FARM IRRIGATION STRUCTURES

Bul. 496-S

Colorado Agricultural and Mechanical College
Agricultural and Mechanical College
Fort Collins, Colorado

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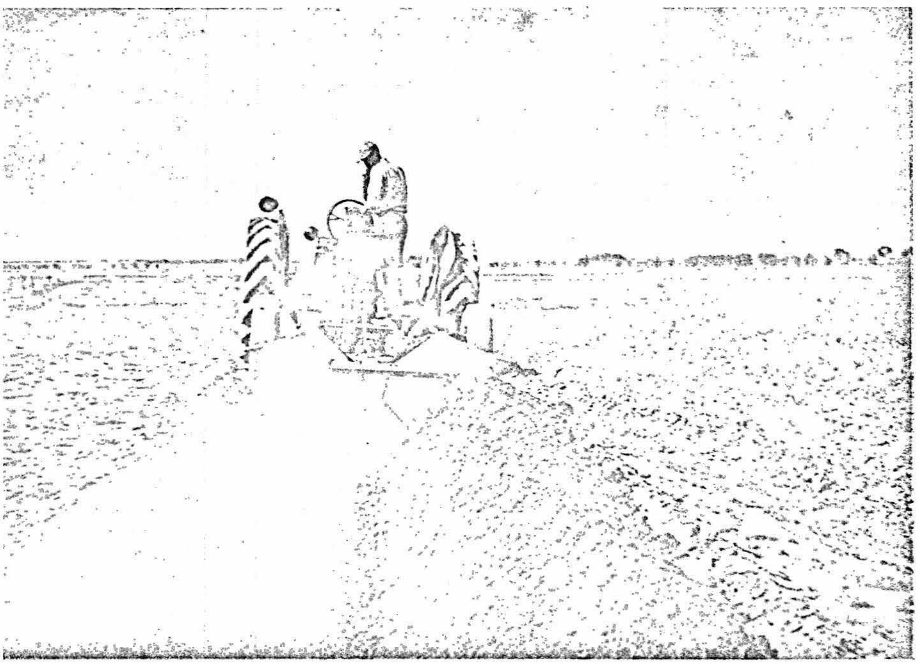

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ACKNOWLEDGMENT

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W. E. Code

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CONTENTS

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By W. E. Code*

FOREWORD

The purpose of this bulletin is to help the farmer (1) build irrigation structures; and (2) estimate sizes where engineering assistance is not readily available.

The sizes and character of the structures discussed are limited to those used on the farm where water quantities seldom exceed six cubic feet per second. Structures of unusual character—including long span flumes and those structures involving high velocities in any open channel—should be built only with competent engineering advice. Tables for flow in open channels and in pipes are limited purposely to the ordinary conditions likely to be encountered on a farm.

DITCHES

Earth Ditches and Ditching Implements

Ditches for farm use usually are made with tractor-drawn implements manufactured for that purpose. When horses were the principal source of power, the V ditcher (figure 1) was used in the construction of farm ditches. It moves earth in one direction only. It is still a useful tool for building higher, more substantial banks than usually are obtained with the modern tractor-drawn ditcher. The modern ditcher throws earth in both directions at once.

The V ditcher is run in a furrow opened by a plow. Two furrows are made almost adjacent to each other and the furrow slice thrown in opposite directions. The ditcher then has a chance to throw loosened earth

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farther out for bank building. Since the ditcher often is constructed so it can be turned upside down, a return trip can be made to throw earth to the same side. Frequently it is necessary to plow a second time in the ditch bottom to obtain more earth for the banks. Should the banks still require more soil, a furrow can be run outside the bank so the ditcher can crowd more earth onto it. This furrow should be backfilled with a drag or other implement. A ditch so made will have a pointed bottom which, except in heavy clay soils, will soon disappear through erosion and sloughing.

Tractor-drawn ditchers may be purchased in many styles and of varying weights. They may be drawn on a loose hitch or may be rigidly attached to the tractor. They may be pre-set and manually or hydraulically operated. In either case only one man is necessary for their operation. The various types are shown in figures 2, 3 and 4. In general, the nose element is at an angle with the mold boards (wings) so when tilted, a somewhat flat bottom is obtained. The wings are adjustable for spread. By combining tilt with wing spread, depth and top width can be varied. The nose element on some ditchers may be as much as 18 inches wide. In use, the first pass is not at full depth unless the earth is reasonably soft. In the second pass, the drive wheels or the tracks of a track layer may ride on earth thrown out on the first

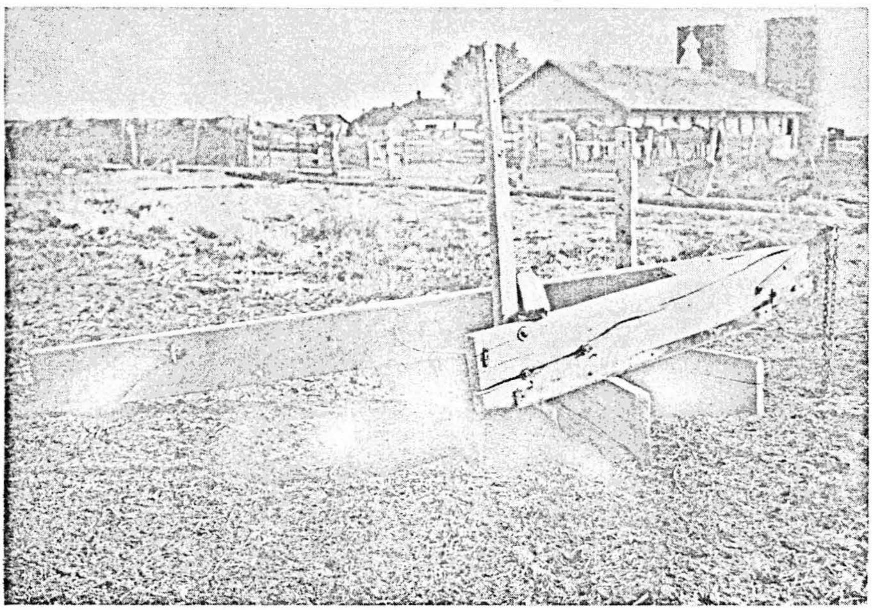


Figure 1—A horse-drawn V or crowder resting on a smaller one. A relic of over 30 years ago.

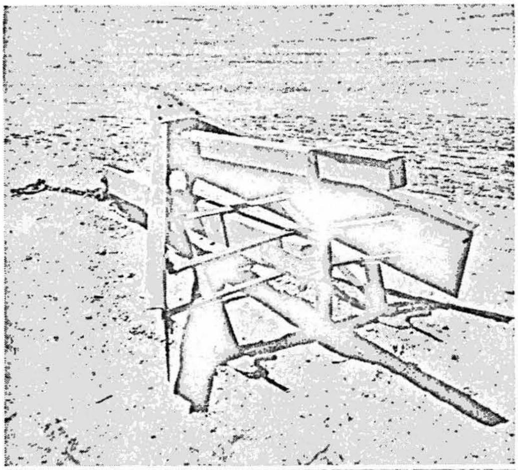


Figure 2 — A blacksmith made ditcher.

