ANALYSIS OF DESIGN AND OPERATION OF A SWIMMING POOL

Thesis for the Degree of B. S.

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1927

SUPPLEMENTARY MATERIAL
IN BACK OF BOOK

THESIS

ANALYSIS OF DESIGN AND OPERATION
OF A
SWIMMING POOL

BY

R. C. HODGKINSON   C. R. V. SHELLEY

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THESIS

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INTRODUCTION

This thesis is divided into two parts, as follows:

Part I. Analysis of Design.

1. Analysis of loads--

   a. Live
   b. Dead

2. Analysis of Stresses--

   a. Steel
   b. Concrete.

3. Anslysis of sizes of

   a. Slabs
   b. Walls

Part II. Analysis of Operation.

1. Study of currents

2. Determination of chemical compounds in water of pools.

3. Study of organic life in pools

4. Suggested improvements in the Michigan State College swimming pool.

Acknowledgement is made of data given on swimming pool filtration by the following firms:

The Everson Filter Co., Chicago, Ill

The Norwood Engineering Co., Florence, Mass

The Sanitation Corporation, New York City

The Roberts Filter Mfg. Co., Darby, Pa.

American Water Softener Co., Philadelphis

International Filter Co., Chicago, Ill

The Graver Corp., East Chicago, Indiana

Robinson & Campau, Architects, Grand Rapids, Michigan, furnished plans for a swimming pool which is being built at the East Grand Rapids High School(May, 1927).

The following text books were used for reference:

Hool. Volumes I and II. Reinforced Concrete Construction.

Turneaure and Russell. Public Water Supplies. Third Edition.

Levine. Bacteria Fermenting Lactose and Their Significance in Water Analysis.

Prescott and Winslow. Elements of Water Bacteriology.

American Public Health Association. Standard Methods for the Examination of Water and Sewage.

Engineering News Record.

American City Magazine

Water Works Magazine

American Journal Public Health Magazine

American Physical Educational Review Magazine.

The Truscon Steel Company, of Youngstown, Ohio, furnished bar plans.

PART I—ANALYSIS OF DESIGN OF A SWIMMING POOL.

Although it was intended to analyze the design of the Michigan State College swimming pool, this could not be done due to the fact that the plans could not be obtained. This pool is of the beam and girder construction, set on columns instead of the usual method of setting the pool on the ground with proper footings.

The swimming pool that was chosen for analysis is the East Grand Rapids High School swimming pool, designed by Truscon Steel Co., of Detroit, Mich., under the architects Robinson and Campau, Grand Rapids, Mich. This pool is constructed of slabs and walls, the botton slab acting as a footing. There are no beams or girders.

The design of this pool was analyzed as follows:

1. Analysis of loads.

   a. Live

   b. Dead.

The loading used in this pool design and analysis is as follows--

The live loads are 150 pounds per square foot on the slab at the edge of the pool where the bathers walk. To take care of the live load for the pool itself, 50 per cent. was added to the dead load. This also took care of impact. When bathers enter the pool thereis no added load due to the fact that the water overflows into a drain thru the scum gutter. The 50 per cent. added to the dead load was considered sufficient for impact due to the fact that when a diver enters the water the added pressure is distributed over a large area.

The dead loads consist of the water at $62\frac{1}{2}$ pounds per cubic foot and the concrete at 150 pounds per cubic foot.

2. Analysis of stresses--

a. Steel

b. Concrete.

According to the Trucson Steel Company's design, the steel in this pool is stressed to 18,000 pounds per square inch of cross sectional area; and the concrete is stressed in compression to 750 pounds per square inch. The concrete is allowed to take tension of less than 200 pounds per square inch, or less than 10% of the ultimate compressive strength.

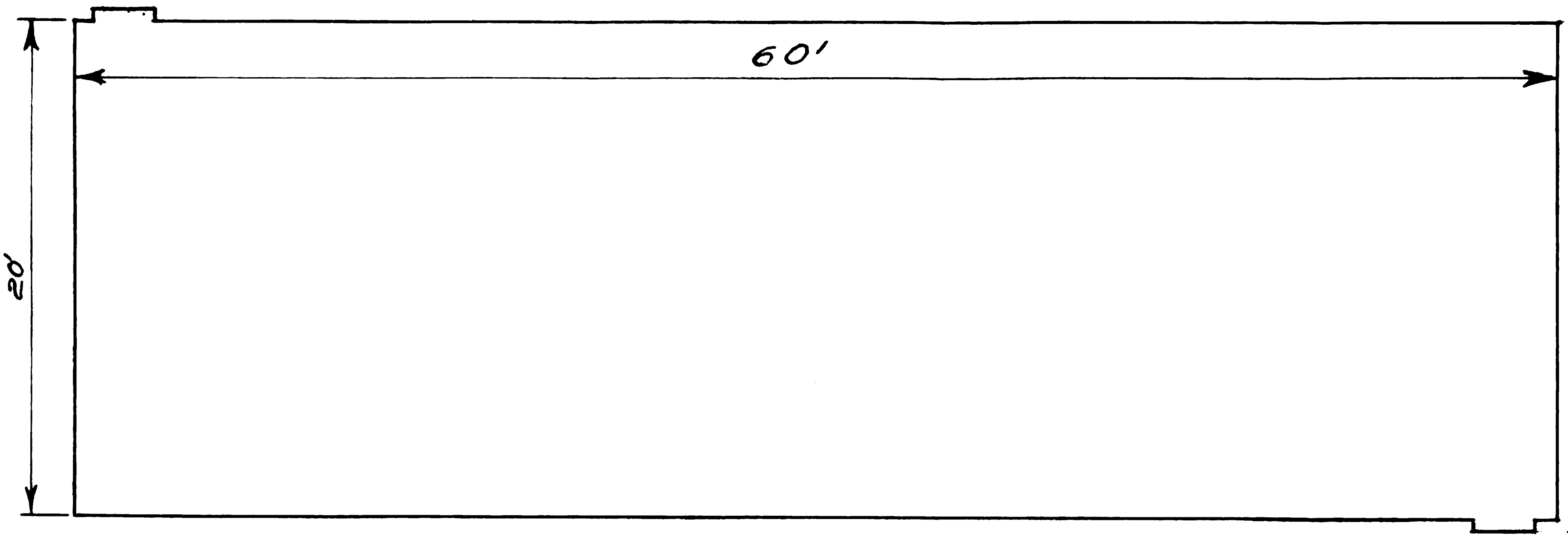
These stresses are higher than are usually used due to improved methods of construction and methods of mixing concrete.

