal and vertical stiffeners, as brought out in the following discussion, though all three methods are feasible.

Design Consisting of Vertical Bracing Only

A typical design with vertical stiffeners is illustrated in figure #1, drawing #3.

On account of the extreme thinness of the shell relative to the diameter, the vertical members must be placed rather close together. Under these circumstances, no effective arch action can be secured, and the shell plate between stiffeners must be regarded as flat. In fact, with the extremely small curvature, the shell between stiffeners will bear about as much load as a flat plate as its collapsing load as an arch calculated by the usual methods, as the following table indicates. Besides showing the allowable span of the shell as a flat plate the table also shows the allowable span as a catenary with a sag equal to the plate thickness.

Plate	Bottom	Middle	Top
Load considered lbs./sq. in.	6.03	3.61	2.29
Plate thickness*	.45"	.35"	.25"
Collapsing span as arch	.51"	.35"	.28"
Span as flat plate, stress equal to yield point**	.45	.45"	.40"
Span as catenary, sag equal to plate thickness, stress 18,000#	.69"	.70"	.63"

*Including corrosion allowance
**Assumed as 30,000 lbs/sq. in. for the purpose of comparison.

As long as the vertical stiffeners are strong enough to carry the total load as beams the integrity of the entire structure is assured even though the stress in the plates exceeds the yeld point in bending and they are pushed inward so as to act as catenaries. Therefore, any span up to that indicated as the yield point by the flat plate analysis is perfectly safe, and will avoid having scallops form in the shell except perhaps under unusual concentration of local loading.

It appears necessary in this design to calculate the stiffeners as beams and to count on no arch action in the plate. For purpose of illustration we have shown 120 vertical members spaced on 31.4" centers around the circumference. These members need a section modulus of 41 to carry the maximum moment determined from the shear and loading diagram on drawing #1. A 12" x 5" 31.8# steel beam is adequate, if the flange is intermittently welded to the shell. The nominal weight of shell of this design is as follows:

Bottom shell plate 314' x 84" x .45"	40,500#	(Nominal Weight)
Middle Shell plate 314' x 84" x .35"	31,400#	
Top shell plate 314' x 81-¼" x .25"	21,700#	
Weight of unbraced shell	93,600#	
Weight of stiffeners, 120 x 21 x 31.8	80,200#	
Total	173,800#	

The relative economy of any system of bracing may be indicated by the ratio of the weight of bracing to the weight of an unbraced shell of minimum thickness which in this case is 86%. The weight could be reduced by using light trusses instead of beams, but it is doubtful if the cost would be greatly affected. Aside from the weight this design has the disadvantage of depending largely on the top and bottom slabs to take the external shell load. The design would therefore be unsuitable if either slab were omitted, or greatly reduced in thickness. Otherwise it is determinate and effective, but not economical.

Design Consisting of Circular Girders Only

Two manufacturers have submitted designs for shell bracing composed solely of circular girders. Typical cross-sections are illustrated in figures 3 and 4 of drawing No. 4. One section shows latticed girders and one shows plate girders. It will be noted that, in both sections, the designers have increased the thickness of at least the two upper plates beyond the minimums (of .45", .35" and .25") required by A.P.I. specifications and assumed corrosion allowance, the reason being to permit a reasonably wide spacing of girders without danger of having the shell crumple.

The weight of bracing plus the extra shell weight shown in figure 3 is 72,000 lbs. (nominal value) and that of figure 4 is 88,000 lbs. or, respectively, 77% and 94% of the weight of a minimum unbraced shell.

These figures are not strictly comparable, nor do they fairly indicate the relative excellence of this type of bracing, because they are not based on exactly the loading shown on drawing 1 nor calculated by the method that the committee recommends. We have made some calculations that indicate that adequate bracing of this type can be designed with a weight not exceeding 65000 lbs. or 70% of the minimum unbraced shell weight.

Latticed girders will weigh less, but the choice could well be left to the bidder if the contract is on a lump sum basis, provided flimsy members are avoided. If latticed girders are used, an inner shelf angle and an outer tee or angle seem most practical for the flanges. The advantage of the ring stiffeners is that they do not impose heavy reactions on the roof and bottom, and would be adaptable in cases where either slab was omitted, or reduced to 4" thickness, which is enough for corrosion protection and insuring a properly sloped bottom if the column load is sufficiently distributed.

While we doubt that the circular girder design will be found as economical as one including both horizontal and vertical members, we consider it acceptable, and suggest the following specifications in case it should be used:

1. The distance between stiffeners should be calculated by formula (5) given in Windenburg's 1934 paper, A.S.M.E. Transactions

A.P.M.-56-20, with a factor of safety of 1.5. (The justification for the use of this comparitively low safety factor is first, that the formula mentioned is an approximate one yielding results on the side of safety for short lengths, and second that the shell stresses are secondary and that minor local buckling will not cause any serious general collapse as long as the integrity of the girders is maintained).

2. The moment of inertial of the girders should be determined by the ring stability formula

$$I = \frac{4}{3} \frac{r^3 q}{E}$$

Where
r = radius of tank, inches.
q = earth load per inch of circumference, taken over half of the two adjacent spaces.
$E = 30 \times 10^6$
4 = recommended factor of safety.

In computing the moment of inertial of the girders a section of shell of width equal to $\frac{1}{2}\sqrt{rt}$ shall be added to the outside flange of the girder (t=thickness of plate).

3. The compressive force in the stiffener, including the section of shell plate considered shall be within allowable limit of 15,000 lbs. per sq. in. when assumed to support the entire hoop compression without considering the remaining shell plate. (This requirement is not onerous).

4. The minimum thickness in any main structural member should be 5/16".

5. In making collapsing calculations the gross nominal thickness of shell should, ordinarily, be used, but the thickness flanges of

structural members should be reduced by the corrosion allowance. (The justification is, that exterior corrosion is most likely to be pitting and that by the time it has taken place, the backfill will have settled to its permanent form and most of the danger of collapse will have passed).

Designs Consisting of Combined Vertical and Horizontal Stiffeners

a. Ring Girders, and Light Vertical Beams

Two designs involving a combination of horizontal and vertical stiffeners have been suggested. The first, which is in figure 7, drawing 5A, involves two heavy horizontal latticed ring girders which act as intermediate supports for comparatively light vertical members spaced about as far apart as the heavy beams in figure 1, drawing 3. We have made only very rough calculations for this design on account of the limited time available, but they indicate it to be entirely practical and considerably lighter in weight than either of the two designs previously discussed, though perhaps heavier than the one discussed further on. The only difficulty appears to lie in getting economical vertical members that do not have an undesirably thin web section. We should prefer to have such sections at least .30" thick; however this is something that can probably be taken care of by using angles intermittenly welded to the shell utilizing the shell for the outside flange, as indicated.

This design is permissible but we do not believe most economical. If used the following specifications in addition to those previously indicated are recommended:

1. The vertical beams (with due allowance for the section of shell

plate effective as outside flange) should be calculated to sustain the entire external load without arch action from the shell.

2. The circular girders should be calculated by the ring stability formula previously given to sustain their proportion of the verticals when the latter are taken as continuous beams, and should preferably be located so as to be identical.

3. The area of the girders should be checked for allowable compression. The inside flanges of the girders should have adequate lateral bracing.

b. Light Arch Members, and Heavy Verticals.

The second of these designs is indicated on drawing No. 2. The section shown on this drawing indicates a weight of bracing of 41,200# (including an allowance of 4,400# for the extra shell thickness of the upper plate beyond the minimum needed for tension plus corrosion allowance) or 42% of the unbraced shell.

In this design the girt members (Ribs) are calculated as arches having a span equal to the distance between verticals; in this case, $22\frac{1}{2}°$, using the formula

$$q = \frac{1}{4}\frac{EI}{r^3}(k^2 - 1)$$

Where q = radial load per lineal inch of arch
E = 30×10^6
r = radius of tank inches
I = required moment of inertial (allowing for the action of the effective width of shell plate).
4 - recommended factor of safety.
k - coefficient depending upon the angle subtended by the arch and the nature of the end constraint. We have taken k intermediate between the values for hinged ends and fixed ends. (See S. Timoshenko: "Theory of Elastic Stability" 1936 pages 226 and 228 (h)).

The distance between ribs has been calculated by using the Widenburg-Southwell-Cook formula previously referred to in connection with the plain ring girder bracing with a factor of safety of 1.5.

The purpose of the vertical members in this design is not primarily to carry load (though of course they do pick up load in proportion to their stiffness) but to form nodes in the ribs so as to permit them to be proportioned as 22½° arches instead of as 360° rings.

The required strength of the vertical members appears to be highly indeterminate, depending both on their elasticity relative to that of the ribs and shell and the irregularity of the loading. The committee has received ideas from various manufacturers regarding the proportions of these verticals. Their ideas are based on the assumed proportion of the total lateral earth load on a 22½° panel that the verticals should carry as beams, ranging from 16 2/3% to 100% of this load.

It is of course obvious that, as long as the ribs are not crippled, there is no possible way for the verticals to pick up all the radial load, or even any major fraction of it. If any of them are crippled (as we have no right to assume if they are proportioned with an adequate factor of safety and initially rolled to a true radius), then the reaction on the adjacent verticals will be mostly tangential rathern than radial.

On the assumption of uniform loading and perfect fabrication the stress in these vertical members could be determined by very tedious calculations. We have not taken the time to attempt these and doubt (in view of the fact that unknown irregularities of loading and fabrication may greatly affect the result) that they are justified. We have, however, made approximate figures on the basis of assumed earth pressure distribution to determine the reaction on the verticals if they were rigid, and have compared their deflection under load with that of the shell and stiffeners. As a result of these figures we believe that the 16", 40 lb., wide flange beams shown on drawing #2 are adequate for reasonably irregular fabrication and loading. Each of these members will carry, as simple beams, the earth load on a vertical strip of shell equivalent to a uniform width of four feet; i.e., 21% of the earth load against each $22\frac{1}{2}^{\circ}$ panel of the circumference of the tank shell.

The weight of the bracing indicated for this design appears to be less than that needed for the other designs investigated, and as the construction appears to be very practical and makes use of standard rolled steel sections throughout it seems preferable to other designs.

Special Designs of Shells

Several special designs for the tank shells have been submitted. The two principal ones are (1) what may be termed the polyconic design, shown in figure 6 drawing #5, and (2), the scalloped design, which has been suggested in various forms. One of these is illustrated in figure 5.

Polyconic Design

The committee has not determined the actual strength of the polyconic design, nor has it been tested. Apparently the purpose of the design is to approximate a double curved surface for the shell. Actually, however, the surface is a succession of four truncated cones. The surface of each is unsupported over a broad area. Under earth loading of the assumed magnitude, the plates will yield plastically and take up some form that will carry the load, the stress distribution being complex. There is danger that an undesirable amount of pull-in and an undesirable stress concentration in the welded joints, may take place.

The extra weight of the design shown is only 18,000 lbs. over the weight of a plain cylindricol shell of the minimum thickness previously considered, but the form of the shell causes a loss of tank capacity of 2,200 barrels. As the tank capacity is worth, roughly, $1.50 a barrel, the capacity loss is equivalent in cost to about 55,000# of additional steel. While it is not a rigorously fair comparision, one may therefore say that the equivalent permissable bracing weight is 73,000 lbs.

Considering this figure in comparison to the weight of bracing required for a plain cylinder together with our doubt about the stress distribution (which could only be resolved by tests) and the extra difficulty of rolling and matching conical plates, we do not feel justified in recommending this nevertheless interesting design.

Scalloped Design

The scalloped design has been presented in several variations, one of which is shown in figure 5 drawing 5. The design shown is light because of the ¼" shell thickness. Even after allowing for the extra perimiter of the scallops and the extra diameter necessary to secure the same contents as a plain 100' cylinder, the overall weight of the steel indicated is some 15,000 lbs. less than the weight of a thoroughly braced cylinder.

Some of this advantage in weight would be lost in more elaborate fabrication. Furthermore, we do not believe that the design shown is adequate.

The stresses do not appear subject to calculation and if enough extra braces were added for one to feel assured against danger of serious collapse, the advantage in weight would disappear.

Another objection to the scalloped design is that it relies entirely on the roof and bottom, not only to carry the external load, but also the much greater internal load.

All in all, we see no reason to recommend this construction, although it is by no means an impossible one.

Reinforced Concrete Design

On drawing No. 6 there is shown a cylindrical reinforced concrete tank with a steel lining. This lining can be made as light as ¼" in thickness except that bottom should be of 5/16" thickness as in other designs.