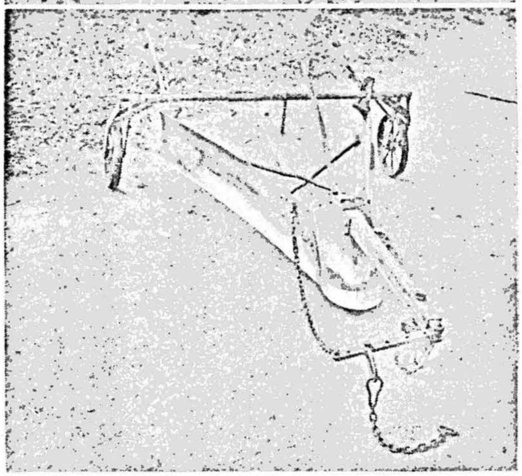


Figure 3—A commercially manufactured ditcher.

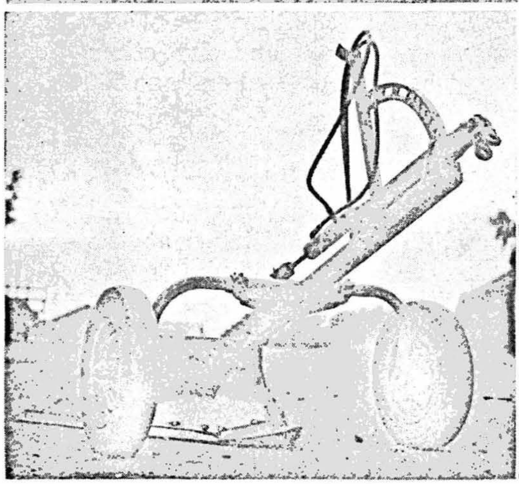


Figure 4—A commercially manufactured ditcher, hydraulically operated.

pass. This gives loose earth banks desirable compaction.

The character of construction depends a good deal on ditch usage. Some ditches—such as those run on a so-called contour in grain—are used only once or twice then filled in. These are often "one pass" ditches. Ditches in alfalfa need to be more substantial since they may be in use for four or five years or even longer. Ditches intended for furrow irrigating need substantial banks and should be higher for spiles and siphon tubes than for open cuts. Permanent carrying ditches need greater consideration, especially if they are used also as irrigating ditches. They should be deeper in the ground and the banks should be no higher than absolutely necessary. High banks prevent the use of mowers for weed cutting. Some farmers plant brome grass on ditch banks to keep down weeds and prevent erosion. Banks must be high enough, however, to allow checking when water is turned out. Use of the farm level for locating ditches and for other purposes is described on page 55.

Lined Ditches

Portland cement seems to be the most satisfactory material for lining farm ditches at the present time. It may be cast in place, applied as a heavy plaster or pneumatically placed. Precast units have been tried in several states but, up to the present, there has been little or no use of them in Colorado. Asphaltic concrete appears to have some merit when applied to large canals where compaction by machines is possible. Asphaltic linings can be damaged by livestock and can be punctured by weeds unless the soil is well sterilized.

Prevention of seepage is probably stressed more than any other feature in canal lining. However, there are other important advantages arising from such an investment. On steep slopes where erosion would be a hazard, linings should be considered an alternative to a series of drops. They prevent weed growth on the canal sides and bottom and, when the banks are properly built, a mower can be used to keep them clean. These maintenance items become important as farms develop more and more into one-man units. Because of the higher velocities, water arrives at a remote point in a much shorter period of time in a lined ditch.

Concrete-lined ditches are useful for transporting water, for direct flooding or furrow irrigation. A large gate-controlled opening is needed for flooding except when the edge of the lining is low enough to permit overflow on one side. Tubes controlled with a slide gate (figure 6) or even a wad of cloth are used for furrow irrigation. Check gates are used to keep the water surface above the tube openings since these openings often are placed above the normal flow. Siphon tubes also (figure 5) are managed easily but these, as well as gated tubes, require planning for ditch grades and location of checks.

Construction of Concrete Linings

Careful attention must be paid to the foundation of any ditch lining, especially when fills are involved. Soil used for building a fill should have some cohesiveness when dry and should be compacted moist by rolling. The top width of the dike should have a minimum berm of 18 inches on each side of the lining. A freeboard of at least two inches below the top of the lining should be allowed in making computations of capacity.

When an earth ditch in a normal location is to be lined, it is often advisable to plow in the old ditch, compact the soil and then excavate it to the neat lines required for linings. Because the lesser resistance to flow causes higher velocities, a lined ditch will have a smaller cross section than the earth ditch it replaces.

A lining method used success-

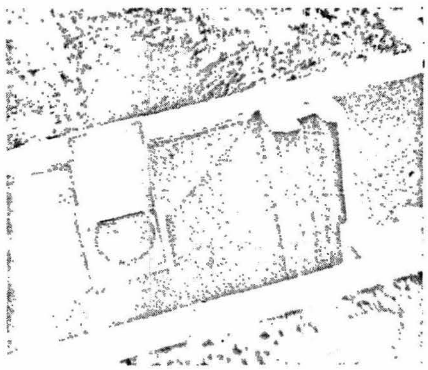


Figure 6—Commercially made metal slide gate on short metal tube installed in concrete lining.

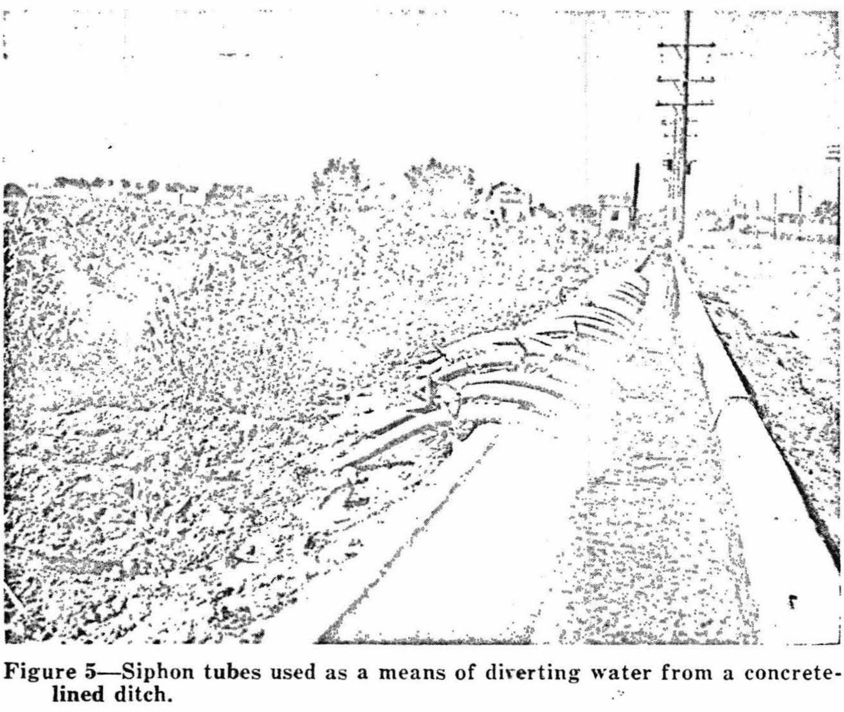


Figure 5—Siphon tubes used as a means of diverting water from a concrete-lined ditch.