3. Analysis of

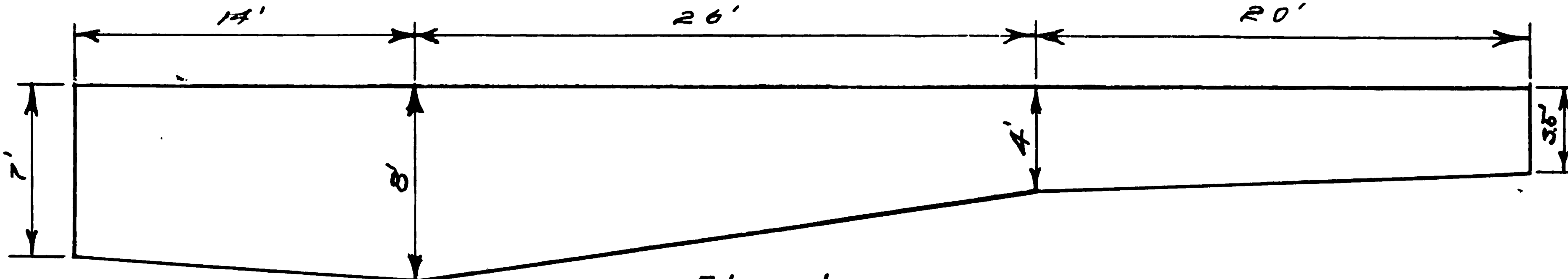
a. Slabs

b. Walls.

These wall and slab depths were designed



Plan



Elevation.

for maximum points only. The reason for this is to save money and time in building forms.

The following formulas were used to determine depth of concrete and size of bars:

$$d = \sqrt{\frac{M}{Kb}}$$

d = depth to steel

M = maximum moment

K = constant taken from tables

b = breadth of beam = 12 inches

D = c + d

D = total depth of concrete

c = concrete covering for steel

$v = \frac{V}{jbd}$ Must be less than 40 pounds per. sq. in.

v = unit shear

V = total shear in section

$j = \frac{7}{8}$

$$u = \frac{V}{\Sigma ojd}$$

u = unit bond stress

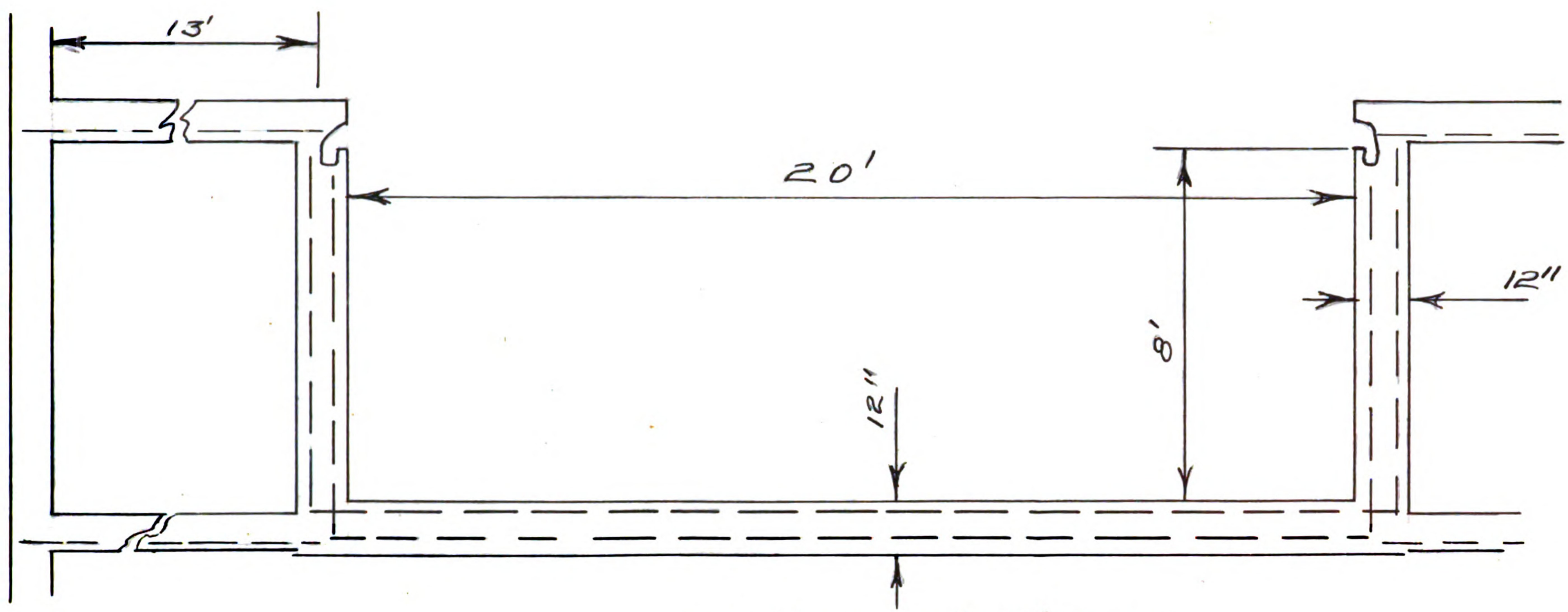
Σ = summation

o = circumference of bars

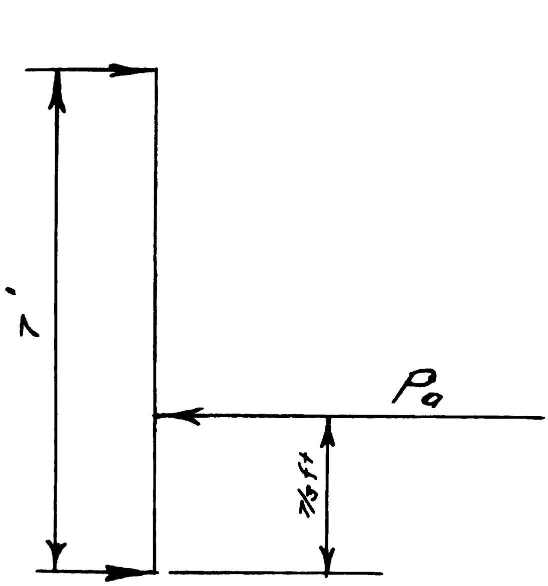
$a_s = pdb$

a_s = area of steel cross-section

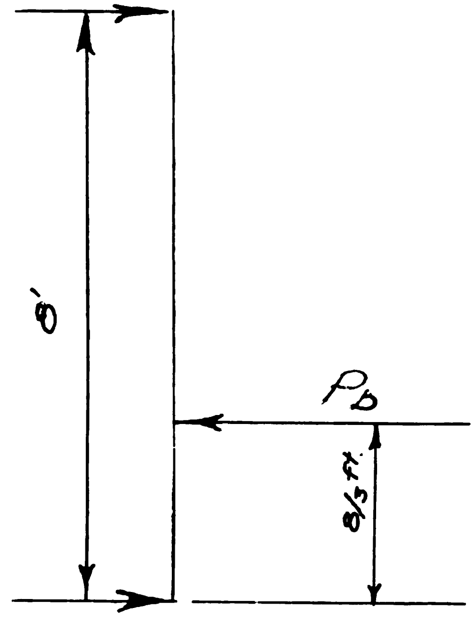
p = .008



Section at 8' depth

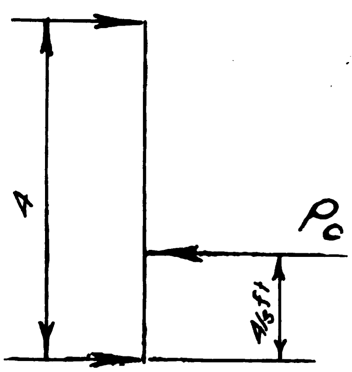


1.