The lining must be anchored to the concrete thruout and the concrete thoroughly waterproofed.

The committee has not checked the detailed structural design of the section shown, except very roughly. However, it has made a rough cost comparison which indicates that this type of construction will cost about 30¢ a barrel more than a steel tank with a braced shell.

We believe that this more expensive construction is perfectly sound but that it is justified only where very severe ground water and corrosive soil conditions prevail. It appears to be well suited to locations in very wet surroundings, such as marshy land near salt water, provided the design is modified to take care of the prevailing loads.

Roof Construction and Support

A number of roof and column designs have been considered. Doubtless the cheapest construction of adequate strength would be reinforced concrete columns with a flat slab without steel lining for the roof. This, has been rejected because the concrete columns are undesirable in a gasoline tank; and because it would be impossible to obtain a vapor-tight seal between the concrete slab and the steel shell.

If we assume that a steel column structure and a tight steel roof are necessary, a plain flat slab becomes an uneconomical construction because of the large column caps required, and it becomes desirable to add roof beams as indicated in drawing No. 2 - - that is, provided the conventional type of columns are used. In fact, the only practical alternatives seem to be the construction shown on drawing 2 and a construction utilizing special columns to support the roof plate at a sufficient multiplicity of points for it to support the load directly, such as those shown in figure 8 and 9, on drawing No. 9.

We have studied both types of roof construction and supports.

The roof and column design indicated on drawing No. 2 needs but little explanation. The columns are 8" x 8" - 35 lb. H sections approximately 18'-6" long (with extra length to provide for bottom slope) set on 12'6" centers. A base plate 15" x 16" x 1-¼" is set under each column. The 12'6" column spacing shown appears to be about the most economical and the section selected about the best available for L/R less than 120. The roof beams are 18" x 6" - 54.7# beams, assembled in the longest lengths that may be conveniently shipped and handled (37½ feet), permitting design on the basis of $M = \frac{WL^2}{10}$.

The 9" slab has one-way reinforcement crosswise of the beams and is designed for 2,000 lb. concrete on the basis of United States Navy

"Standards of Design for Concrete" No. 3YB. Interior portions of the slab were considered continuous and designed on the basis of $M=\frac{WL^2}{12}$ while exterior portions were designed on the basis of $M=\frac{WL^2}{10}$ and $\frac{WL^2}{8}$ as applicable. It is necessary to support the roof plate between girders, and the simplest and most economical method appears to be to lay the bottom reinforcing bars directly on the roof plate and to weld them adequately to the roof plate at the points where they are bent up over the girders and at one or two intermediate points. While the plate will doubtless act to some extent as added reinforcement, this has not been considered in the design.

Temperature reinforcement of .25% on 18" centers should be laid crosswise of the structural reinforcement.

The roof plate should be thoroughly wire brushed and broom cleaned before the slab is poured, but need not be otherwise treated.

During construction it will be necessary to support the columns and beams laterally and to shore the roof plate until the concrete has set. A suggested method of construction is to use temporary wooden cross members resting on the lower flanges of the beams to serve both purposes. Temporary steel shoring has also been suggested in case a number of tanks are to be built in one location; see drawing No. 2.

Two alternate designs of closely spaced direct acting columns not requiring roof beams are indicated on drawing No. 8, figure 8 and figure 9. One of these is called the tooth-pick design, and the other the basket design, for evident reasons.

The former consists of four 1-¼" x 1-¼" x 5/16" angles shop-bent and intermittently welded together in a jig in the field to form a box column in the center. In the section shown the L/R of the ends where the angles are splayed is more than 120. This objection could be avoided by minor changes, although it may be argued that this is an arbitrary limitation that need not be met, if the angles have an adequate factor of safety by Euler's formula, especially as this detail has been used successfully under light loads. The L/R ratio for the box center is amply safe.

These columns support the roof on 24" centers, square pitch. The stress in the center of a flat plate so supported has been calculated and is well within the yield point. The initial stress at the points of support, however, is far beyond the yield point, and in order to carry the load the plate must yield plastically and assume a bulge at each point of support. Although the final stress may be at the yield point experience shows that this is safe for one-way loading, especially in this case where the concrete will limit the deformation and prevent working.

As the committee does not believe ¼" angles are desirable for main members, the weight of this design has been estimated on the basis of 5/16" angles.

The basket design illustrated in figure #9 of drawing #8 is a variation of the tooth-pick design but differs from it in (1) using a heavier roof plate and wider spacing of supports, (2) placing the supports on 60° triangular pitch instead of square pitch, and (3) adding angle rings at the top to facilitate construction and to reduce stress concentration in the plate.

The 1½" x 1½" x 5/16" angle legs are arranged in groups of seven, one in the center and six on the periphery. This places the angles under the roof on a uniform 48" triangular pitch when the baskets are properly oriented. It also places the groups on a uniform 127" triangular pitch.

The stress distribution in the plate with this arrangement is more difficult to determine than with the tooth-pick arrangement on 24" square pitch, but it is certain that the plate must bulge over the supports in order to carry the load. The angles help to reduce the concentration.

The $\frac{L}{R}$ ratio for the basket columns indicated is just over 120, and on this score the design seems satisfactory, provided the intermediate ties are made strong enough to prevent crippling.

While we believe that this design is safe, it has not been tested. It is suggested that one of these columns be made up and subjected to a load test simulating conditions in a complete tank before any design using this type of support is finally approved.

Until one of the basket columns has been tested and approved it is recommended that the conventional design and layout of roof supports shown on drawing No. 2 be used.

The conventional column design, of course, has the evident advantage of being easy to design by well-known methods and capable of erection by any reliable steel concern. It also simplifies the difficulty of getting a sloping bottom and a flat roof. It utilizes heavy sections that would be more resistant to corrosion. Finally, it is decidedly superior in case tanks ever have to be repaired or cleaned, offering convenient working space, good visibility, minimum obstruction to cleaning, and probably easier repair in case of damage.

On the other hand, the basket design, if proved by test, has advantages that may better suit high ground water conditions if the soil condition is otherwise stable.

The conventional design requires a sturdy reinforced concrete top slab or equivalent structural roof support, which, though it may be needed for other reasons, is optional with the basket design. Even if used with this design it would not have to be shored during construction or heavily reinforced. The most important consideration favoring the basket design is the bottom. The conventional design absolutely requires a heavy bottom slab or individual piers for distributing column loads unless the bottom rests on sound rock. Furthermore it requires the bottom to be anchored to this slab on fairly close centers between columns if there is any possibility of having ground water above the level of the tank bottom. This anchorage is both expensive and troublesome to install. The slab becomes more and more expensive with deeper cover and heavier column loads, and the anchorage becomes a matter of more and more concern as the level of bottom water rises.

With the basket design the bottom anchorage problem does not exist and the bottom slab may in most cases be reduced in thickness to the minimum of 4" needed to level off the supporting subsoil. In fact the slab may in some cases if desired be dispensed with, and replaced with a good asphaltic pavement to smooth the grade aid in protecting the bottom from corrosion.

While the advantages of the conventional design are real, they are not necessarily determining. We do not expect rapid corrosion in these tanks, cleaning may be very infrequent, and repairs are problematical. The relative cost of fabrication and erection will depend to some extent on the individual contractor as well as local conditions. We believe, however, that the basket columns promise a saving of at least $3,000 a tank in concrete work and anchorage under the conditions assumed for the present study.

For these reasons if tests are favorable on the basket type of roof support we believe the tank design using this detail should be given full consideration in entertaining bids.

The following tabulation has been drawn up to illustrate the comparative amounts of steel and concrete required for the three designs considered. It should be taken as a preliminary comparison, being based on an assumed spacing of the basket columns and an assumed thickness of roof plate which may not be found correct when the results of tests are known.

Rough Weight and Cost Comparison

of Column and Roof Structures

Design	Conventional Columns and Beams, Reinforced Slab	Distributed or Direct-Acting Design a Tooth-pick Type	b Basket Type
Spacing of supports	12'-6" square pitch	24" square pitch	44"** triangular pitch
Number of supports	44	1960	560
Roof plate thickness	.25"	.25"	.312"**
Weight of column structure	35,000#	93,000#	60,000#
Weight of roof plate	80,000#	80,000"	100,000#
Weight of roof beams	37,000#	-	-
Weight of anchorage in bottom slab	8,000#	-	-
*Total Steel	160,000#	173,000#	160,000#
≠Comparative cost @ 6¢	$ 9,600	$ 10,400	$ 9,600

Table continued on next page

Thickness of bottom slab	12"	4"	4"
Yardage of concrete in slab	291	97	97
Cost @ $20	$ 5,920	$ 1,940	$ 1,940
Comparative cost, steel and concrete	$15,520	12,340	11,540

≠ It is assumed that the actually higher fabrication cost of the basket and tooth-pick designs would be offset by the shoring, anchorage, and reinforcing steel required for the conventional design.

* For comparative purposes, these are nominal weights, not allowing for overweight tolerances.

** The design submitted showed 48" pitch but was laid out for only 500# load; though it may be good for 620# it has been shortened for this estimate. The necessary thickness of roof plate is not quite certain.

ALTERNATE DESIGN.

<u>Reservoir Type Design</u>

Various plans of tanks having other than cylindrical shapes have been suggested. One of these is the steel-lined resevoir design shown on drawing No. 7, laid out after the fashion of the concrete oil reservoirs in California but provided with a steel roof and lining. It has been found that the walls of such reservoirs will stand up indefinitely in good ground with a slope of 1¼ to one. This design presupposes a well drained site, and therefore no anchorage between the concrete and lining has been provided. The cost of this construction does not seem very different from that of the cylindrical design, as the following table indicates. (Note: The weights shown do not quite agree with the drawing. They should be considered approximate, and the drawing, diagrammatic).

Design	Cylindrical	Reservoir
Top and bottom diameter	100'	124' x 74'
Nominal capacity	27,000 bbls.	27,000 bbls.
Target area for direct hits	7,850 sq. ft.	12,000 sq. ft.
Steel weights (nominal).		
Bottom - 5/16"	101,000#	55,000#
Side walls (½" for reservoir)	93,000	95,000
Side wall bracing	45,000	-
Roof sheet ¼"	80,000	122,500
Roof beams	37,000	59,000
Column structure	35,000	58,000
Steel*	391,000	389,000
Concrete Yardage		
Roof 9"	218	313
Bottom 12"	292	163
Side walls 4" incl. extra col. footings		172
Total	510	668

It appears that the reservoir design requires about 160 extra yards of concrete and presents 53% more target area. However, it does protect all the steel with concrete, and would be a practical construction for well drained locations.

All in all, however, we do not think the reservoir design is particularly well adapted to aviation gasoline service. For fuel oil

*Nominal - no overweight and no anchorage between steel concrete provided on either design.

service, where concrete columns can be used, where the steel roof lining is unnecessary, where, with adequate concrete columns and caps a flat slab roof can be used, and where an .18" steel side lining would be sufficient, we believe the reservoir design has much to commend it we expect to present this design with cost figures very shortly in another report on underground fuel storage.

Foreign Designs

The committee has had the opportunity of examining certain foreign designs for underground tanks. In deference to the source from which these were secured and in view of the unknown extent of the circulation that this report may have we have not reproduced these designs for purposes of comparison. They do not, in our opinion, give any greater degree of security than the designs suggested here and are somewhat more expensive than most of them. They are available for the inspection of the Army and Navy officers on request. It should be understood that the designs referred to are laid out for conditions comparable to those assumed here, and are not the special deeply protected containers that we understand have been built in some parts of Europe. Some of the latter are briefly mentioned in appendix I.

CORROSION PROTECTION

The concrete slab suggested for roof and bottom will furnish adequate corrosion protection for these surfaces. Even though some water penetrates between the bottom slab and the bottom, it will tend to become passive after losing its initial content of corrosive substances, and, under ordinary circumstances, should not cause any serious trouble. This will be especially true if cathodic protection is adopted for the shell.

For the shell it is recommended that a simple protective enamel be applied to a thickness of about 1/8 inch (3/32"minimum). This should cost not over 15¢ per sq. ft. or $950, including grit blasting the outside of the plates in the shop. This recommendation assumes that cathodic protection will be applied to take care of the holes and breaks in the coating. If it is not to be used, the coating should be further protected with a 30 lb. saturated felt coating for protection particularly lining backfilling.