fully for 25 years in northeastern Colorado will be described in detail. It involves considerable hand labor. Often ditches are located where machines cannot be used to advantage. Grades are established by surveys and need not be uniform; however, frequent changes in grade to save a little earth moving are not justified. Major changes in grade may require changes in the cross-section. If water is to be turned onto a field directly from the ditch, the top of the lining should be placed so that—when checked—the normal water surface is about one-half foot above the field surface. If the water is not to be checked for field irrigation, the top of the ditch can be less than one-half foot above the ground surface. It may be desirable to set the top of the lining flush with the ground surface if, in so doing, it can capture and carry storm water down a steep slope.

Surveying stakes are set at 25-foot intervals, usually two feet off centerline and to the grade of the top of the concrete. Guide rails of 2 by 4 lumber are set edgewise to line and grade of the outside edges of the finished lining. These guides are nailed to stakes and become the outside form at the top. A template of the outside shape of the

Figure 7—Setting guide rails for concrete ditch lining. Rails serve as a guide on which an excavation template (arrow) rides as an outside form for the top of the lining and as a support for the inside forms.

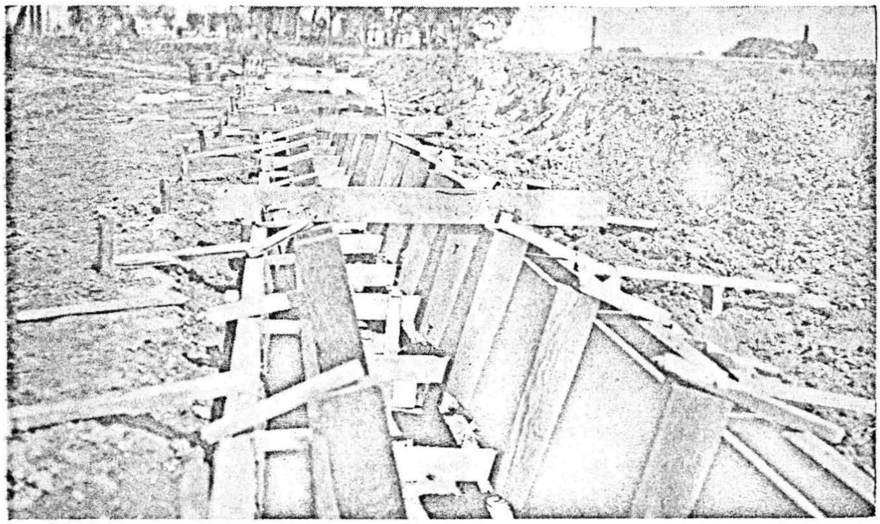


Figure 8—Forms in place ready for casting concrete ditch lining.

lining fits on top of the guide rails and guides the work of the excavators when they remove the earth with shovels. The seting of guide rails is shown in figure 7. Attempts to cut down on hand work by using plows have not met with success because of the small amount of earth involved. Favorable soil moisture conditions make digging easy and are the greatest construction aid.

The guide rails hold up and position the inside forms. Spreaders between the form and earth preserve straightness. As may be seen from figure 8, the forms are simple in design. The side slope is one horizontally to four vertically and the depth is chosen to fit the conditions. For the ordinary farm ditch, a depth of 16 inches is satisfactory. This depth is obtained by using three pieces of 1 by 6 tongue-and-groove fir flooring for the sides. To provide for the desired capacity, the bottom width can be adjusted by changing the length of the spreader pieces. A form length of 12 feet is very convenient from the standpoint of weight and transportation. A 3½-inch wall thickness for a ditch depth of 16 inches is greater than necessary for strength but it does permit spading and the use of rather large aggregate (passing two-inch screen).

When a desirable length of form is set, concrete mixing begins. Concrete is wheeled in barrows and delivered to a ridge-shaped platform on top of the forms. From this platform the concrete can flow to either side. The concrete should build up evenly on both sides to prevent side thrust. When 10 or 12 feet of wall have been cast, the bottom is poured and finished with a trowel. If contraction joints are desired, they

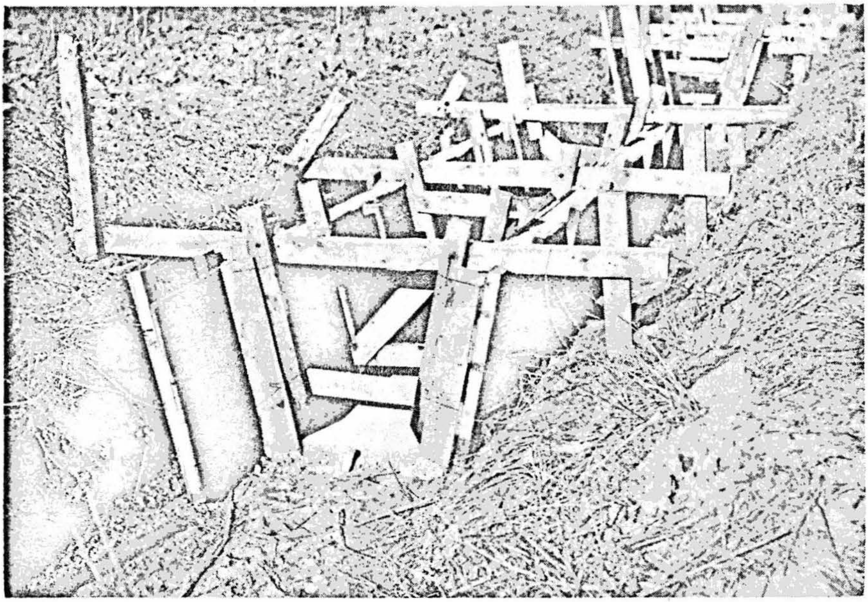


Figure 9—Use of both inside and outside forms for casting concrete ditch linings. The forms here are 16 feet long and are set up with 16-foot gaps to be filled in later.