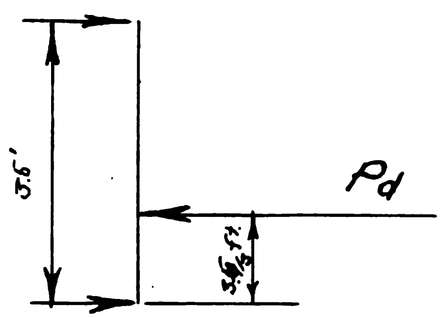


2.

Cross section
Mom. Arm.



3.



4.

$a_s = \frac{}{f_s jd}$

f_s = unit tensile stress of steel = 18,000 pounds

$P = \frac{1}{2}wl^2$

P = total pressure

w = weight per foot

l = total length of beam

For the walls we consider that the concentrated load P acts at a point one third the height from the bottom. Using the value for P the two resultants were found (see figure 1). The maximum moment is found at P and equals R_1 times a.

The resultant R_1 was found to be 510 pounds and a = 4.66 feet.

Refering to figure 1, the moment was found to be 510 x 4.66 = 2400 foot pounds.

Refeerring to figure 2, the moment = 666 x 5.34 = 3550 foot pounds

Referring to figure 3, the moment is 166 x 2.66 = 450 foot pounds.

From figure 4, the moment = 128 x 2.33 = 300 foot pounds.

Referring to section 5, moments are equal ~~to 400 x 1150 = 4600 foot pounds.~~

These moments are increased by one-half to allow for impact.

Design of slab in bottom of the pool---

This also is the footing for the pool. This is designed as a simple beam supported at the ends. Width of beam is taken as 12 inches. R_1 is found by computing liye + dead weight on one slab. Live + dead weight equals = $R_1 = (1 \times 10) + (150 \times 13) + (1 \times 13) = 1975$ #

$R_2 = 765$ #

This resolves into a concentrated load of 2740 pounds at 15 feet. The moment = 6 x 1975

$$d = \frac{\sqrt{1975 \times 6}}{\sqrt{125}} = 9.5 \text{ inches}$$

D = 12 inches

To get the amount of steel for the floor slab--

$a_s = .008 \times 10 \times 12 = .96$ square inches

Five one-half inch round bars. This is OK

The above steel is for the top of the slab. The same amount is used for the bottom of the slab. This was found to be greater than the amount actually needed.

Design of floor slab around sides of the pool--

Span = 13'

Moment = $1/12\ w\ l^2$ = 4300 foot pounds

$$d = \frac{\sqrt{4300}}{\sqrt{125}} = 6 \text{ inches}$$

D = 9 inches, using three inch cover.

To find the depth of wall slab from the largest bending moment---

$$d = \frac{\sqrt{3550 \times 12 \times 1.5}}{\sqrt{125 \times 12}} = 6.5 \quad \text{Called } 7''$$

Two and one-half added on each side to cover steel.

Therefore, D = 12''

To find the area of the steel--deep part---

$$a_s = \frac{3550 \times 12 \times 1.5}{18000 \times 7/8 \times 7} = .58 \text{ sq. in.}$$

Two 5/8 inch round bars used. This gives .60 square inches. Bars spaced six inches on centers.

To find steel area for the shallow part of the pool---

$$a_s = \frac{1550 \times 12 \times 1.5}{18{,}000 \times 7/8 \times 7} = .30$$

One 5/8 inch round bar used--spaced at twelve inches center to center. Steel area for one 5/8 inch round bar = .30 inch.

Examination for bond--

$$u = \frac{2000}{12/6 \times 2 \times 1.96 \times 7/8 \times 7} = 42 \text{ pounds}$$

$$u \text{ at shallow end of pool} = \frac{2000}{2 \times 1.96 \times 7/8 \times 7} = 84\#$$

Therefore, bond is OK

a_s = .008 x 6 x 12 = .58 square inches

Three 5/8 inch bars used. Spacing is 4 inches on centers.

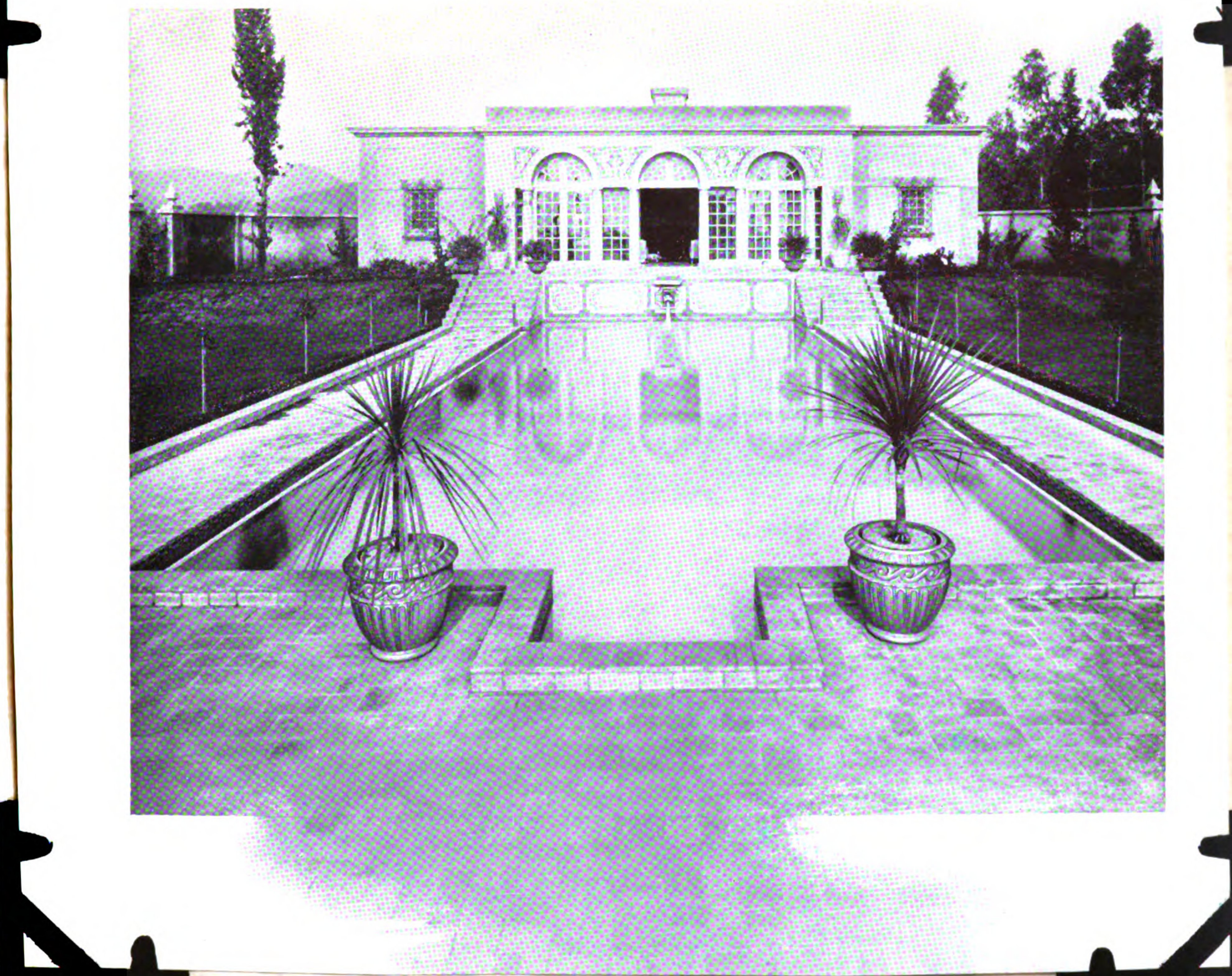
The same area of steel is used all the way around the pool, even tho the span changes.