In addition, for permanent protection, especially in corrosive soil, it will be well to consider cathodic protection, which has been so successfully applied to oil pipe lines in various parts of the country in the past few years. In this protection, a diagramatic layout of which is given in Drawing #11, a current of electricity is passed from an anode located far enough away to give reasonably uniform distribution to the structure to be protected.

It has been amply demonstrated that underground or underwater corrosion of steel structures is electrolytic in nature, and results from the e.m.f.'s generated by concentration cells formed by the different nature and proportion of soluble salts and the varying water content of the soil together with the irregular distribution of impurities in the steel itself. In some cases, external currents such as stray current from street railways may also be a factor.

The method of cathodic protection is to apply an e.m.f. from an external source adequate to blanket the effect of the concentration cells and make the whole surface of the protected structure cathodic, or negative to the surrounding soil or water. When this condition is obtained, corrosion simply stops.

The amount of current required depends mainly on the conductivity of the soil or water and the insulating value and degree of continuity of the protective coating, and must be determined at each location by test after the structure to be protected is in place. Certain approximate values or limits determined by experience may however be given. A coating of some sort is advisable on new structures to cut down the amount of current required, although old uncoated structures may be protected without prohibitive expense.

On the assumption that the roof and bottom are protected by a concrete slab, which nevertheless has some conductivity, that the soil is fairly corrosive, and that the protective coating recommended for the shell is continuous over 80% of the surface, it is estimated that cathodic protection can be secured with a current of about 15 amperes per tank at a potential of 10 to 15 volts. The efficiency of a three-phase selenium rectifier and necessary transformers is about 80%, so the power consumption per tank under the conditions assumed would be about 280 watts, costing at 1½¢ per kwh. .42¢ an hour or $37 a year. The installation cost for a single tank would be ont the order of $1500. and the cost per tank for a group of eight tanks would perhaps be $1000.

For establishing a limit it may be indicated that a bare tank in marshy ground might require 10 milliamperes or more per sq. ft. or 65 amperes for the shell alone, and 220 for shell, roof and bottom. (Actually it would be difficult to protect the roof without a good protective cover of concrete or asphalt mastic paving, because the conduction of the 4' of earth cover is limited and the center of the roof would therefore be starved of current.)

We should like to repeat before closing this discussion that the figures and layout given are illustrative only, that a cathodic protection system should only be designed after a survey by an engineer experienced in this work, and that the results achieved should be investigated by another survey after the installation is completed.

CONCLUSION ON TANK DESIGN

As a result of the figures and other considerations indicated, we believe that, for average conditions, and with the initial assumption outlined, a cylindrical tank with a shell braced by a combination of vertical and girth stiffeners and with a distributed column structure promises the most economical satisfactory underground tankage for aviation gasoline, and that it can be built in average locations for $1.50 per barrel, exclusive of piping, pumps and auxiliaries which will be discussed further on. We somewhat prefer a conventional column structure, other things being equal, but doubt that the extra concrete work it involves is warranted under average circumstances. For extreme conditions of corrosion and underground water we recommend a cylindrical concrete steel lined tank which would cost about $1.80 a barrel.

Various alternative storage schemes, some of which may be adaptable to certain conditions, but which in general are not economical for the assumed conditions, are discussed briefly in Appendix I.

LAYOUT AND PIPING OF STORAGE CENTERS

Proposed diagrammatic layouts for storage centers are shown on drawings No.9 and No.10. The tanks are shown located on the circumference of a circle, with a clear distance of 200 feet between shells. It should, of course, be understood that the circular layout is merely schematic and may be varied to an elliptical or other convenient shape to fit the nature of the ground, or other local conditions. The general thought behind it is to avoid placing a number of tanks in a line where they might all be damaged by a string of bombs discharged from a single plane. A generally circular layout also makes it easy to loop the piping in such a way that any portion may be destroyed without putting the rest out of service. Besides being looped, the piping indicated is doubled and sectionalized by block valves for further security. Most of the lines shown on the drawing should be about six inches in diameter to provide economically for a discharge rate of 1000 gallons a minute (1440 barrels an hour) through any two lines taken together. Main lines extending to the barge dock, pipe line station, or rail terminal may be 6 inch or 8 inch, depending on the number installed and the proposed flow rate, and may have one or more 4 inch branches to the truck loading rack if one is installed.

The pipe lines should be welded throughout. The pipe should be of good weldable quality, and as high bursting strength is not necessary, while reliability and resistance to concussion are, it is recommended that it be A.P.I. grade A seamless line pipe or equivalent. Eight-inch lines if installed should have a minimum nominal weight of at least 24.74 lbs. per foot and smaller sizes should be of standard weight. Lines should be laid 18 inches under the surface. More cover unless very deep will furnish no appreciable extra protection and will greatly increase the difficulty of making repairs as well as the original cost of the installation. Some flexibility should be provided near connections to pumps and tanks by the use of pipe bends but no special provisions for expansion need be placed in the main lines and packed expansion joints should be avoided.

Valves should be of steel, and A.S.A. 150 lb. steel gate valves with 18-8 chrome nickel stems and trim are suggested. As the valves are relatively expensive it is suggested that wherever convenient, gate valves be made not over 60% of the diameter of the piping in which they are placed, and that they be connected to the line with welded tapers (nor ordinary swaged nipples) having a uniform taper of one inch in diameter to five inches in length. If so installed a worth-while saving in cost will result, the valves will be quicker to operate, and no material increase in frictional resistance will result.

Enough of the block valves in the main system should be provided with small internal grease-gun type spring-loaded relief valves set at 200 pounds per square inch to relieve, back to the tanks, any pressure that might be built up in blocked-off sections of the pipe lines as a result of temperature increase. While this precaution is not so vital in buried lines as in exposed ones it should not be omitted.

Lubricated plug cocks are optional and are preferred to gate valves by many because of their quick action and tightness. If used they should, in general, be installed full size because of their greater frictional resistance. A reasonable compromise would be to use cocks for the valves controlling the individual tanks and gate valves for the rest.

Besides the block valves used for sectionalizing the piping and cutting off individual tanks it is recommended that a non-slam check valve be installed near the discharge of each pump. These check valves are omitted in many commercial installations but are considered very desirable to diminish the possibility of having a tank flooded, or of having any pump operate in reverse direction as a turbine at runaway speed in case the valves are improperly operated. Such runaways may unscrew the internal parts of pumps of some designs unless special provisions are made to prevent it. The safeguard of the check valves may be particularly important in emergencies when normal precautions may be overlooked. The check valves and the remote control of the pumps will also make it possible to transfer stocks without having men walk about the ground over the tank sites.

All the pipe lines are laid out on the assumption that individual pumps will be used for each tank. This arrangement is recommended after consideration of the various alternatives and on the basis of experience in handling gasoline in commercial terminals. It is, of course, possible to handle gasoline under vacuum, even from underground tanks, to a central pump house through lines laid not over, say, thirty feet above the tank bottoms. Experience, however, has proved all vacuum systems to be very

1382

troublesome and apt to fail when most needed. They cannot, therefore, be recommended or even seriously considered. Leaks around valve gaskets and stuffing boxes are certain to occur after a period of time and are hopelessly difficult to locate. A vacuum system can also be put out of commission very readily by intelligent sabotage.

The other alternative is to install the pipe lines in tunnels at a level below the bottom of the tanks, a plan which we understand has been used in Europe. This plan has some advantages, but is both expensive and hazardous. The tunnels that have been used have been elaborately sectionalized with gas-proof doors and they and their concomitant underground pump house have had to be equipped with expensive ventillating arrangements and provided with frequent inspection to guard against the formation of explosive mixtures. The piping recommended here, on the other hand, can be forgotten when it is not in use. It is fortunate that, in this country, the vertical pumps and explosion-resisting motors needed for the individual tank installations have been thoroughly worked out and are now standard commercial equipment.

In many if not most locations the pipe lines should be protected by some kind of an outside coating. A survey of soil conductivity with Sheppard rods will greatly assist in estimating the amount of corrosion to be expected and the expense justifiable for protection. Some kind of a coating, if even a light one, is needed where cathodic protection is used in order to keep the pipe lines from picking up too great a proportion of the current supplied for protecting the tanks. Protective coatings range from simple bituminous enamels through single and multiple wraps of felt saturated and interlaid with asphaltic material to heavy mastic applied by extrusion. If cathodic protection is used the more expensive coatings are probably justified only when exterior conditions are severe. If cathodic protection is not used, the lighter paints and dopes are virtually useless, for they all fail sooner or later from soil stress, and unless cathodic protection is there to take care of the broken places the pitting may be nearly as bad as if no coating were used.

Needless to say the same care should be exercised in rejecting undesirable material for backfill as recommended for the tanks themselves.

Before backfilling all pipe lines should be tested to a minimum pressure of 150% of the expected working pressure and not less than 200 pounds per square inch. The test pressure should be held for three hours while the lines are inspected for leaks. It is further recommended that a repetition of the pressure test be required at three-year intervals.

During construction every reasonable precaution should be taken to avoid getting foreign matter into the pipe lines. At the best, some can be expected, and, after testing and backfilling, all lines should be thoroughly washed out at as high a rate of pumping as possible. In the initial stages of operation care should be taken not to damage the valves by forcing them closed against stones, tramp iron, or other possible obstructions.

PUMPS AND TANK APPURTENANCES

Recommended appurtenances for the tanks are not shown on the drawings but include for each tank:

1. A suitable transfer pump.
2. A small sump pump, taking suction from the depression in the center of the bottom.
3. Two vacuum and pressure relief valves.
4. A mercury manometer, graduated to 2 lbs. per sq.inch pressure and 5 lbs. per sq. inch vacuum.
5. A float gage for reading the approximate levels of the gasoline without opening the tank.
6. Approximately four access hatches in the roof, three of which may be covered with earth, and one of which should be housed in a suitable underground box with concealed access cover for ease in making gages and inspections.

Pumps and Motors.

As previously stated it is proposed to equip each tank with an individual transfer pump, which should have a capacity of the general order of 1,000 gallons a minute; as circumstances may dictate. The required head will probably be about 100 feet (30 lbs.per sq.in.) and on this basis each pump will require a 25 h.p.motor. The pumps will be of the vertical centrifugal type, similar to those used for pumping water wells, except properly fitted for gasoline service. The lowest impeller of the pump should be set as close to the bottom of the tank as possible (not over 8 inches) and should have a bell-mouth suction extending to within three inches of the tank bottom. The bottom diameter of the bell mouth should be large to minimize formation of vortices. Between the inlet and the tank bottom radial vanes may be installed to prevent formation of a large vortex. Consideration has been given to the possible desirability of submerging the lower part of the pump in a depression below the tank bottom. This is not thought to be necessary if the lowest impeller is kept within 8 inches of the bottom, as the sump pump can be used after the main pump loses suction.

The motor and supporting head will be mounted on the concrete top slab. It will be located in a concrete or brick box and arranged for reasonably easy access for lubrication and repair.

Pumps of this type are a common design with a number of manufacturers most of whom are thoroughly familiar with the special requirements for gasoline service. Case hardened or stellited shaft sleeves are recommended in preference to the soft bronze frequently offered. 18-8 chrome nickel is an ideal material for impellers and trim, but for this class of service the less expensive bronze should be entirely acceptable. Cases may be cast iron. The motors should be of the vertical hollow-shaft type approved by the Underwriters' Laboratories for use in Class 1, Group D, hazardous atmospheres as defined in the National Electrical Code.

The sump pump proposed will be similar in general design but will have a capacity of only 100 gallons a minute, against a head of, perhaps

40 feet. The suction opening will extend into the 8-inch sump depression provided in the center of each tank for accumulating water and bottom sediment.

The motors for both pumps will have explosion-proof push button starters located inside their inclosures, but the main pumps will also be provided with remote control located either near the loading rack, the auxiliary power plant, or some other convenient point.

Parkway cable is recommended for underground wiring. Its location need not be marked on the ground, but should be carefully referred to known landmarks before any backfilling is done. It should of course be placed below the depth of cultivation if the land is to be cultivated.

Relief valves.

Vacuum and pressure relief valves are necessary to relieve vapor and aid or admit air when the tanks are being filled or emptied. These valves should discharge into short vent lines, which may be carried approximately 200 feet from the tank sites as indicated on drawings No.9 and No.10. In view of the small and slow temperature changes in buried storage the size of the valves can be determined entirely from the requirements for passing air and vapor during emptying and filling. It is recommended that two valves be provided, each good for both vacuum and pressure, and that the capacity of each one be equal to 125% of the possible filling and discharge rate. (These valves are ordinarily built with both vacuum and pressure elements in one assembly. If separate valves are used for vacuum and pressure two of each must be provided.) The pressure valves should be set to open at not less than 1½ lbs. per sq.inch, and to pass their full rated capacity at not more than 3 lbs. per sq. inch. The vacuum valves should be set to open at, or near, atmospheric pressure and to pass their rated capacity at not more than 1/2 lb. per sq. inch vacuum.