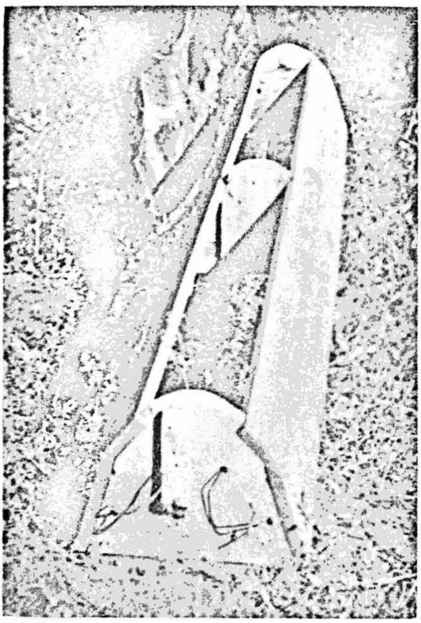


Figure 10—A simple inside form for casting concrete ditch linings not intended to extend above the ground surface. Tar paper was used as an outside form.

Figure 11—A 3-inch concrete plaster lining 15 years old.

should be placed at about 12-foot intervals. To place the joints, support the mastic (one-half inch) on a board inserted behind the form as concrete is poured on both sides and withdraw the board when concrete reaches the top. Unless the soil contains an excess of sulphates, rich concrete is not necessary for this kind of work. It is important to make dense concrete and use the least amount of water that will produce a smooth surface on spading (see page 16). A mixture of one part cement, three of sand and four or five of graded gravel from ½ to 1½ inches in size makes a strong and durable lining. In alkaline soil, an alkali-resistant cement should be used.

Larger ditches than those for farm use have been lined by the method just described. In these cases, considerable backfilling and straightening of alignment generally were required. Old ditches usually have varying cross-sections because of erosion and cleaning operations. Both outside and inside forms may be used in an over-size ditch to simplify backfilling (figure 9). When so constructed, the forms cannot be removed until the concrete has attained sufficient strength for the walls to stand without support. A wait of at least 48 hours (longer in cold weather) may be necessary. Figure 10 shows a simple inside form from which the entire perimeter of the ditch was cast at one time. Tar paper laid in the formed trench provided an outside form. The paper was brought up high enough above the sides to facilitate concrete placement without contamination from earth clods.

Satisfactory concrete linings can be applied as a plaster. Although less thorough preparation of the trench is warranted, this operation should not be carelessly done. In some situations a ditcher can be used to form the trench. Centerline stakes should be close together to insure straight tractor driving and the earth should be in a soft condition. An acceptable piece of work is shown in figure 11. A neater job is shown in figure 12 where poured construction joins plaster construction. The edges show the difference in appearance. By using a guide rail, a constant thickness and a straight edge are maintained. A minimum side slope of one to one will be found satisfactory with a concrete of workable yet

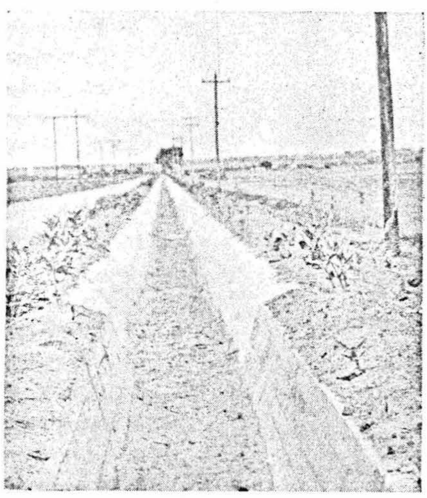


Figure 12 — Junction between cast concrete and plaster linings.

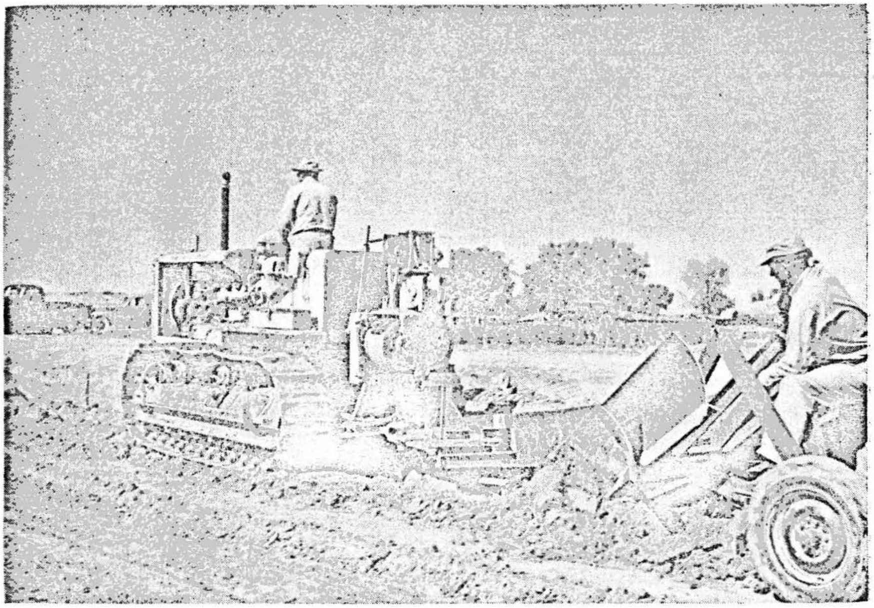


Figure 13—Trench preparation with special ditcher for slip-form method of applying concrete linings. Picture was taken near Rocky Ford.

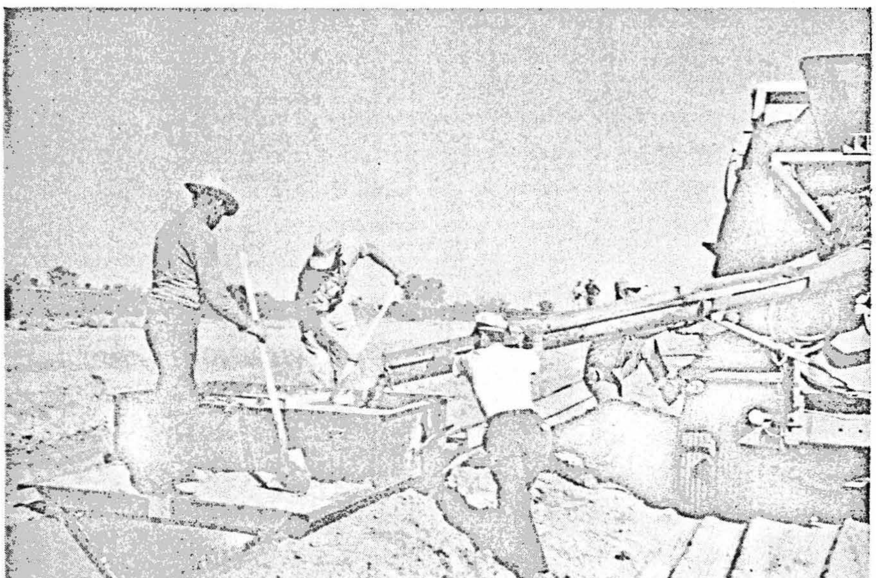


Figure 14—Casting two-inch concrete lining with a slip form. Form is pulled on long hitch by tractor.

stiff consistency. Although a grain scoop makes a fairly good troweling tool which requires no kneeling, screeding and a short wood trowel give a more satisfactory surface. The plaster should be not less than 2½ inches thick and should be well tamped or worked. The coarse aggregate should not exceed three-quarters inch (passing one-inch screen).