To care for thrust at R_2 a 9 inch slab is used with the same steel area and spacing as for the slab designed above.

Test for compression—to care for R_1 and R_2

$$\text{Unit stress} = \frac{1332}{12 \times 9} = 12.35 \text{ for concrete } \#/\text{ sq. in}$$

This is OK, as a compression of 750 #/ sq. in is allowed.



A private pool at Beverley Hills, California.

Heater and filter for the above pool.

PART II-ANALYSIS OF OPERATION, WITH RECOMMENDED IMPROVEMENTS OF EXISTING DESIGNS.

Very often a swimming pool is considered merely as a tank to store water for the use of swimmers. This is the wrong viewpoint, as a pool should be designed for the special purpose of providing bathers with a supply of clear, pure, sparkling water, free from dirty film or deposit on the sides and bottom.

There are two methods of maintaining the water supply of pools: the "fill and draw" and the recirculatind and refiltering methods. With the fill and draw method the pool is filled directly from the water supply and is emptied into the sewer when it is too dirty for further use for bathers. In this case the pollution of the pool is progressive as the bacteria, dirt, lint, etc. from the bodies of the bathers accumulates in the pool. This method is unsanitary and uneconomical and in some localities is impossible to use. Also, the pool is out of use much of the time while the operations of draining, cleaning, and refilling are going on.

With the use of the recirculating and refiltering method as usually installed, the water is filtered, heated, and disinfected. The water is drawn from the pool by a pump, forced thru filters, sterilized, and returned to the pool. The generally accepted circulation time for the contents of the pool is from ten to eighteen hours, ten hours being preferable.

As generally understood, filtration of water means the removal of suspended matter visible to the eye. To be efficient, a filter must also remove color and odor, as well as pathogenic bacteria, from the water. B.Gage and Bidwell have worked out the law of purification by consecutive dilution as applied to recirculation and flowing thru pools, as follows:

"It is proposed that the rate of water interchange in a recirculation for flowing-through pool be expressed as the ratio of the volume of lcean water entering the pool in 24 hours to the total pool volume. This ratio is called the turn-over rate or T, as T = 1 when all the water is circulated in 24 hours; T = 2 when the water is circulated twice in 24 hours, etc. It is demonstrated by computation and experiment that 7 turnovers are required to remove 99.9 % of the dirt in the water.

1st.	turnover	removes	63% dirt
2nd.	"	"	86%
3rd.	"	"	95%
4th	"	"	98%
5th	"	"	99.3%
6th	"	"	99.7%

To accomplish a purification of 99.99% ten turnovers would be necessary

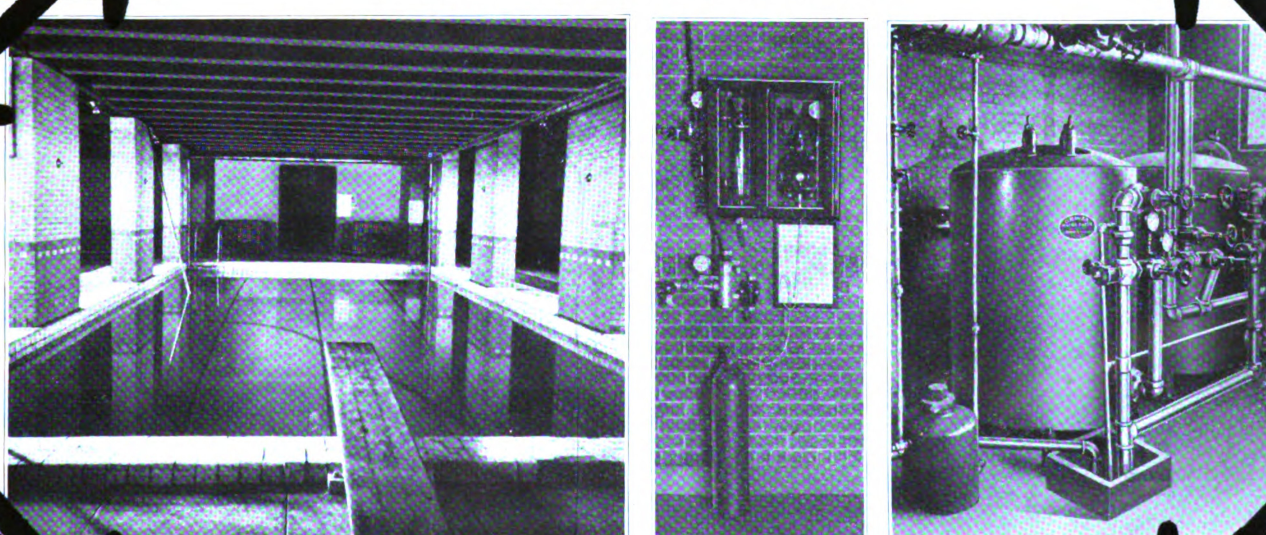
If the pool is used regularly by bathers further increments of dirt will be introduced into the water daily, and the removal of each successive daily increment will proceed according to the law. Assuming a daily increment of dirt equal to that in the pool at the start and a filter efficiency of 100% with a daily turnover of T = 1, equilibrium will be reached at the end of the ninth day when the accumulated dirt in the pool will be equivalent to about 58% of the amount present when recirculation and daily bathing started; with T = 2, this is about 16% in 4 days; with T = 3, it is 5% in 3 days; and when T = 4, 2% will be obtained in 2 days.