Several types of valves that would give fair service are available. However, it is recommanded that the valves be of the mechanical spring backed type, and (very important) that they be fitted with non-corrosive seats, discs, springs, stems, and guides, perferably made of polished 18-8 chrome nickel. The matter of free drainage that will keep moisture condensation away from the working parts should be carefully looked to in order that the valves will not freeze and stick closed in cold weather. They should be housed in an underground box permitting occasional cleaning and inspection.

It will either be necessary to secure relief valves capable of being easily opened manually, or to install a separate by-pass valve for relieving excess pressure or vacuum when it becomes necessary to open a tank.

Gaging.

As stated, one of the access openings should be installed in an underground inclosure arranged for reasonably easy but concealed entrance from the ground surface. The cover of this opening should be provided with a gasketed opening about 6 inches in diameter for taking gages, securing samples for inspection, or determining the amount of bottom water. A simple float gage that will read the approximate level in the tank without opening the hatch, or blowing down the pressure is considered to be a very desirable accessory. Other special gaging arrangements, such as remote reading and automatic devices operating on electric or pneumatic principles are considered optional.

ETHYL BLENDING PLANT

As it is understood to be the intention to store most of the reserve aviation gasoline without Ethyl fluid an Ethyl blending plant will be needed for each storage center. It is not impossible to place such plants completely underground, but in order to secure a passable degree of safety the installation would have to have very elaborate facilities for ventillation, and would not only be expensive but a continued source of apprehension. It is therefore suggested that, if at all possible, the Ethyl blending plant be placed above the surface of the ground. Of course it need not be placed in the immediate vicinity of the tanks as shown on the diagrammatic layouts, but may be located at any reasonable distance, perhaps disguised as a farm house, or barn, or any structure common in the vicinity, or concealed in woods or other natural cover.

For most if not all locations it is believed that a very simple plant utilizing Ethyl fluid supplied in drums will meet every requirement. The plant itself may be built on a concrete slab elevated about 3½ feet above the surface of the ground. The required showers and safety equipment for the men should be installed at one end of the slab. The adjacent or working area should house the eductor equipment for emptying the drums, the scales, and a necessary small eductor pump, while the other end provides space for a current supply of drums. Extra drums may be stored underneath the slab or in some neaby safe place. If other storage is provided the slab may be placed only one foot above ground. It seems unnecessary to include further details of Ethyl blending equipment here.

The pumps and piping system indicated in drawings No. 9 and No. 10 is very flexible and well adapted to ethylizing rapidly and circulating the contents of tanks to secure a good mix. Obviously, in a real emergency when the Ethyl plant was damaged, drums of fluid could be poured into the individual tanks which could then be circulated. It is not supposed that knock testing equipment will be needed at the storage centers themselves.

AUXILIARY POWER PLANT.

A utility power supply is probably desirable if it can be readily obtained. At least two separate sources of power are necessary and at least one must be independent of outside supply. An auxiliary power plant is therefore required. A suitable plant might consist of three 25 kilowatt generators driven by high-speed gasoline or diesel engines of the automotive type, and equipped with simple switchboards including modern high-speed direct acting voltage regulators, a minimum of necessary meters, switches for paralleling generators and controlling the feeder circuits, and a remote control master switch for cutting off all power including the outside service in an emergency. Remote control buttons for the individual pumps may be located in the power plant or elsewhere.

Particular attention must be given to the size of the generators, the exciters and voltage regulators and the engine governors to insure reliable starting of the motors which will be large in comparison to the size of the power plant. No difficulty should be experienced in obtaining suitable equipment.

If placed underground the station must of course be well ventilated and put far enough away from the tankage to avoid the possibility of having gasoline leaks find their way into it. Blower operated radiator cooling is suggested and will itself provide effective ventilation.

Proper protection of the air intakes, disposal of exhaust gases without a plume that would reveal the position of the station, and fire precautions will depend upon circumstances and need only be mentioned.

It will probably be convenient to include in the same structure as the power plant a small office, shop, lavatory, toilet, store room, and perhaps some of the fire-fighting equipment.

In case there is no outside power available it will either be necessary to build two separate power stations or to provide shomewhere in the vicinity two or three portable generating units that could be quickly hauled to the site on trucks, the latter plan probably being considerably the cheaper.

FIRE PROTECTION

Storage tanks of the type considered are virtually immune from fire resulting from ordinary or natural causes. They are not merely difficult, but impossible to set on fire, even by sabotage, unless actually blown open. If fire does start as a result of bombing the location of the fired tanks below the surface, the good protection of the remaining tanks, and the kind of piping recommended should all tend to prevent its spread.

For this reason, any elaborate and permanent fire fighting system, such as a permanent foam system is entirely unjustified. As a matter of fact a permanent foam system would probably be put out of commission by the same explosion that fired a tank.

The things that should be provided if possible are:

1. A supply of water under pressure.
2. Water supply mains capable of delivering at least 500 gallons a minute to hydrants suitably located.
3. A supply of hose stored in a convenient place.
4. One or more portable foam generators.
5. A supply of foam powder.
6. Portable fire extinguishers of the foam type at loading racks and platforms, and Ethyl plant, and carbon tetrachloride or carbon dioxide extinguishers for fighting electrical fires.

Of these the most important is a supply of water. As this will depend entirely on local circumstances, general discussion seems impossible. Advantage should of course be taken of municipal or industrial supply or of lakes, springs or rivers. A supply reservoir or tank may be needed.

The amount of powder to be stored will depend both on the size of the storage center and upon the possibility of getting a reserve supply quickly from some nearby municipality or oil industry plant.

All these things must be decided for each plant location.

APPENDIX I.

OTHER PLANS FOR GASOLINE STORAGE

It must be realized that the designs for storage discussed in the body of this report are all based on certain assumed conditions, one of which (arrived at after early conferences with Army and Navy representatives) was that, in most locations where storage would be needed, it would not be justifiable to attempt the deep cover necessary to protect against direct hits by demolition bombs.

There may be favorable locations where these assumptions would not apply, and it seems well to consider briefly certain other schemes that have been suggested. Some of these plans laid before the committee verge on the fantastic, but others have a greater or less degree of merit at least under some circumstances. The following is not an exhaustive list.

1. Storage in abandoned mines and caves.

One of the suggestions most frequently made to the committee is to build tankage in abandoned mines or natural caves, or, as an alternative, to store gasoline in drums in such available sites.

The suggestion of storage in drums, either in caves or anywhere else can, we believe, be dismissed at once, not because drums cannot be used, nor might not have to be used in an emergency, but because we are not considering emergency storage but reserve storage. The cost of drums, the danger of leaks in confined spaces, the cost of handling them, and the relatively large amount of manpower needed to handle them rapidly rule them out for other than special or emergency use, even if there were no question about deterioration of drummed gasoline after, say a year's storage; and there is such a question in the mind of every competent authority that the committee has consulted, although the emporical background for it appears to be very sketchy and inconclusive.

The question of building tankage in caves and mines cannot be discussed intelligently in general terms. It simply comes down to this: Name the cave or mine and decide whether its location is reasonably near a place where storage is wanted by the Services and then, after inspection of the site and consideration of transportation and other local factors, a recommendation can be made.

There are a few generalities, however, that may be worth mentioning.

Borings are necessary, particularly in natural caves, to determine the foundation conditions. Most mines and daves that members of the committee are familiar with have comparatively small open spaces, and considerable excavation and shoring would be necessary to permit installation of tanks a any size.

The installation of standard, low-cost steel tankage in large caverns or galleries has been suggested. It may not be impracticable, where such large spaces exist, but it involves serious hazards that ought to be well considered before plans are made. No one can guarantee that any gasoline tank will be completely liquid or vapor tight after a period of years. This means that every avenue by which vapor could drift from the place where the tanks are installed to other shafts or galleries must be blocked off, and that thorough rapid ventillation must be provided. It will also be necessary to extend the vent lines from the relief valves of the tanks themselves to an outside location. It might be feasible to surround the tankage with some oxygen-lean or inert gas such as CO_2 or nitrogen except when men need enter the space. All such provisions will add, not only to the first cost of the installation, but in many cases to the inspection and attendance required - and they will never eliminate the hazard completely.

It may be feasible to fill in solidly around tanks located in mines or caves, thus disposing of the explosion hazard. This would rule out standard tanks and raise the question of access for repair, inspection, or cleaning.

The committee does not wish even to seem to condemn the mine and cave suggestion on general grounds but doubts that many favorable sites can be found near the places where gasoline is needed by the Army and Navy.

2. Underwater storage.

Underwater storage has been suggested as frequently as cave and mine storage, and numerous patents have been granted to cover particular features. The committee has been told that such storage has been constructed in Europe. It must admit approaching this suggestion with a certain lack of enthusiasm due, perhaps, to its experience, which may lead it to give too much weight to commercial factors as compared to military ones. No attempt has thus far been made by our committee to calculate the cost of this type of storage nor to work out any actual design, but a few governing conditions may be mentioned.

In order to avoid excessively heavy anchorage and expensive bracing it is necessary to operate underwater tankage on the water displacement system, and this is the system invariably proposed in one form or another. As aviation gasoline weighs about 104 pounds per barrel less than water, and as a steel tank structure of any size would hardly weigh over 10 pounds per barrel a very substantial anchorage would be required even with the displacement system - say 1300 effective tons (equal to 1100 cu.yd. of concrete) for a 25,000 barrel tank. In theory, the tank would have a perfectly open bottom. In practice, this might be rather undesirable, increasing the possibility that a slight tilt would release the contents, and that the site might become surrounded with dead fish. (This is mere speculation). Leakage would be greatly to be feared in many if not most locations.

In many waters corrosion would be a very serious consideration. It is well known that pipe lines 5/8" thick have pitted through in three or four years in sea water. Some kind of protective coating would be desirable. It might take the form of reinforced concrete or, probably better, asphaltic concrete or mastic.

Cathodic protection could be used, and in fact would probably be essential in salt or brackish waters if long life and reasonable freedom from leaks were to be expected, even with a coating. It would not be prohibitive in cost, particularly if an insulating coating were used on the outside. It would also be desirable to have the cathodic protection cover the inside of the tank. This would argue for an open bottom. Of course, it would not be necessary to use the water surrounding the tank for displacement purposes, and some relatively passive water might be supplied for this purpose under normal circumstances.

In order to facilitate inspection and repair, it would be desirable to be able to raise the tanks from time to time. This would increase the complexity of the installation, but would not be impossible.

The committee does not know how much protection any given depth of water would offer to bombs, nor whether a depth bomb exploding near the tank would do great damage if the inside were completely filled with gasoline. The amount of concealment provided by the water would of course depend upon its purity and the smoothness of the surface.

Pumping equipment could be located on shore or on barges which could be moved about as required.

Perhaps the governing condition for this kind of storage is the availability of suitable sites where the storage is needed. It would seem that any further study would best be pursued on the basis of some specific site rather than mere general speculation.

3. <u>Storage in solid rock</u>.

It has been reported that in certain places in Europe storage has been provided in vaults excavated deep in rock cliffs. The feasibility and cost of such construction would be governed by local conditions. The cost would hardly be less than $3.50 a barrel.

4. <u>Pipe line storage</u>.

It has been suggested that pipe lines, with sectionalizing valves, be used for storage. The cost of such storage would be very high, and the surface area exposed to soil corrosion and action on the gasoline would also be high. Unless carefully graded, the pipe lines would be impossible to empty without special pumps or connections at low points.

5. <u>Underground tanks buried in hillsides</u>.

To get deep cover it has been suggested that an easy plan would be to drift into the side of a hill. This construction has been reported in Europe. Again it is evident that the cost of it must depend largely on local conditions. Many hillsides are treacherous, and heavy shoring and very strong tank bracing might or might not be needed. The cost at the best would run higher than that of shallow underground tankage.