The use of expansion or contraction joints is optional. Their use probably reduces cracks to some extent but, unless the lining is quite thick, contraction cracks will appear anyway. For the small ditches considered here, steel reinforcing is not warranted.

The slip-form method of applying a 2 to 2½-inch concrete lining has considerable merit on large jobs. The side slopes of these ditches must be no steeper than one to one. Linings can be poured at a very rapid rate once the ditch shape has been prepared. A special plow rough-forms the trench in a succession of passes. The final treatment is accomplished with a combination finish grader, concrete spreader and steel-plate trowel for finishing the surface. These operations are shown in figures 13 and 14. Because of the speed of concrete application, adequate delivery by ready-mixed concrete transports becomes a problem.

Figure 15 shows the application of lining by the pneumatic method. Wire mesh reinforcing is needed in the pneumatic method because of the thinness

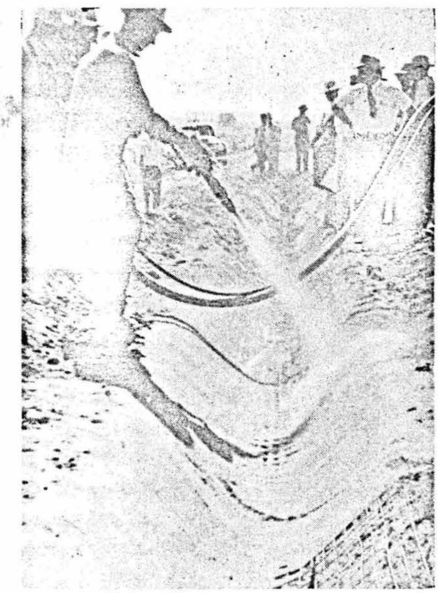


Figure 15—Placing one-inch concrete ditch lining pneumatically at a demonstration near Littleton.

(1½ inches) of application. Concrete so placed is very dense and strong and has been found satisfactory in its limited use in Colorado.

Small concrete ditches or flumes are sometimes built on top of the ground and used for applying water directly to a crop. Figure 16 shows such a ditch equipped with slide gate controlled openings for furrow irrigation of an orchard.

Design of Ditches

Water velocity in a ditch is determined by its slope, size, shape and surface roughness. Shape and size factors are combined in a term called hydraulic radius. This is found by dividing the wetted cross-sectional area by the wetted perimeter. Roughness, denoted as n in Kutter's

TABLE 1—Capacity of earth ditches with 1-to-1 side slopes.

n = .025*

Water depth inches	2 in. Vel. f.p.s.	2 in. Disch. c.f.s.	3 in. Vel. f.p.s.	3 in. Disch. c.f.s.	4 in. Vel. f.p.s.	4 in. Disch. c.f.s.	5 in. Vel. f.p.s.	5 in. Disch. c.f.s.	6 in. Vel. f.p.s.	6 in. Disch. c.f.s.
	Bottom width 6 inches									
4	0.61	0.17	0.73	0.20	0.84	0.23	0.96	0.27	1.03	0.29
5	0.71	0.27	0.86	0.33	0.97	0.37	1.13	0.43	1.23	0.47
6	0.79	0.40	0.96	0.48	1.12	0.56	1.28	0.64	1.35	0.68
7	0.87	0.55	1.05	0.66	1.24	0.78	1.41	0.89	1.52	0.96
8	0.96	0.75	1.15	0.89	1.33	1.03	1.52	1.18	1.65	1.28
9	1.04	0.97	1.24	1.16	1.43	1.34	1.64	1.54	1.80	1.69
10	1.10	1.22	1.33	1.48	1.55	1.72	1.76	1.95	1.92	2.13
11	1.17	1.52	1.41	1.83	1.65	2.14	1.88	2.44	2.07	2.69
12	1.23	1.85	1.49	2.23	1.77	2.65	2.00	3.00	2.20	3.30
	Bottom width 12 inches									
4	0.72	0.32	0.87	0.39	1.00	0.44	1.12	0.50	1.25	0.56
5	0.81	0.48	1.01	0.60	1.16	0.68	1.34	0.79	1.46	0.86
6	0.92	0.69	1.11	0.83	1.28	0.96	1.47	1.10	1.60	1.20
7	1.01	0.93	1.22	1.13	1.42	1.31	1.60	1.48	1.77	1.63
8	1.11	1.22	1.34	1.47	1.55	1.71	1.75	1.92	1.90	2.09
9	1.20	1.58	1.44	1.89	1.68	2.20	1.90	2.49	2.10	2.76
10	1.28	1.95	1.54	2.35	1.78	2.72	2.00	3.05	2.20	3.36
11	1.34	2.35	1.63	2.86	1.90	3.33	2.12	3.72	2.32	4.07
12	1.40	2.80	1.72	3.44	2.00	4.00	2.24	4.48	2.50	5.00
15	1.61	4.52	1.98	5.57	2.32	6.52	2.60	7.30	2.80	7.86
	Bottom width 18 inches									
4	0.77	0.47	0.94	0.57	1.10	0.67	1.24	0.76	1.32	0.81
5	0.88	0.70	1.06	0.85	1.24	0.99	1.40	1.12	1.51	1.21
6	1.00	1.00	1.20	1.20	1.40	1.40	1.58	1.58	1.71	1.71
7	1.10	1.34	1.33	1.61	1.55	1.88	1.75	2.13	1.91	2.32
8	1.20	1.73	1.44	2.08	1.68	2.42	1.90	2.74	2.10	3.03
9	1.29	2.17	1.56	2.63	1.81	3.05	2.05	3.46	2.25	3.80
10	1.38	2.68	1.66	3.23	1.92	3.73	2.18	4.24	2.38	4.63
11	1.46	3.23	1.76	3.90	2.03	4.50	2.30	5.10	2.52	5.58
12	1.54	3.85	1.85	4.62	2.13	5.32	2.42	6.05	2.64	6.60
15	1.72	5.91	2.09	7.18	2.42	8.31	2.74	9.41	2.90	9.96

Fall in inches per 100 feet.

*Kutter's coefficient of roughness. This is for reasonably clean ditches with a fairly rough bottom.

and some other discharge formulas, has a very large range of values. It has a decided effect on velocity. Since formulas are difficult to evaluate, discharge tables 1 and 2 are given for earth and concrete-lined ditches for common values of *n*. Table 2 shows only the maximum capacity of ditches lined as described on pages 5-9.