It is evident, therefore, that if clean water is to be maintained, the recirculation or flowing through systems must be designed to providd a turnover tatio of at least two and that where heavy bathing loads are anticipated, the turnover ratio should be three or four".

As filtration is usually practiced, ti consists of passing the water thru layers of sand or crushed quartz or gravel. This may be done either by gravity or pressure, called "slow sand" and "rapid sand" filters. Slow sand filters require a large area and are usually impractical for swimming pool work. Pressure filters operate 40 or 50 times as fast as the gravity, occupy a relatively small space, can be easily cleaned by back-washing, and provide uniformly filtered water at all times, with but small waste of water (some is wasted in back-washing).

A large outdoor pool at Newark, New Jersey.

Filters for the above pool.

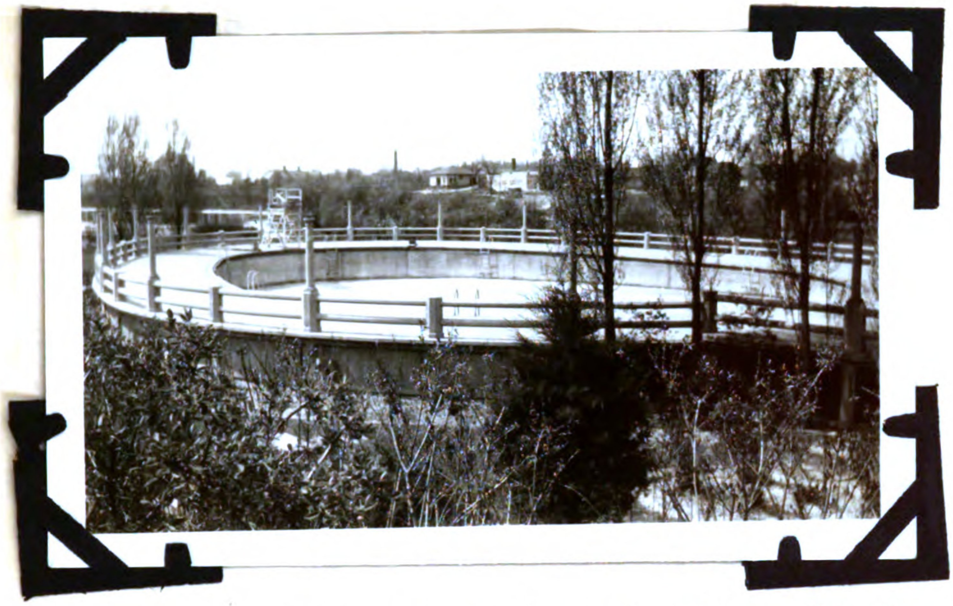


Pool, sterilizer, and filters—Ohio University, Athens.

The efficiency of the pool itself depends upon whether or not all of the water circulated thru the filters. With some designs, there are "dead areas" which are missed by the currents. This was found to be true of the Michigan State College swimming pool. An experiment was made upon a small model, made in exact proportion to the big pool, with inlet and outlet in the same relative places, and of relative size. It was found, by use of black ink as a dye, that there are dead areas in each corner and along sides. There should be enough inlets and outlets in the proper places to cause currents to circulate all of the water. A design of a pool which it is beleived will do this, is a paft of this thesis.

The chemical composition of the water of pools differs slightly from the chemical composition of the water supply from which it is taken, due to chemicals added for sterilization and clearing of water.

There are three practical methods of sterilizing water (boiling is too expensive as a rule) : 1. chlorine, either as the gas or as hypochlorites; 2. ozone; and 3. ultra-violet light. Chlorine is generally used, and it is this which makes the greatest change in the chemical composition of the pool water. In outside pools $CuSO_4$ is used to destroy the diatoms and algae which cause green scum on the sides of pools, and this of course enters into the composition of the water



Kearsley Park pool, Flint, Michigan.

Kearsley Park pool, Flint, Michigan

Lakeside Park pool, Flint, Michi

In cases where the filters are entirely inadequate, and where large amounts of organic matter enter the pool, nitrogen is found as albuminoid ammonia, free ammonia, nitrites, or nitrates, depending upon the state of decomposition of the organic matter. In all natural sources of water there are sertain chemical compounds, such as SiO_2 , FeO_3, Al_2O_3 $Ca(OH)_2$, $Mg(OH)_2$, NaCl, HCO_3.

Chlorine in pool, or other, water, must be in the molecular, Cl_2, form to be effective in destroying bacteria. The amount of excess chlorine must be 0.1 p.p.m. or not over 0.5 p.p.m. (parts per million) The reason is that at least 0.1 p.p;m. is necessary to be effective as a sterilizing agent, and if it gets over 0.5 p.p.m. there are offensive chlorine odors, as well as smarting of the eyes.

Wherever sulphate of alumina is used (as a coagulant) during purification of swimming pool waters the water should be slightly alkaline at all times

A test on the water of the Michigan State College pool gave the following results:

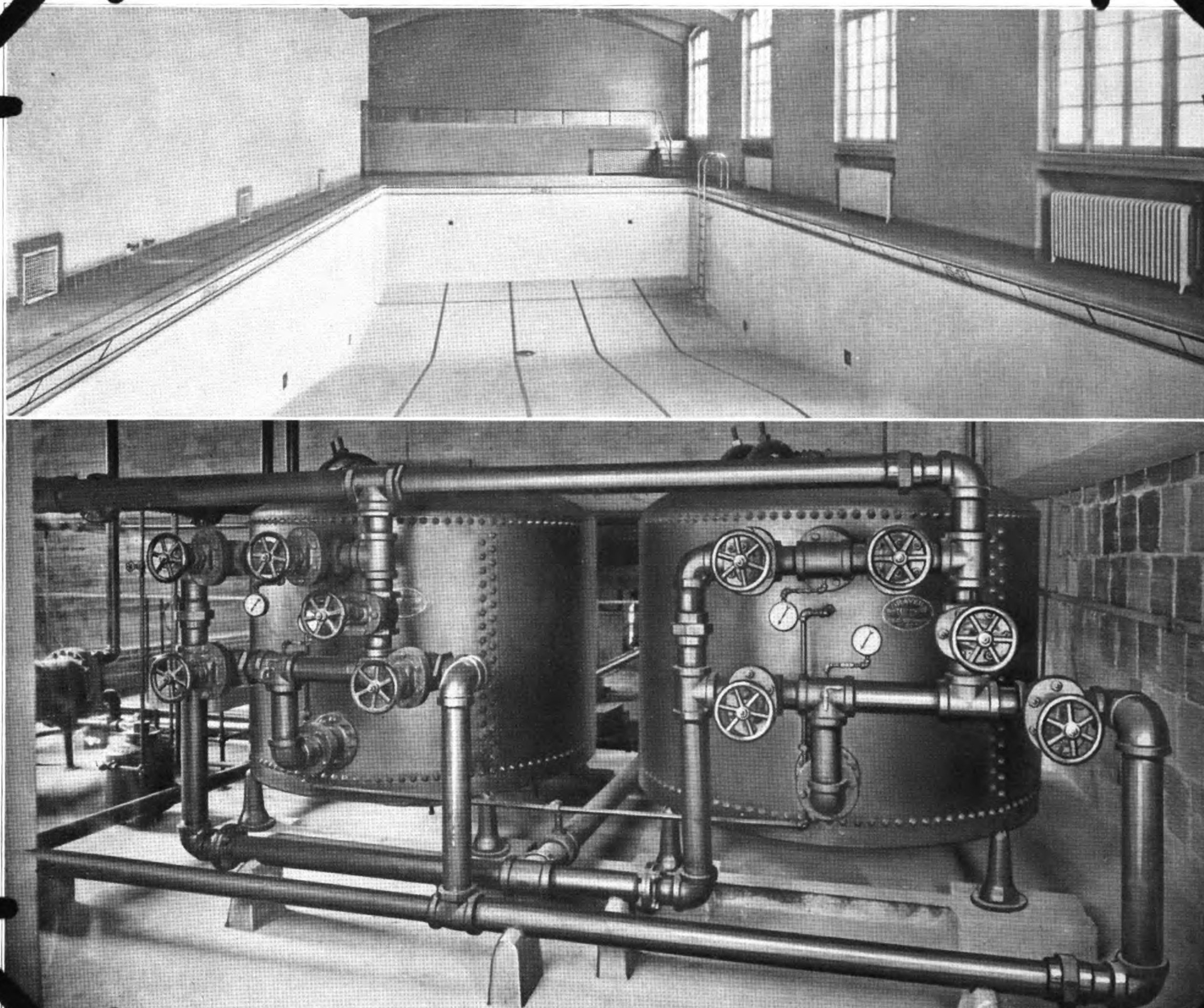
		Limit
Total solids-	240	500
Organic matter	95	less the better
Mineral matter	145	OK for pools
Free NH_3	0.02	.05
Albuminoid NH_3	0.01	0.15
Chlorine	4	5
Nitrate	0.35	0.5

The sample for the above test was taken

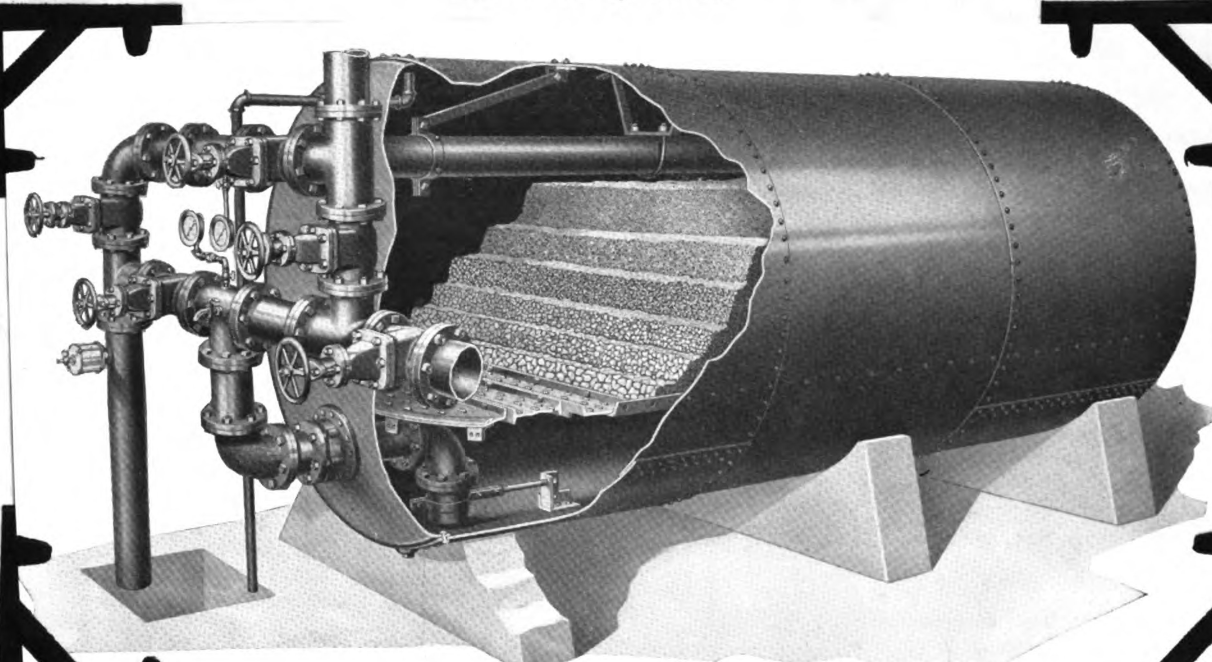
soon after the pool had been in use for several hours, and the water had not been thru the filter. This accounts for the high organic matter as well as the nitrogen compounds.

At the college pool chloride of lime is used as the disinfectant. This is mixed with the water as it goes thru the filter in a special mixing device. The chloride of lime is of a 0.5 to 1.0 per cent strength. The cost of the treatment is quite low, ranging from ten to thirty cents per million gallons. In cases where the pool is grossly polluted it is necessary to apply the chlorine directly to the pool. This is best done by making a sack of some porous cloth, as cheescloth, filling it with chloride of lime, tying it on the end of a pole, and dragging it thru the water of the pool. In this way, the dead areas in the corners can be thoroughly disinfected.

It has been siad that the pool water should be on a "drinking water" standard. Few pools measure up to this standard, and certainly the M.S.C. pool does not (1927). Tests of the pool water showed that gas was produced in lactose broth fermentation tubes, showing the presence of B.Coli, which is an intestinal organism. It is not necessary to go further with the A.P.H.A. or Treasury Dep't tests to show that this water in not up to the standard mentioned above.



Pool and filters, K. of C. Club House,
Columbus, Ohio



A horizontal pressure filter.

A sample of water taken at random from a swimming pool is sure to contain much minute life. The character of this life varies somewhat with indoor and outdoor pools, as well as with climatic conditions. However, there is sure to be certain organisms from the bodies of the bathers, due to the fact that bathers do not take a cleansi g shower before entering pool, and that ordinary decency is not always practiced while in the pool. Sometimes pools are used by those having skin disease, sore or inflamed eyes, cold, nasal or ear discharges, or communicable diseases--all of which cause pollution of the water.

There is another class of organic life in pools--the minute flowering plants, or Algæ. In outdoor pools which are not properly treated with copper sulphate, there is found growths of such plants as vallisneria (ell grass), pontederia, alisma, lemna, etc. As these do not cause objectionable tasts and odors, and do not have pathogenic reactions, they are of importance only in a mechanical way; that is, they must be removed if they get too thick in the pool.