6. Protection by natural cliffs or canyons.

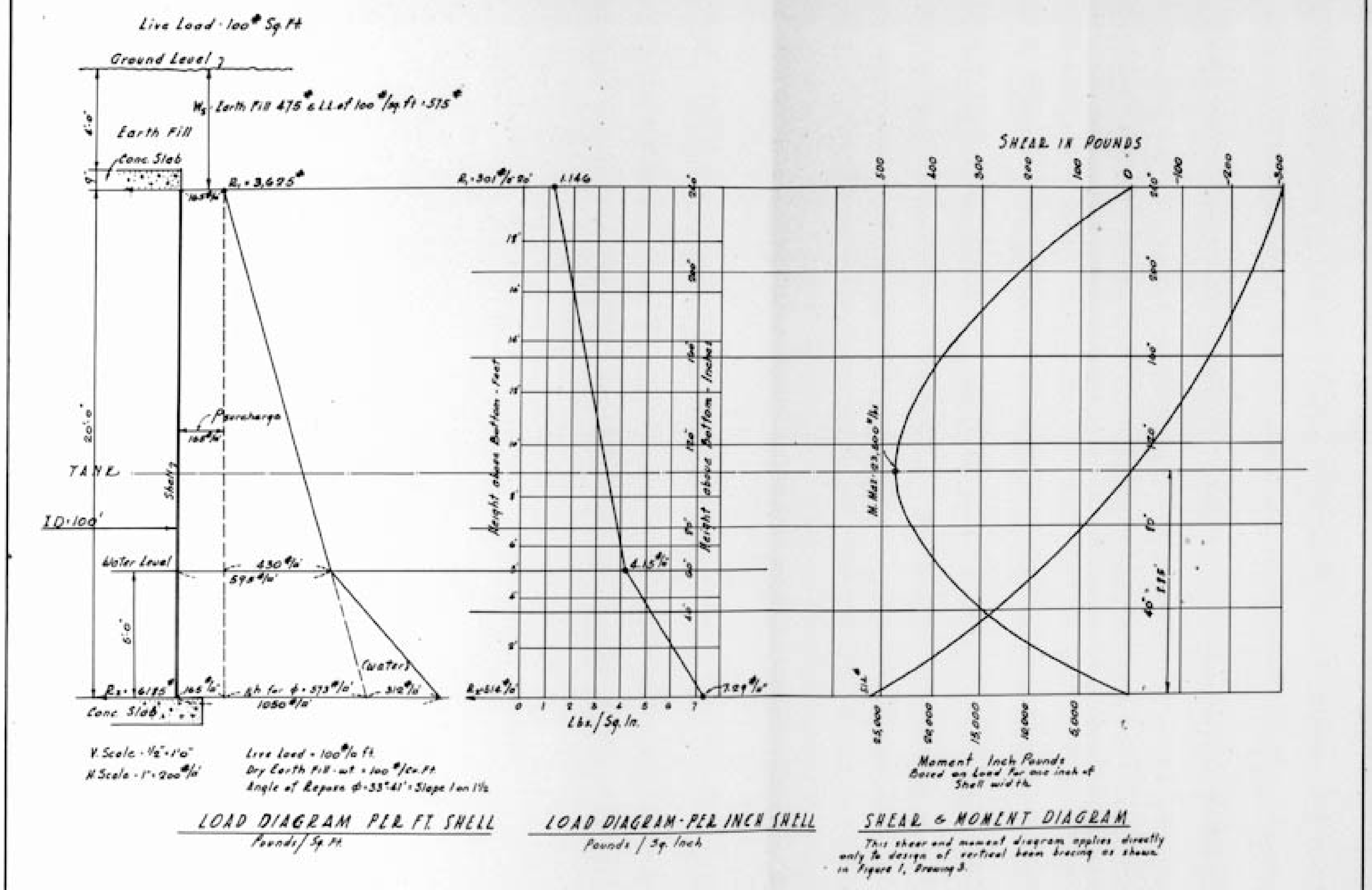
It has been suggested that tankage be protected by overhanging cliffs or by filling in deep canyons. Obviously no general statements can be made about this suggestion.

7. Protection of above-ground tankage.

Various bomb deflectors, nets, and types of camouflage have been suggested for above-ground tankage. It seems unnecessary to comment on these suggestions.

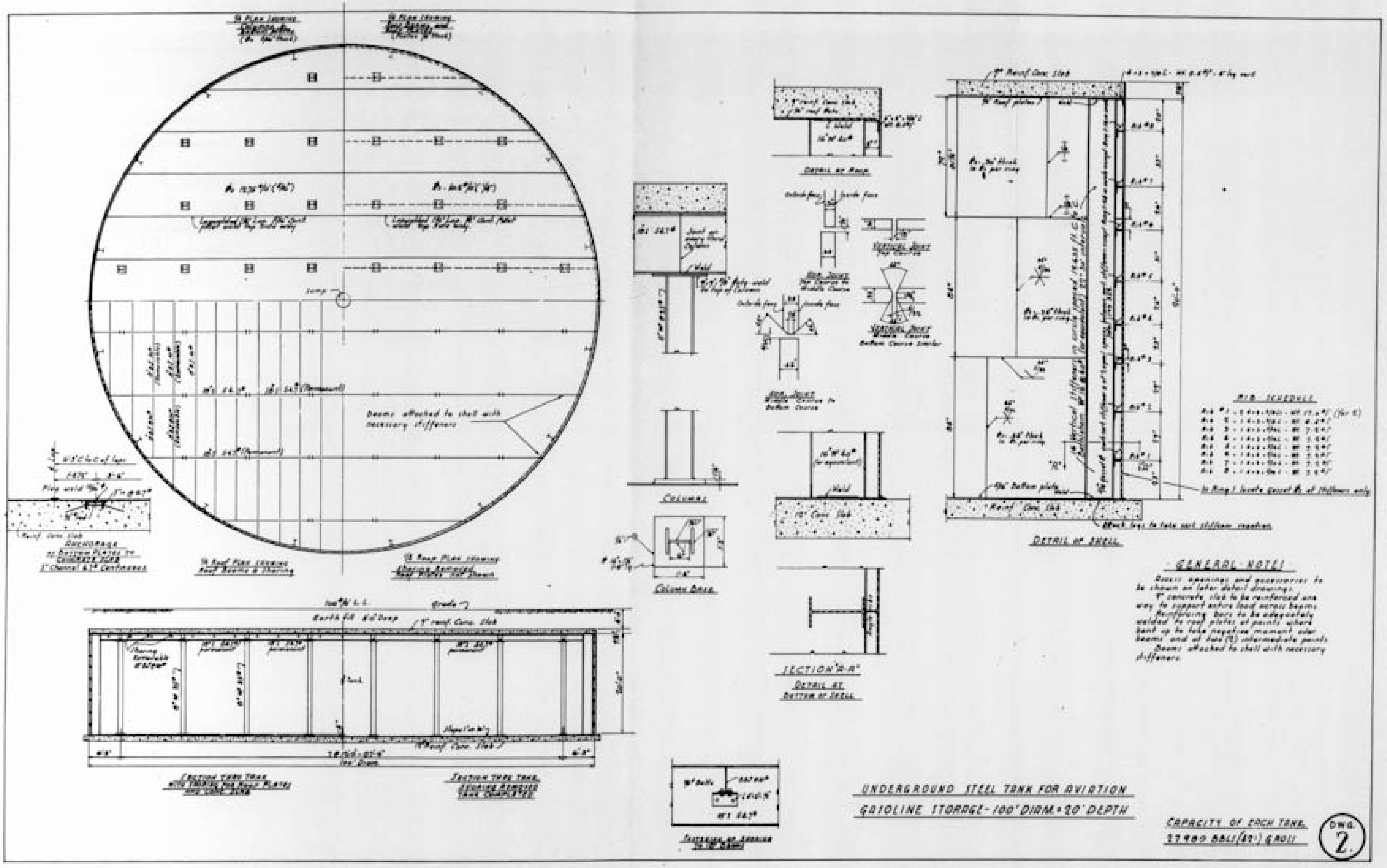
8. Storage in barges.

For emergency (rather than reserve) storage steel barges are very practical and flexible along the coast or in lakes and rivers. A steel barge 195' x 35' x 9' -6" having a capacity of 10,000 barrels complete except for pumps may be secured for about $25,000. These barges can be quickly built and may be moved from place to place as required. They may be sunk for protection and concealment, or buried in sand or mud or concealed in swamps or under trees. While barges are admittedly not suitable for long-time reserves, they appear to furnish an ideal solution to the problem of supplying storage quickly at outlying points accessible by water.



LOAD DIAGRAMS FOR UNDERGROUND TANK 100' DIA × 20' DEPTH FOR GASOLINE STORAGE

DWG 1



½ Roof Plan showing Roof Beams & Shoring
½ Roof Plan showing Shoring Removed Roof Plates not Shown
Sump
Beams attached to shell with necessary stiffeners
Anchorage
Columns
Column Base
Detail at Roof
Detail of Shell
Rib Schedule
Section "A-A"
Detail at Bottom of Shell
Earth fill
Grade
Section thru Tank
GENERAL NOTES
Access openings and accessories to be shown on later detail drawings.
Reinforcing bars to be adequately welded to roof plates at points where bent up to take negative moment over beams and at two (2) intermediate points.
Beams attached to shell with necessary stiffeners.
UNDERGROUND STEEL TANK FOR AVIATION
GASOLINE STORAGE - 100' DIAM. x 20' DEPTH
CAPACITY OF EACH TANK
DWG. 2.

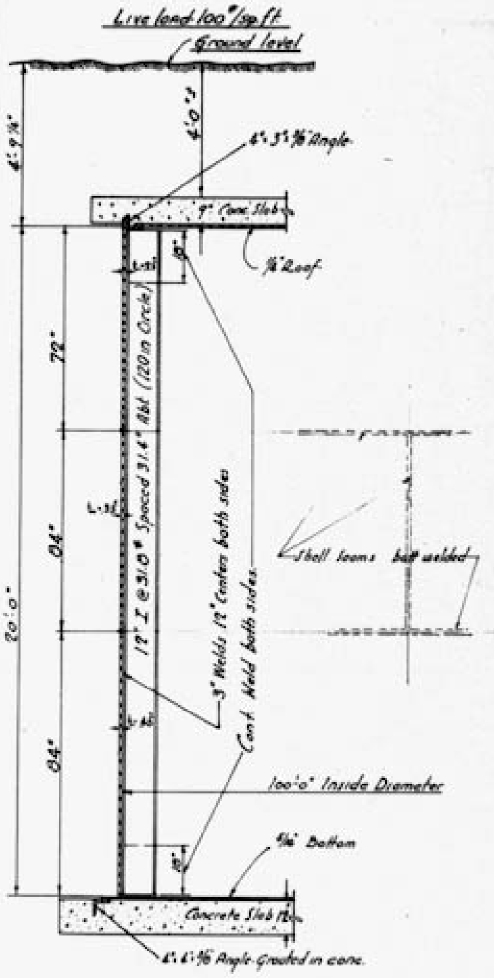


FIG Nº 1

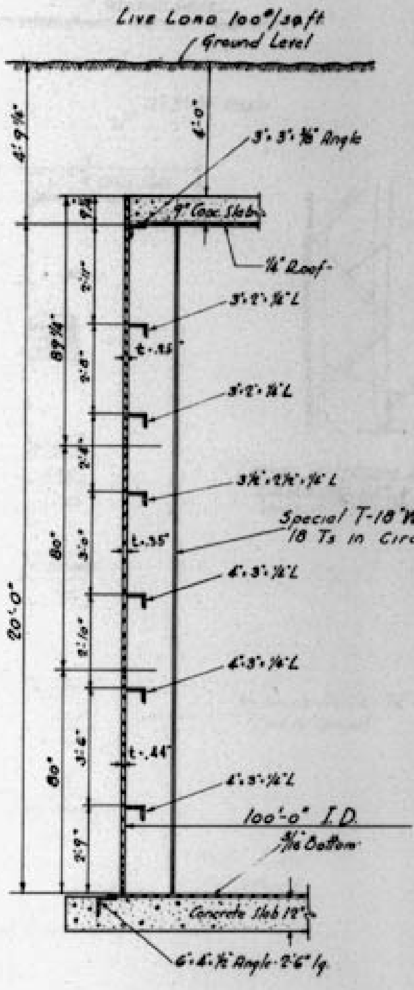


FIG Nº 2

·SOME · ALTERNATE · TYPES · OF·
·SUGGESTED · SHELL · SECTIONS·
(NOT · APPROVED · FOR · USE)

DWG 3

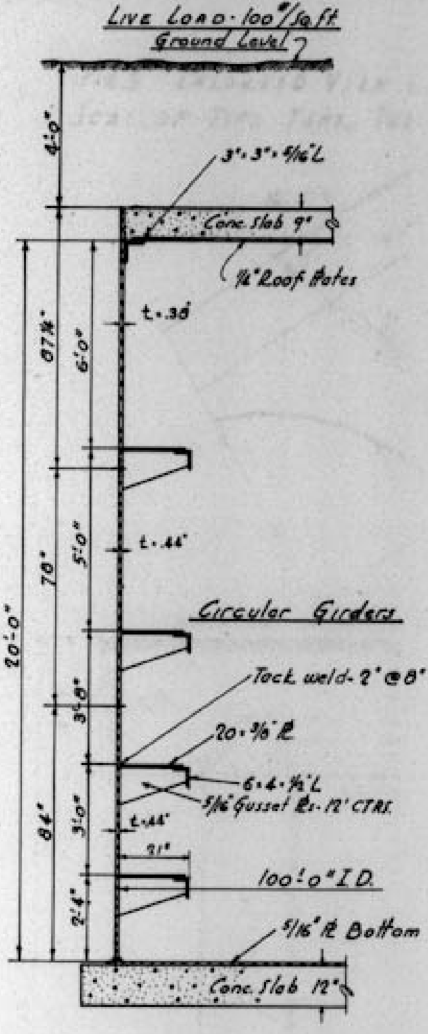


FIG. No 3.