Velocity is the principal cause of erosion in ditches. Various soils have varying resistance to erosion according to their cohesiveness or particle size. To keep erosion at a minimum, the velocity for ditches in sand should not exceed 1.5 feet per second (f.p.s.); for loams, 2.0 to 2.5 f.p.s.; and clays, 3.5 f.p.s. Mountain ditches in cobbles may withstand velocities higher than 3.5 f.p.s. Roughness of these ditches greatly exceeds that for earth, and the velocity will be less for comparable cross-sections and grades. Where conditions do not permit a choice of grades, drops or linings must be employed.

Example: Wanted: a ditch in loam soil with a bottom width of 12 inches to carry 2 cubic feet per second. What grades are permissible to prevent the velocity from exceeding 2.0 feet per second? From table 1 under the section *"Bottom width 12 inches"* and in the column headed "6 inches fall per 100 feet", find the discharge closest to 2 c.f.s. This is 2.09 c.f.s. and the corresponding velocity is 1.90 f.p.s. for a depth of 8 inches. Any lesser slope will cause an increased depth, a 10-inch depth for example with a slope of 2 inches per 100 feet. If the flow had been 4 c.f.s., the slope would have to be limited to 4 inches per 100 feet.

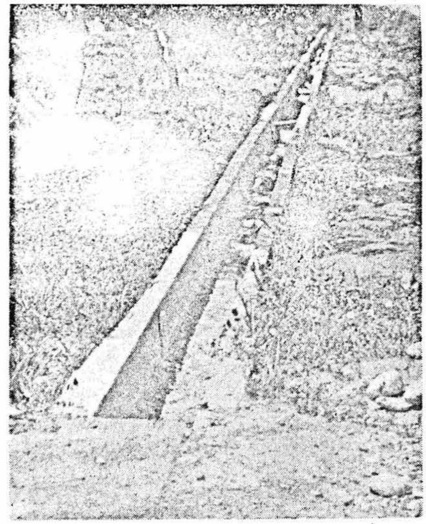


Figure 16—Concrete ditch set on ground surface and equipped with small slide gates for orchard irrigation.

TABLE 2—Capacity of concrete lined ditches in cubic feet per second with side slopes 1:4, water depth 13 inches.

n = .015

Bottom width inches	Fall in inches per 100 feet 1	2	3	4	5	6
12	2.2	3.1	3.8	4.4	4.9	5.4
18	3.5	4.9	6.0	7.1	7.9	8.6
24	4.7	6.8	8.3	9.6	10.7	11.8

DITCH MAINTENANCE

A clean, smooth, straight ditch is subject to less water loss. The water depth in a clean ditch is less and there is less area exposed to leakage. Because of the greater velocity, the water arrives at a given place in a shorter time. Less silt will be deposited at the higher velocities. If silt is deposited it usually will reduce seepage.

Cleaning is the principal maintenance operation on ditches. In Colorado this is done in the spring before water is turned in. The permanent farm ditch and the smaller service laterals require about the same kind of maintenance. Usually the cleaning is done with hand tools although in some cases a ditcher can be used. Old dead weed growth and silt deposits have to be removed and the weak or low spots in the banks repaired. The dry, dead material is forked into piles for burning and burning is frequently the only treatment banks receive. Burning of dry weeds should be done in the fall before the seeds shuck out of their pods. In either fall or spring, burning should be employed only on those days when fire can be controlled. Portable pressure tanks filled with water should always be on hand to douse burning wood structures, fence posts, power and telephone poles.

Grass and weeds start growing about the time water is turned into ditches. They can be removed by mechanical means only by dewatering the ditch. Bank growth sometimes can be mowed but burning is the better method. Burning also will destroy underwater growth after dewatering; however, chemicals can be effectively used for that purpose. Burning is rather expensive but is effective on young green growth. Elaborate equipment complete with long boom burners is rapidly becoming available on a custom basis. Hand-carried burners can be used effectively on green stuff and these burners are particularly useful in fall burning when trash is a bit damp.

Chemicals can be put into the water to kill aquatic plants. The latest of these chemicals are solvent naptha and some similar compounds. They are effective on underwater growth and animal life. If the chemicals are permitted to exhaust themselves by traveling a reasonable distance, they will not injure crops. Many chemicals are available for specific ditch bank weeds. Before using weed control chemicals, a careful study of the literature should be made or competent advice sought.*

Since some of the chemicals that are useful in controlling aquatic growth are also injurious or lethal to animal life, they

*Chemical manufacturers can furnish descriptive literature on their own products. Information can be obtained from the U. S. Bureau of Reclamation in Denver. **Control of Aquatic and Ditch-bank Weeds**, Circular 158 of the Extension Service, College of Agriculture, University of California, contains valuable information.

may also be used to kill crayfish. Crayfish undermine concrete structures and are a source of leaks in ditch banks. Rodents are difficult to control because they are hard to find. Trapping, poison gas and poisonous bait are used with varying success against rodents.

Concrete-lined ditches may develop temperature cracks. Ordinarily these cracks are small and the slight leakage in solid ground is of small consequence. However, should they occur on dikes, they should be filled with an asphaltic pitch similar to that used in repairing cracks in concrete pavements. Crack repair should be done on a warm spring day.

DITCH STRUCTURES

Construction Materials

Although lumber is still used as a building material in canal structures, concrete is definitely more satisfactory. It is true that a structure can be built of lumber in less time than a form can be built for concrete. If lumber is used, it should be rot resistant. Redwood, cedar or creosoted pine or fir offer rot-resistant qualities. Untreated one-inch pine or fir boards warp badly and rot in a relatively short time.

Concrete is one of the most common construction materials used on the farm. And no material receives such careless attention as to its composition and manufacture. Two glaring faults are common: (1) too much sand and (2) too much water. Too much sand is likely to occur if pit-run gravel is used. Good concrete cannot be made from inferior materials. Avoid using water high in alkali salts and gravel containing vegetable matter and clay balls. Cement that has hardened so it cannot be crushed in the hand should not be used.

Proportioning is usually based upon the ratio of cement to fine (less than one-quarter inch) and coarse (¼ to 1½ inches) aggregate. This is a reasonable approach but may be modified according to the use of the concrete. For walls five or more inches in thickness, coarse aggregate up to a two-inch size is desirable. For four-inch ditch lining, about one inch should be the maximum size and for plaster lining, one-quarter to three-quarter inch is recommended. The coarse aggregate should be well graded—it should contain all the sizes between one-quarter inch and the largest to obtain maximum density. Bank-run gravel usually has too large a proportion of sand and often contains more than the recommended five percent limit of silt.