There is another group of the algae which posses bad odors and tastes, and areof importance in pools--the Chlorophyceæ. These are grass green in color, and when allowed to grow they form a thick scum, commonly called "frog spit" or "Pond scum", on waters. Members of this group are the Schizophyceae, Synura, and Sycnrypta

There are only a few species of diatoms which are known to give rise to serious trouble in swimming pools. When these are present the infected water has an odor resembling fish or geraniums. This condition is often produced by Asterionella. None of these were found in the M.S.C. swimming pool, the water having no odor either cold or heated

For safety of bathers the bacteriological examination of pool water is of paramount importance. This thesis will not give the technical deatils envolved in the various procedures for determining the bacteriological content of pools. They are outlined in the "Standard Methods of Water Ananysis" issued by the American Public Health Association.

For the benefit of any who may wish to use this thesis later, some standards for the water of swimming pools will be given.

A. Bacteria count on agar-2 days-20° C. Not more than 10% of samples covering any considerable period shall contain more than 1000 bacteria per c.c. No single sample shall contain more than 5000 per c.c.

B. Bacteria count on Agar or Litmus Lactose Agar-24 hours-37° C. Not more than 10% of samples covering any considerable period shall contain more than 100 bacteria per c.c., and no single sample shall contain more than 200 per c.c.

C. Partially confirmed test. Not more than two out of five samples collected on the same day, or not more than three out of any ten consecutive samples collected on different dates to show a positive test in 10 c.c. of the water at times when the pool is in use.

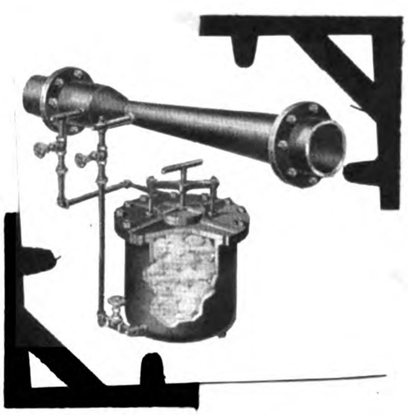
The above is adapted from the American Journal of Public Health.

Bacteriological examinations of the water of the college pool showed positive in the presumptive tests for Bact. Coli, there being gas-producing organisms in a majority of the 1 c.c. samples. Typical colon bacilli were isolated. Careful isolation of bacteria in pool waters shows the following groups: fluorescent bacteria, the chromogenic bacteria (violet, yellow, and red forms), organisms of the colon-aerogenes group, organisms of the proteus group, non-gas-forming, non-chromogenic, non-spore forming rods which do not produce proteus colonies and may or may not liquefy gelatin and acidify milk, spore formers of the B. subtilis type, and white, yellow, and pink cocci.

The swimming pool at the college gymnasium should be improved in two respects--more efficient filtration and sterilization of the water, and some arrangement of inlets and outlets which will permit all the water to go thru the filters, eliminating the "Dead areas".

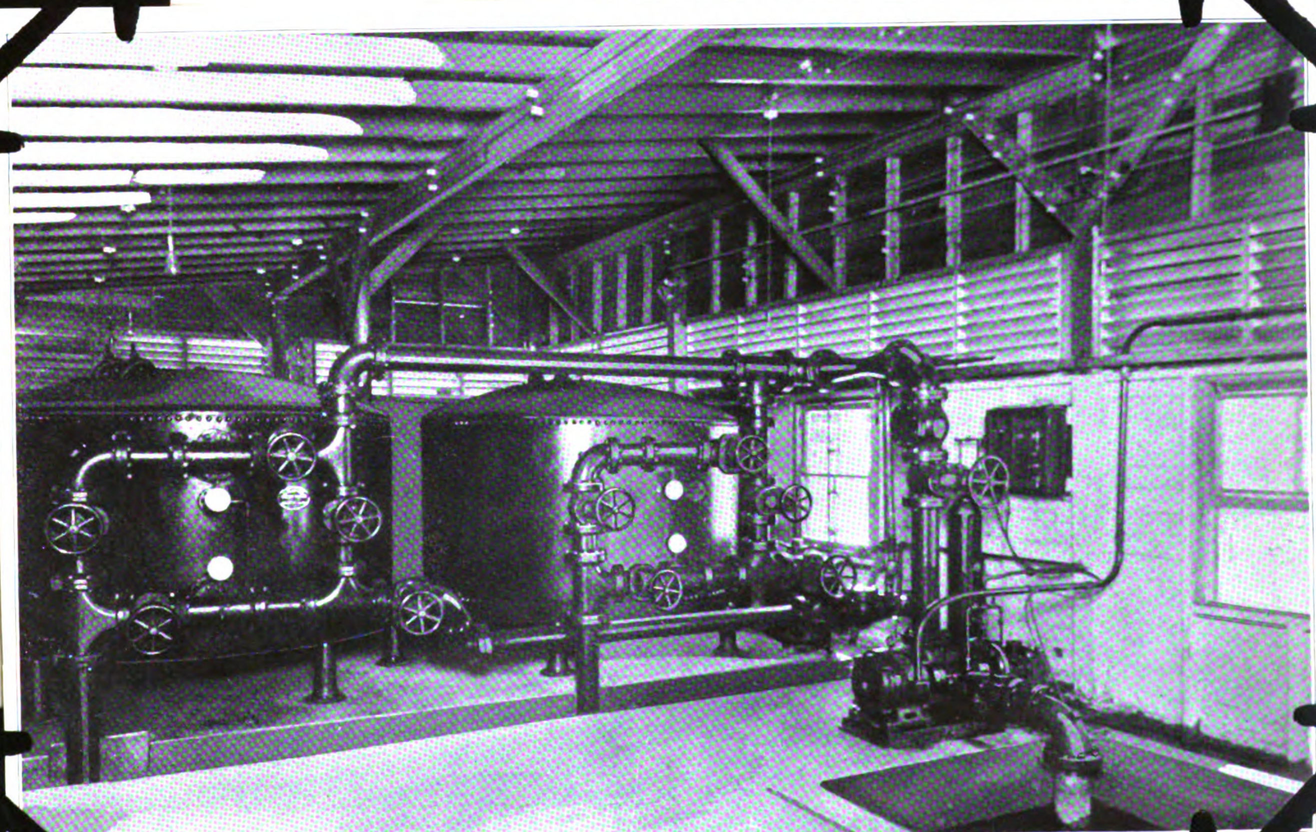
The former may be handled by installation of another pressure filter plus improvement of the operation of the existing one.

The M.S.C. swimming pool is 90 feet long by 30 feet wide. The depth at the shallow end in $3\frac{1}{2}$ feet; at the deepest part, 10 feet; and 8 feet at the deep end. The inlet is in the denter of the shallow end, about 18 inches from the top of the pool. The outlet is at the deepest part of the pool. There is only one inlet and one outlet. This pool should be improved by installing at least three more outlets, evenly spaced in the deepest part of the tank, making 4 in all. Five more inlets, making six in all, should be installed so as to cause the currents of water to flow thru the entire pool toward the outlets. To do this, inlets should be placed at about the seven foot level in the deep end of the pool. Care must be used in dealing with the hydraulics of this situation. The two inlets at the seven foot level of the deep end should be placed about 18 inches from the sides of the pool and the third inlet at this endshould be about three feet below water level. The three inlets at the shallow end should be placed similarily to those at the deep end.