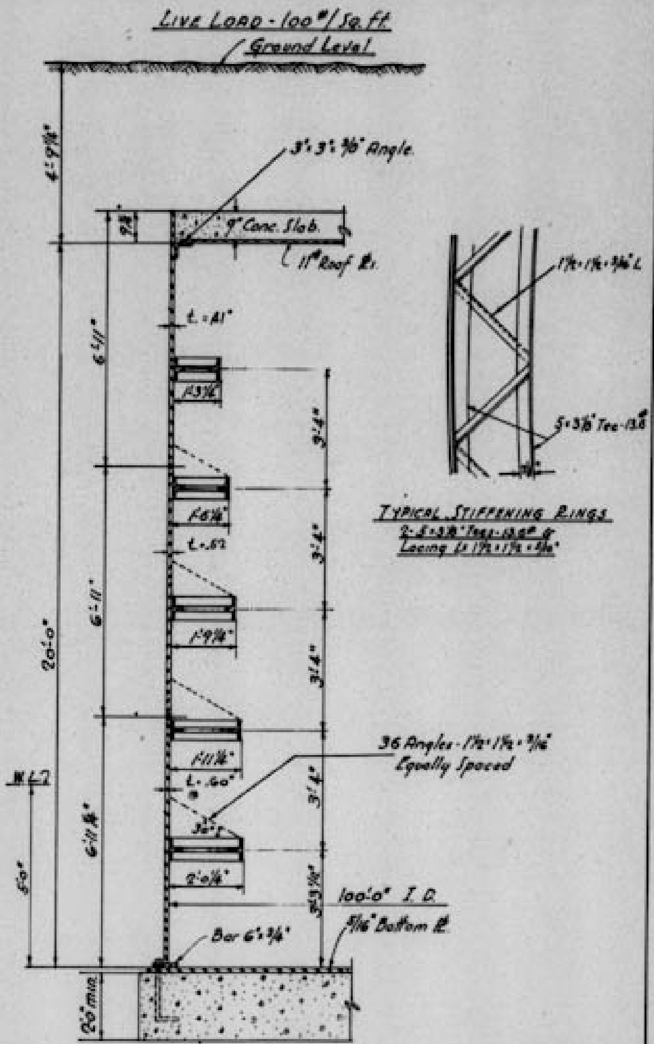


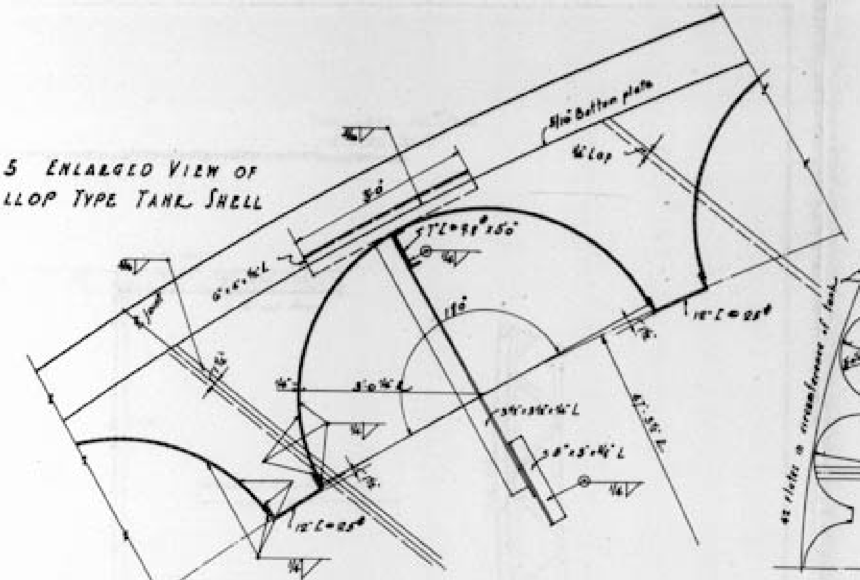
FIG. No 4.

·Some · Alternate · Types · of ·
Suggested · Shell · Sections ·

(Not · Approved · for · Use)

DWG 4

FIG. 5 ENLARGED VIEW OF SCALLOP TYPE TANK SHELL



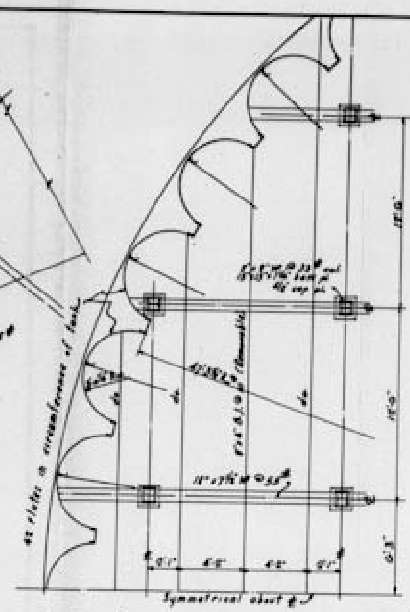


FIG. 5 PLAN OF SCALLOP TYPE TANK SHELL

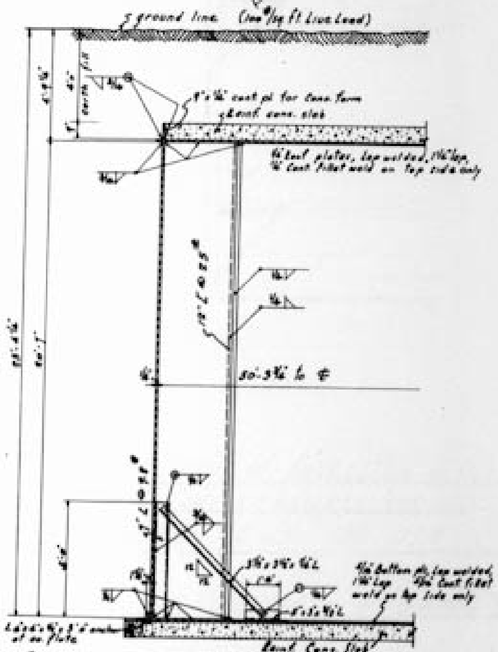


FIG. 5 ELEVATION OF SCALLOP TYPE TANK SHELL

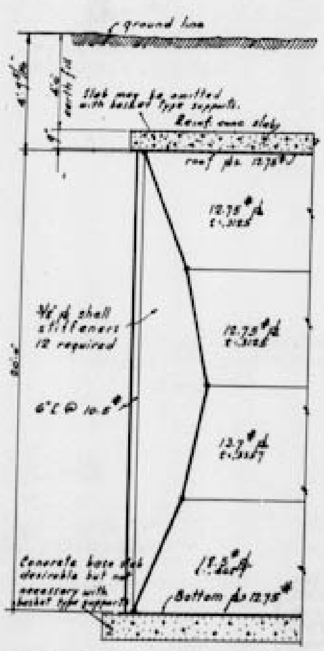


FIG. 6 ELEVATION OF POLYCONIC TYPE TANK SHELL

SOME ALTERNATE TYPES OF SUGGESTED SHELL SECTIONS

(SCALLOP TYPE AND POLYCONIC TYPE)

(NOT APPROVED FOR USE)

DWG 5

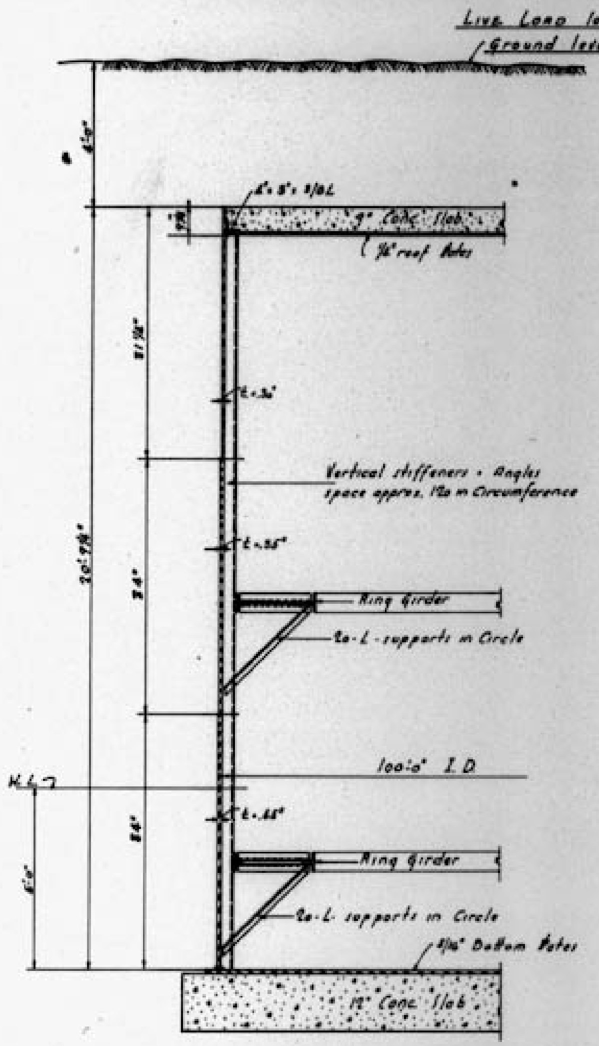
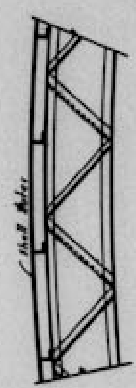


FIGURE 7



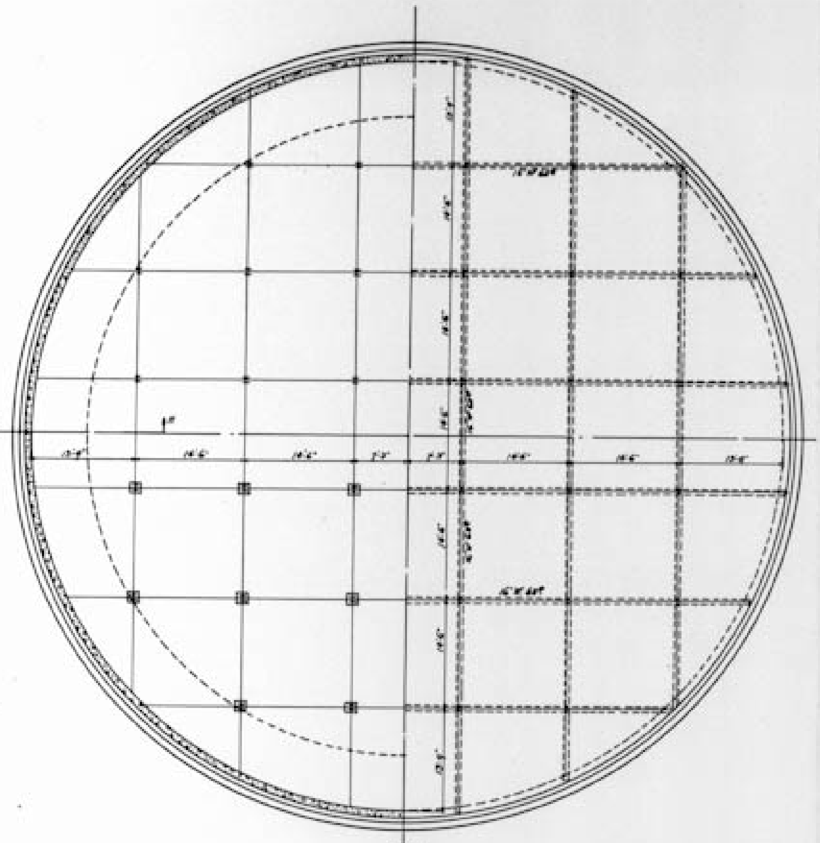
TYPICAL RING GIRDER COMPOSED OF T SECTIONS & LACING ANGLES

Note - This type of design is acceptable, but layout shown is schematic only. DO NOT SCALE.