A sack of cement contains one cubic foot. This unit determines the water to be used. If the sand is dry, about 6½ gallons of water will be needed for a one-sack batch; if damp, 6 gallons; or if wet, 5 gallons. The resulting consistency on a trial run should be mushy, not soupy. Too much water results in a weaker concrete because of the voids it causes. Should more or less water be required, the amount should be measured so that in succeeding batches the proper quantity of water can be used. The recommended proportions of cement, sand and gravel for walls and footings are 1:2, ½:4. Strong, dense concrete results when the cement coats the grains of sand and fills the voids. The resulting grout should fill the voids in the coarse aggregate. If bank-run gravel is used, it should be tested by screening with a ¼-inch mesh screen. If the gravel is short of coarse material, more should be added or the cement adjusted to the amount of sand.

As concrete is poured into forms, no more than six inches of depth should be permitted at a time. This depth is easily "spaded" with a straight-bladed hoe or a stick. This working releases air pockets next to the forms, insuring a smooth finish to the walls. Concrete should be protected against freezing for the first few days after pouring. The surface of concrete should be kept damp during the first week to obtain a hard, durable finish. Coverings and spraying will help greatly in this respect.

Concrete building blocks have considerable merit for use in irrigation structures but are not now in general use for these structures. Their use obviates the necessity of building forms except perhaps for the foundation floor. Blocks are available in 4, 6 and 8-inch widths and are 8 or 16 inches long. In order to avoid mistakes in laying, set up the blocks without mortar to see how they will fit together. Grooves for stop boards are easily made at joints through wider spacing.

Several types of aggregate are used in building blocks; however, choice may be limited to one kind. Light-weight blocks are made of volcanic cinders and burned clay or shale aggregates. Blocks made of gravel concrete are much heavier and probably are better suited to ditch structures. By filling the cells of six-inch blocks with concrete, a very substantial wall is obtained, adequate for a structure four blocks high. Soft wire of about nine gage laid in the mortar between horizontal courses helps hold the blocks in place. For greater height or for narrower blocks, vertical reinforcing rods with one end embedded in the foundation are threaded through the cells. A concrete block structure is shown in figure 18.

In an area where flat rock materials abound, satisfactory masonry structures can be built. Masonry structures, especially drops, should have good foundations.

Farmers aren't likely to build a structure out of steel. However, there is on the market a corrugated steel pipe shape to be used as a drop (figure 24). There are also steel gates attached to pipes which can be either incorporated in structures or used independently of any structure. One manufacturer offers a steel divisor.

Checks and Turnouts

Checks in ditches are required to divert water to another ditch or serve as a control when the water is being diverted directly onto a field. In the first case, checks are placed at junctions with lateral ditches. Such laterals should be located on ridges or other points as topography or field shape might require. In the second case, checks are placed according to the position of the water surface flow line and the height of the ditch banks. The water surface in the ditch must be three or four inches (four or five inches for spiles or siphons) above the ground surface. Also a freeboard of about four inches below the top of the bank must be maintained.

With these limits in mind, the location of the check is found by use of the farm level (see page 55). The rod is held on the ground surface at the upper end of the reach between checks and a reading is then made. From this reading subtract five inches to obtain the rod reading for the presumed height of the water surface in the ditch. If you want a freeboard of four inches at the lower end of the reach, subtract an additional four inches for a total of nine inches. The rodman proceeds down the ditch and finds a place where the bank is nine inches higher than the first rod reading on the ground surface.

As an example, suppose the rod reads three feet, four inches on the natural ground. When nine inches are subtracted, the required rod reading will be two feet, seven inches. If the rod is equipped with a target, set it at that reading. At the upper end of the reach, the rod will read less when held on the bank in accordance to its height. If the ditch is made with a ditcher, the bank would have a uniform height of perhaps 14 inches. As the rodman walks down the ditch a sight is taken at intervals with the rod held on top of the bank. At first the crosswire of the level will hit below the target. When the cross-wire coincides with the target (rod reading two feet, seven inches), you have found the location where the check is needed. The water-surface height of five inches above the adjacent ground surface is desirable for siphons or spiles. For flooding, this difference can be reduced perhaps two inches. The checks then would be farther apart.

Checks may have openings on both sides (thus requiring three gates) or they may be a simple straight wall with a notch and gate. A precast, commercially made check is shown in figure

17. Instead of gates, boards may be used as stops and, by varying the number or height of the boards, any degree of overpour control can be attained. Overpour control is much more satisfactory than endeavoring to adjust flow under a board or gate. Boards dropped into grooves are usually quite leaky and the farmer customarily shovels earth against them or tucks in canvas around the edges to reduce the leakage. A double set of boards spaced about four inches apart permits the placement of a water-tight earth wall. Very little earth need be wasted upon removal of such a dam. All openings should be of the same size so that any gates or boards will be interchangeable and will fit.

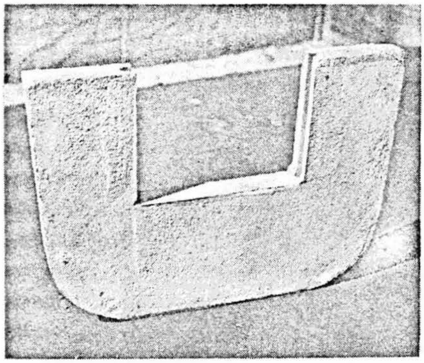


Figure 17—A precast check for a metal gate. Precast checks also are obtainable with groove for stop boards.

Metal gates together with their frames are available commercially or can be made in local shops (see figure 19). Some are of rather light-weight metal strengthened by turned-back edges. Plain leaf gates should not be made of any heavier material than can be cut with power shears. Torch cutting may result in warped surfaces. The top of any gate or stop should always be lower than the walls of the structure to allow excess water to escape.

The floor of a check and turnout should be set two or three inches below ditch grade. This also is true with the sill of a simple check. In order to avoid erosion below a structure, water velocity through it should be low. To gain low velocity the waterway should be about as wide as the ditch. With low velocity, the turbulence and eddies that induce erosion are reduced. Wing walls or riprapping may not be needed in heavy soils but are needed in light soils.

A cut-off wall is necessary on the lower side, reaching eight inches below the floor for heavy soils and 12 inches for light soils. When double stop boards are used, grooves in the floor are optional for widths under 18

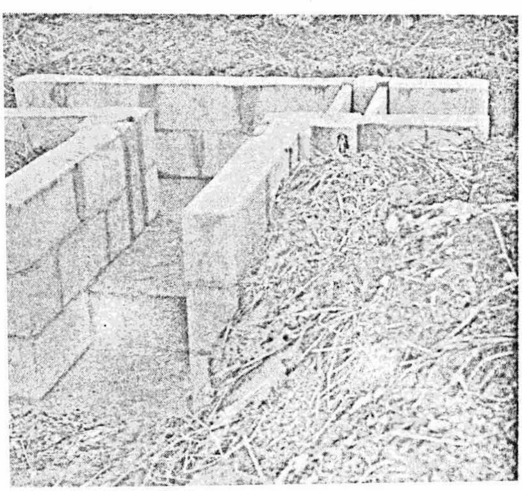


Figure 18—A turnout containing short drop constructed of six-inch concrete wall blocks.

inches. For greater widths, the side of the groove in the floor gives support to the lower board and prevents bulging. The groove width should be one-quarter inch greater than board thickness. Photographs of checks and turnouts are shown in figures 18 and 20.