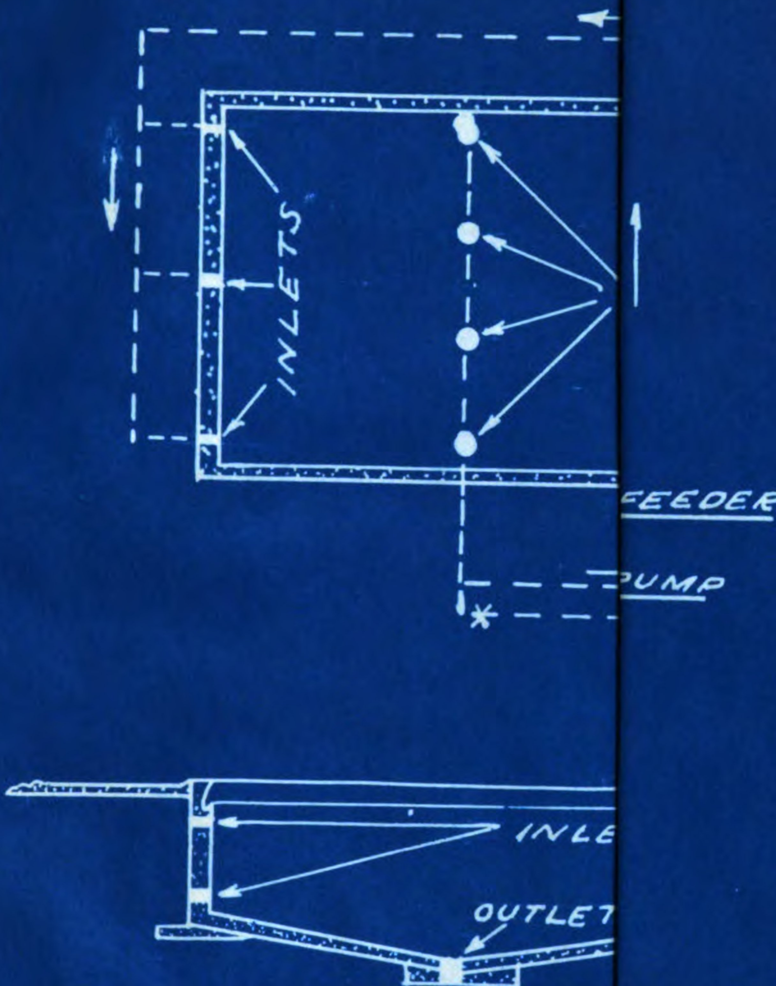


Method of feeding a chemical to water.

Rosedale Park Swimming Pool—Covington, Ky.

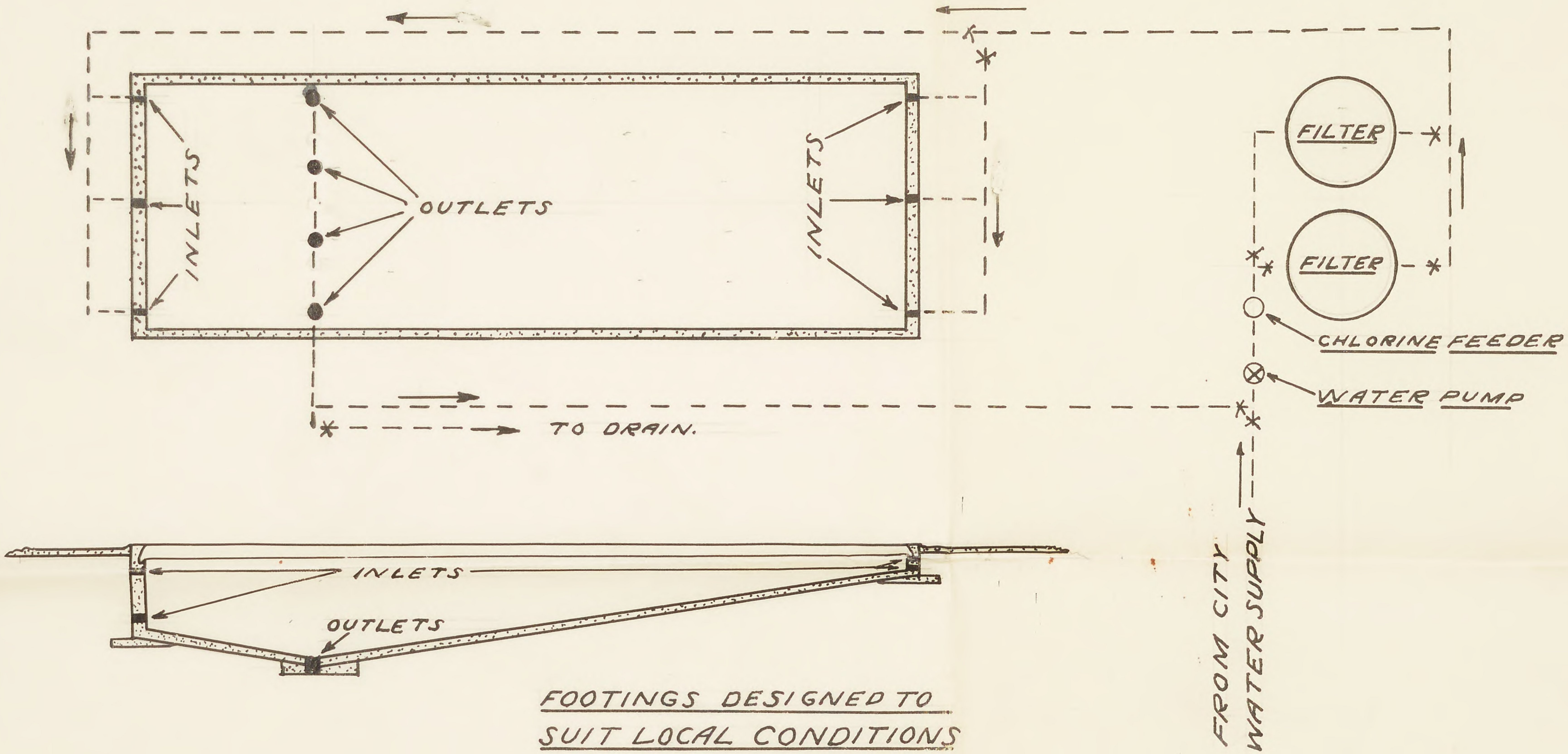


Filters for above pool.



SWIM

R.C. HODGKINSON, '27 C.E.



SWIMMING POOL CONSTRUCTION.

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