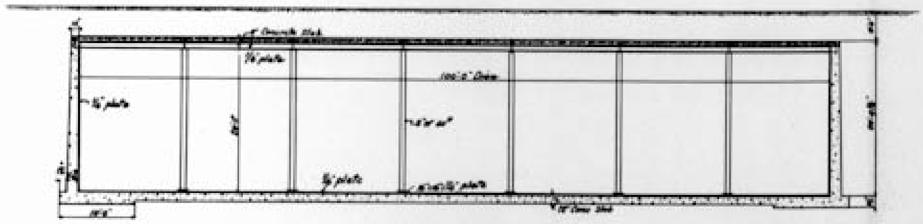
ALTERNATE TYPE OF SUGGESTED SHELL SECTION
(NOT APPROVED FOR USE)

UNDERGROUND TANK 100' DIA × 20' DEPTH
FOR
GASOLINE STORAGE.

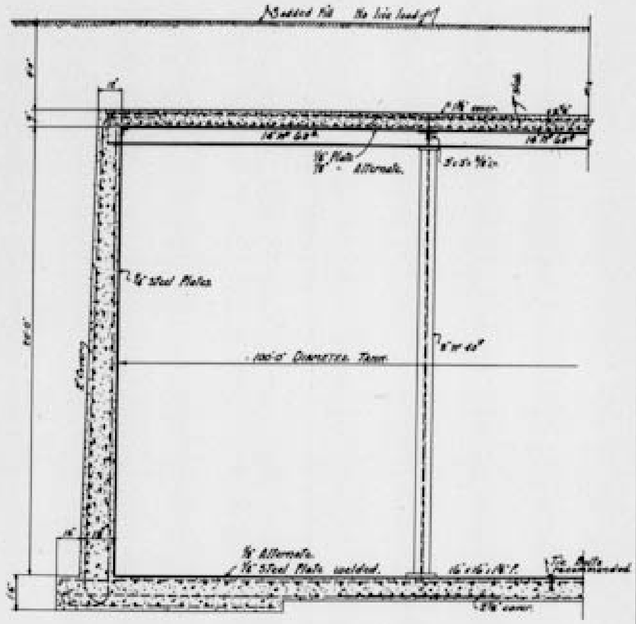
DWG 5A



PLAN



TYPICAL SECTION



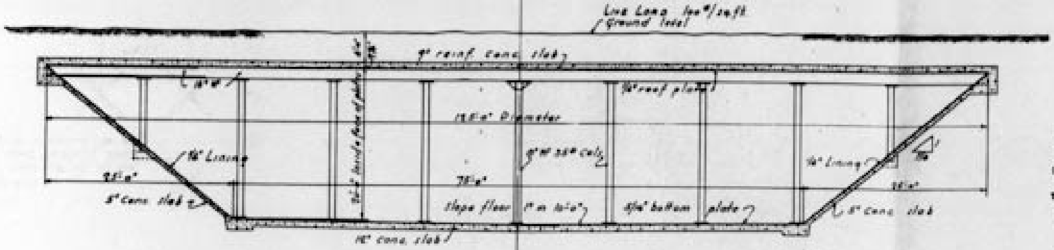
DETAIL SECTION H-H

All concrete to have a unit strength of 3000#/□" @ 28 days.
Reinforcing steel intermediate grade billet steel, deformed bars.

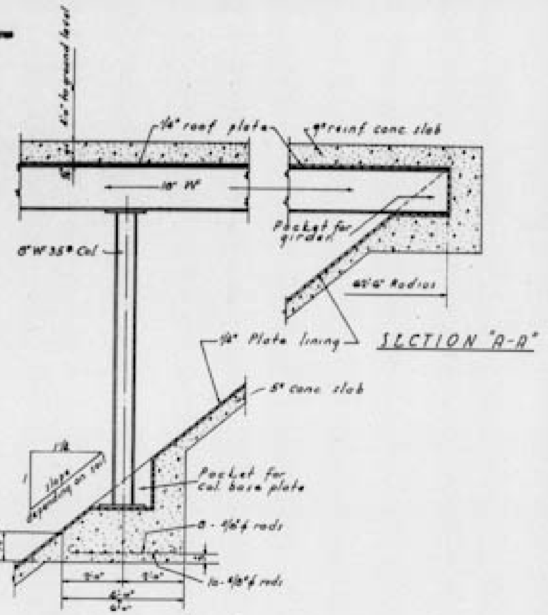
SUGGESTED DESIGN FOR
STEEL LINED CIRCULAR CONCRETE TANK

CAPACITY OF EACH TANK
27,980 BBLS. (42') GROSS

This Type of design applicable for special conditions. See Text.
Column & roof beam layout shown can be improved.

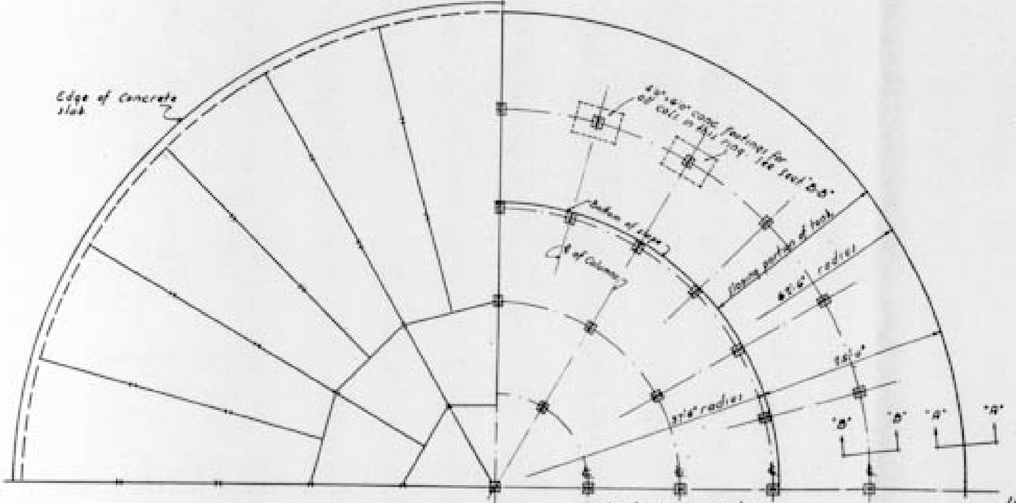


SECTION THRU TANK



SECTION "A-A"

SECTION "B-B"



1/4 PLAN SHOWING COLUMNS
BEAM & GIRDER ARRANGEMENT
(ROOF PLATES NOT SHOWN)

1/4 PLAN SHOWING LOCATION OF COLUMNS.

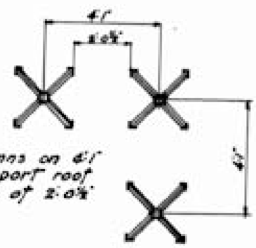
1/2 PLAN OF TANK

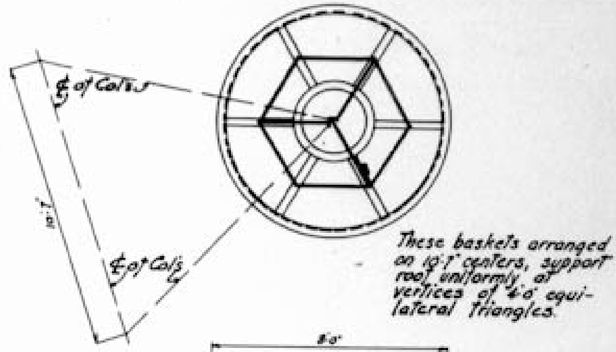
UNDERGROUND STEEL LINED RESERVOIR TYPE CONCRETE TANK FOR GASOLINE STORAGE

(NOT APPROVED FOR USE)

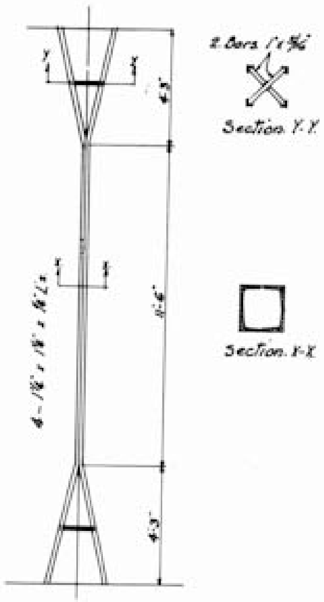
CAPACITY OF EACH TANK
27900 BBLS. (42") GROSS.
(APPROXIMATE)

DWG 7



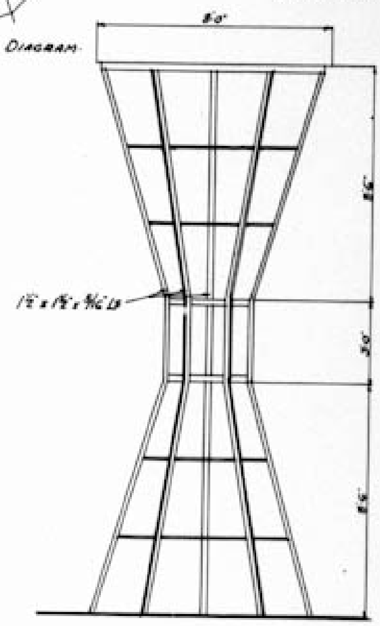


Spacing Diagram.



·Toothpick Type Column·

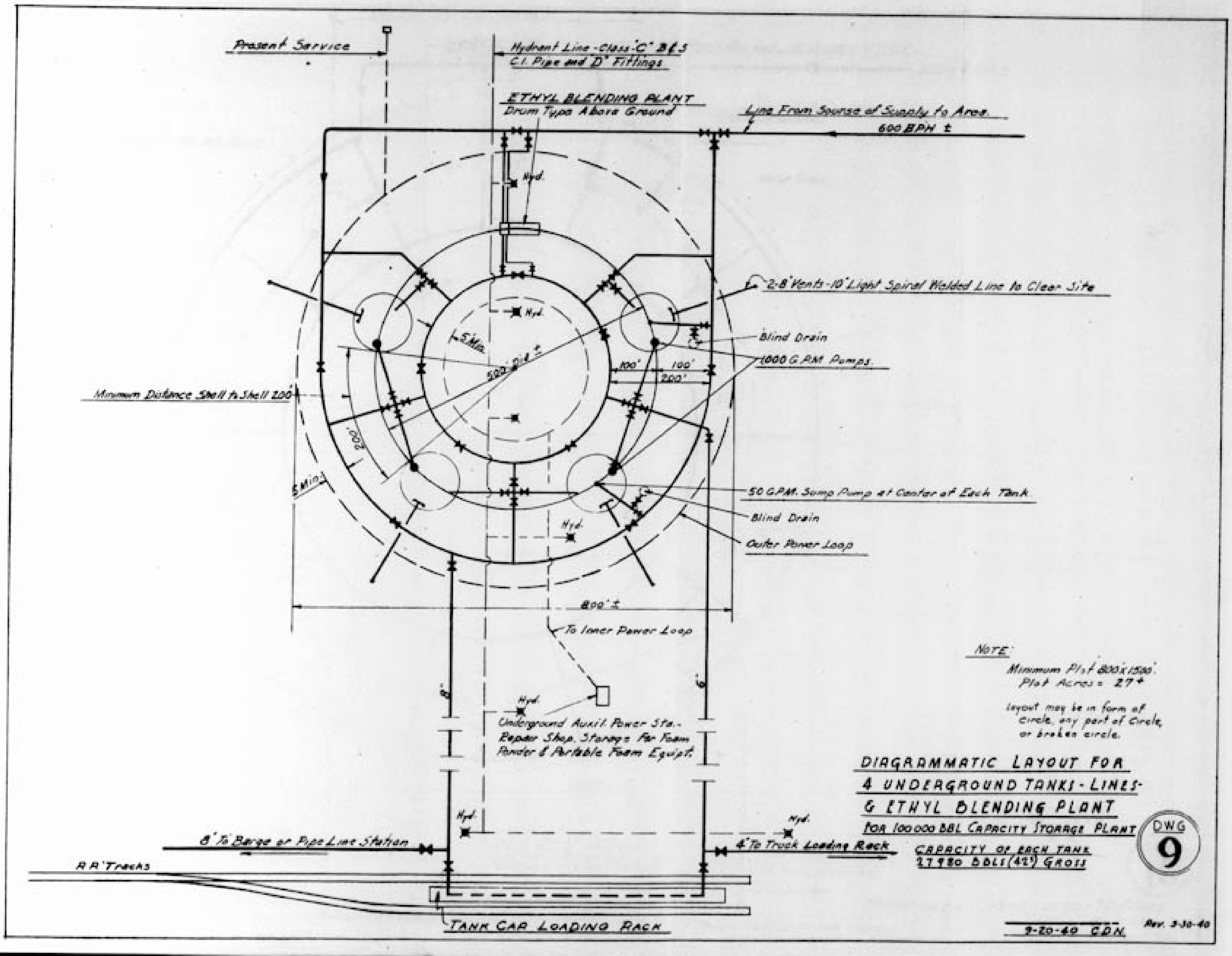
Fig. 8

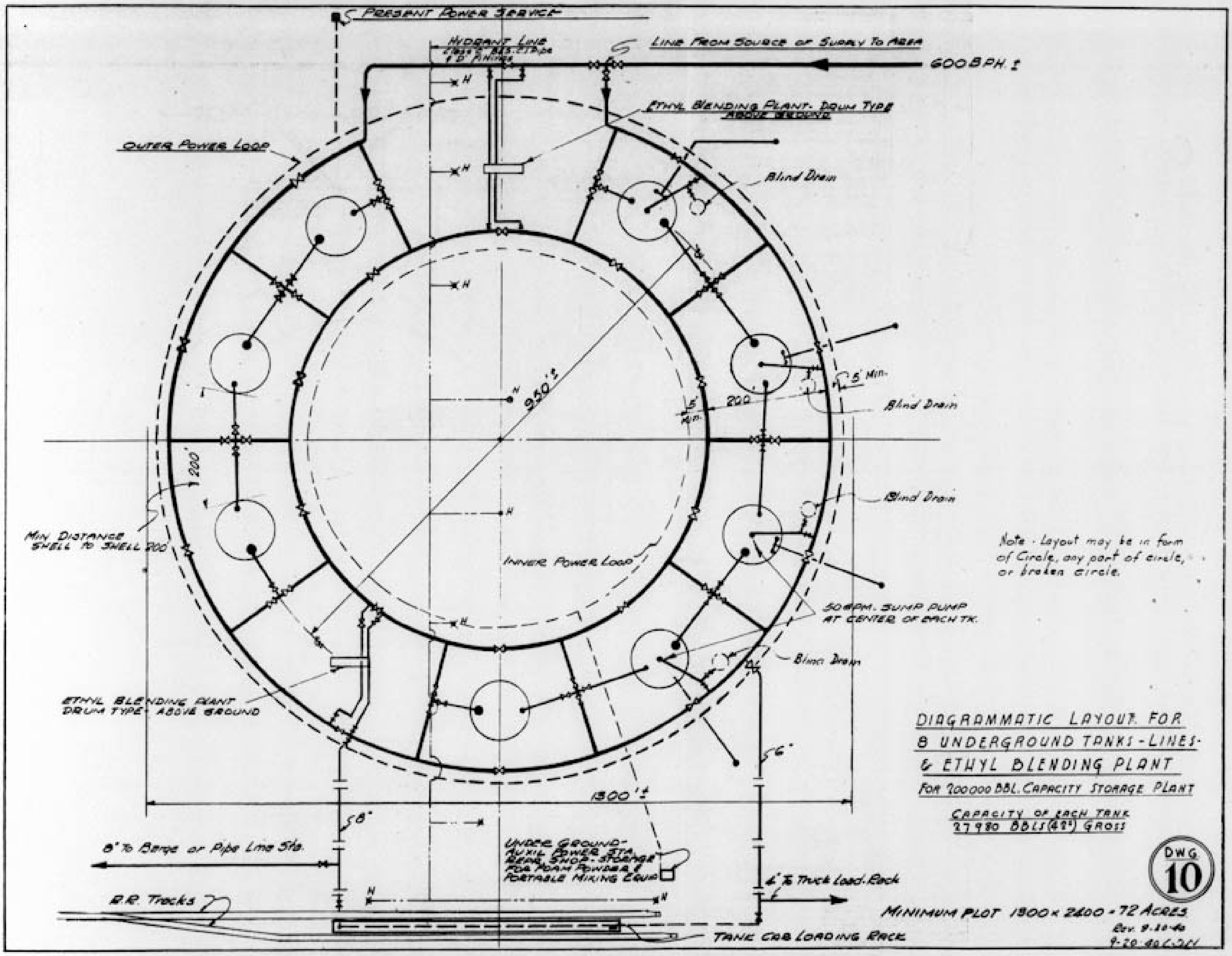


·Basket Type Column·

Fig. 9.

-Alternate Basket Type & Toothpick Type of Column-


Present Service
Hydrant Line - Class "C" B & S
C.I. Pipe and "D" Fittings
ETHYL BLENDING PLANT
Drum Type Above Ground
Line From Source of Supply to Area.
600 BPH ±
Hyd.
2-8" Vents - 10" Light Spiral Welded Line to Clear Site
Blind Drain
1000 G.P.M. Pumps
5' Min.
500' Dia. ±
100'
100'
200'
Minimum Distance Shell to Shell 200'
200'
5' Min.
50 G.P.M. Sump Pump at Center of Each Tank
Blind Drain
Outer Power Loop
800' ±
To Inner Power Loop
8"
6"
Underground Auxil. Power Sta. - Repair Shop, Storage for Foam Powder & Portable Foam Equipt.
8" To Barge or Pipe Line Station
4" To Truck Loading Rack
R.R. Tracks
TANK CAR LOADING RACK
NOTE:
Minimum Plot 800' x 1500'
Plot Acres = 27 +
Layout may be in form of circle, any part of circle, or broken circle.
DIAGRAMMATIC LAYOUT FOR
4 UNDERGROUND TANKS - LINES - & ETHYL BLENDING PLANT
FOR 100 000 BBL CAPACITY STORAGE PLANT
CAPACITY OF EACH TANK
27 980 BBLS (42) GROSS
DWG
9
9-20-40 CDN
Rev. 3-30-40



DIAGRAMMATIC LAYOUT FOR 8 UNDERGROUND TANKS - LINES - & ETHYL BLENDING PLANT

FOR 200000 BBL. CAPACITY STORAGE PLANT

CAPACITY OF EACH TANK 27980 BBLS (42°) GROSS

DWG. 10

Rev. 9-20-40
9-20-40 C.J.H.

GENERAL NOTES.

Perforate sides of Anode every four feet so that Anode bed may be wet by pouring water thru riser.

Place 4 to 10 tons of salt around each Anode before back-filling if soil resistance is more than 1000 Ohm CM. by Shepard Earth Resistivity Meter.

Wet down Anode bed while back-filling.

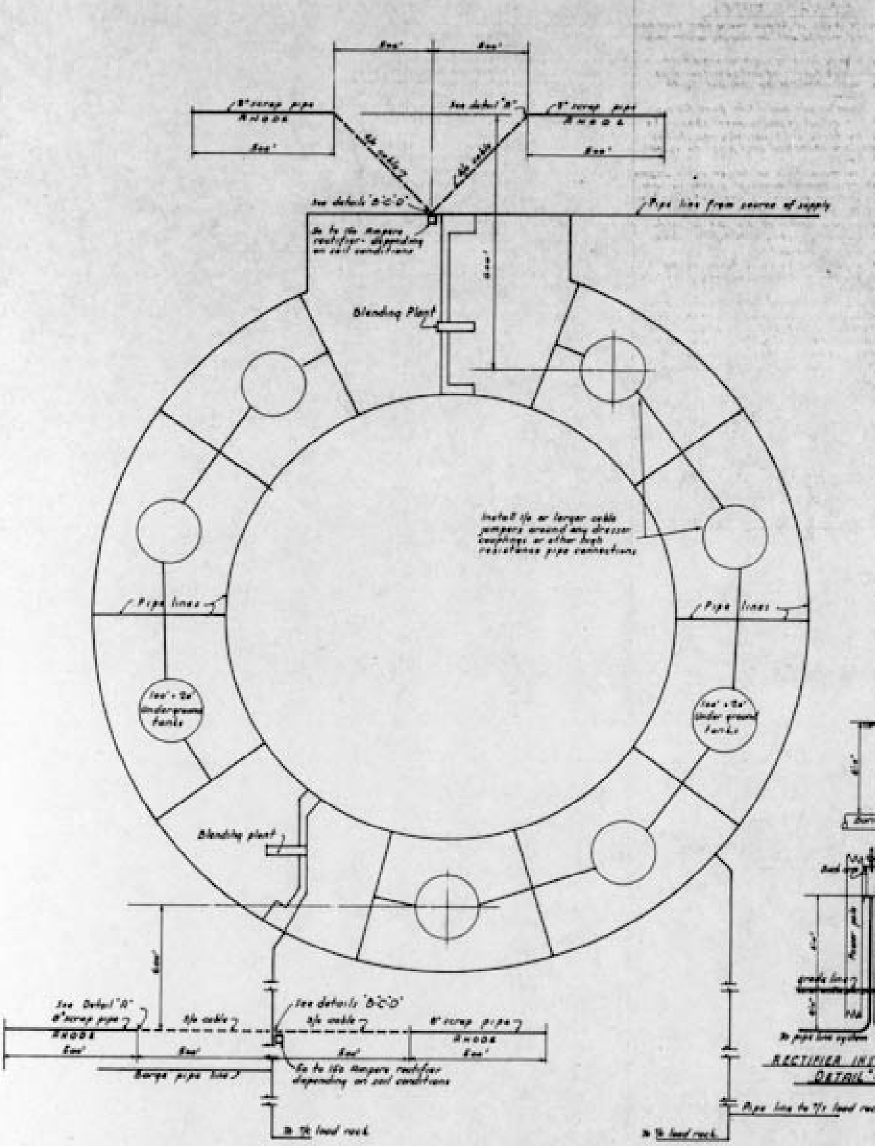
Rectifier output requirements should be determined by tests with welding machines after Anodes are installed and prior to selection of rectifiers.

Place permanent 1/0 or larger cable jumpers around high resistance joints of piping system for example dresser couplings. After the system is in operation temporary bonds should be placed around any point of the line prior to opening. These bonds should be left in place until lines are reconnected.

Coat pipe lines in tank farm using 2 coats of asphalt or better coating to reduce current pickup.

Tanks are assumed to be coated with Bitumine Enamel or equivalent coating if soil resistance is less than 2000 Ohm CM.

A competent Electrolysis Engineer should make complete tests and adjust the rectifiers when the system is placed in operation.



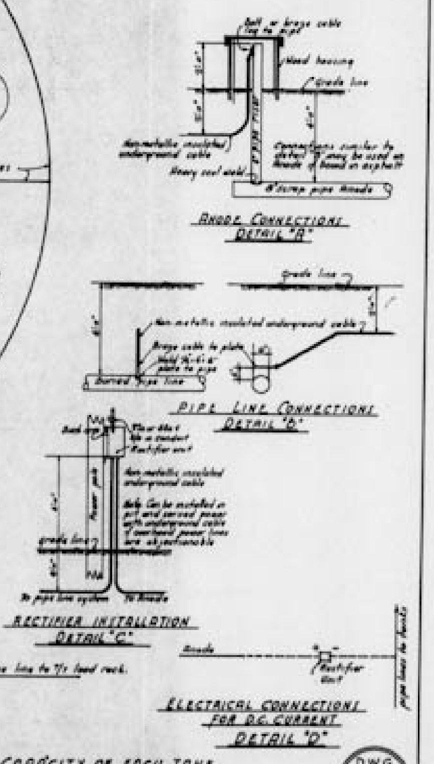


DIAGRAM OF TYPICAL CATHODIC PROTECTION FOR 8 UNDERGROUND GASOLINE STORAGE TANKS (100' x 20')

CAPACITY OF EACH TANK
27,980 BBLS (42') GROSS

DWG. 11