Drops

Drops are needed to flatten the grade on a steep slope. They require more attention than checks to prevent erosion and washing out. The greater the height of drop, the greater the turbulence will be below the structures. Do not reduce the crest width of a drop to much less than the bottom width of the ditch. This will avoid much of the erosive back eddy at the sides below the drop. Suggested dimensions of a particular structure are shown in figure 21. The criticism of the timber drop, figure 22, is the concentrated overpour. A wide crest would have been more desirable. The water falls into a pool, which is good, but the downstream wall reconcentrates the flow and it is quite obvious that active erosion is in progress downstream. The gradually expanding downstream training walls shown in figure 23 have contained the turbulent

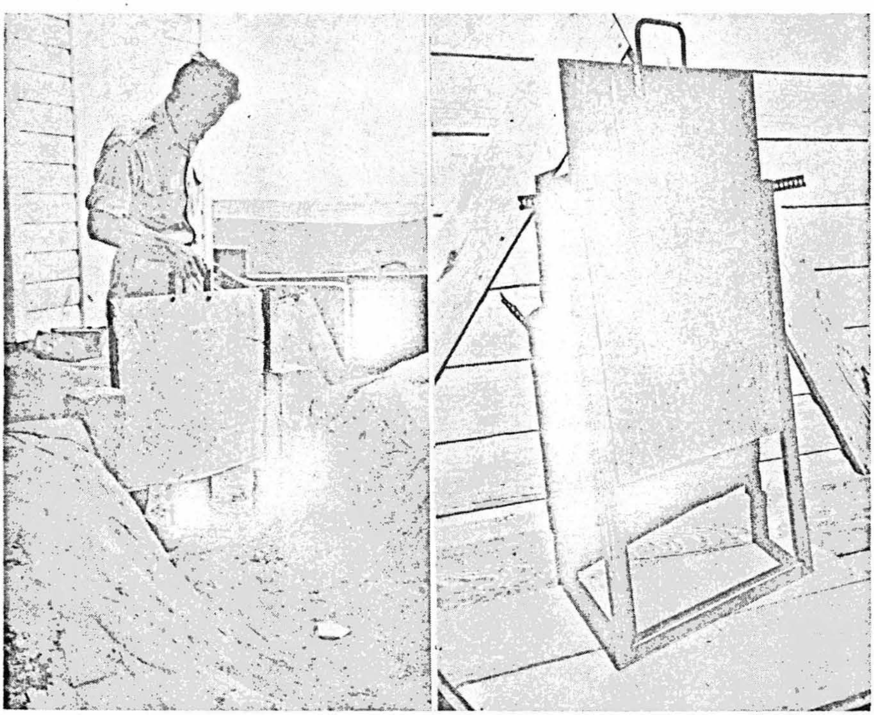


Figure 19—Slide gates locally manufactured. Three pieces of strap iron frame the guides; the middle piece is thicker than the gate leaf. The right frame shows continuous welding. Four spot welds are sufficient with less danger of warping.

Figure 20—Metal slide gates attached to concrete pipe. It is possible to avoid a box structure with this arrangement.

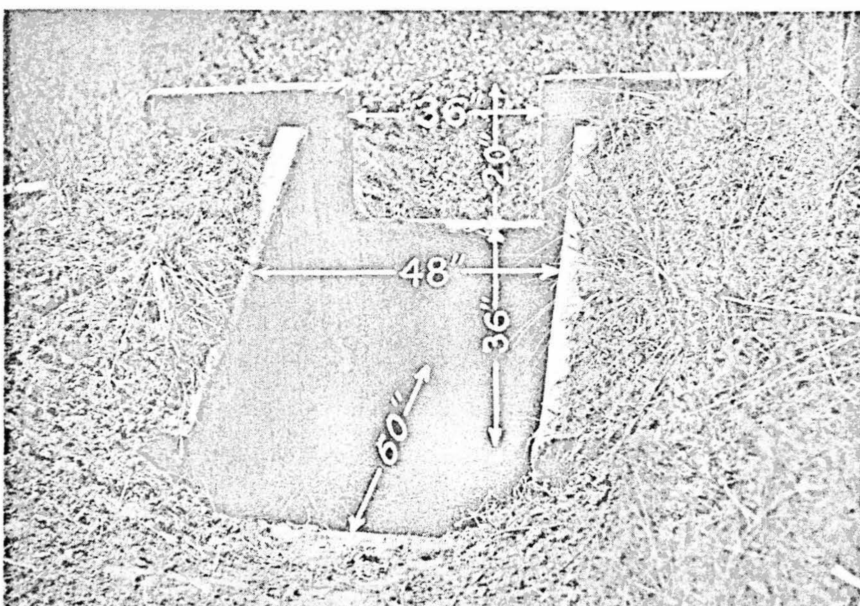


Figure 21—A well proportioned two-foot concrete drop.

part of the flow and there is little or no active erosion.

Although it would be desirable to still turbulence within the structure, this usually is not economically feasible. A large part of turbulence is killed as water falls into a pool. When the depth of overpour does not exceed one foot, the water depth in this pool should be about 18 inches for drops up to 2 feet and 24 inches for drops of 2 to 3 feet. A riprapped section below the structure is nearly always necessary to reduce erosion and allow the cross-sectional area to gradually expand to the shape of the ditch section.

Corrugated steel pipe with a short right angle elbow at one end is offered as a drop by some steel fabricators (figure 24). In use, the long leg is laid at a slight adverse tilt with the elbow upstream. A well-compacted earth dam is then built over the horizontal run. Protection must be provided to keep large trash from plugging the entrance and riprap erosion protection is needed at the downstream end. This type of drop is vulnerable to burrowing rodents and should be inspected frequently.

Divisors

Divisors are used to split flows into two or more parts, each of which is to be a definite percentage of the whole. The advantages of such a device, provided it functions properly, are obvious in a system where each

Figure 22—V-notch timber drop. A horizontal crest would have reduced the depth of overpour and the downstream wall should have had a wider opening. Timber structures are subject to fire damage.

Figure 23—Use of masonry for a drop.

user is entitled to a definite proportion of the total supply. Most canals have a changing supply based on the amount available in the river. These devices were used extensively on main canals in the past but there has been a slow steady change to measuring devices.

Because of the extremely disproportionate sizes of the streams, it is very doubtful whether divisors equitably apportion the flow. On laterals, where the proportions of flow are more nearly equal, the chances of equitable division are much better. Divisors may have fixed openings or they can be made adjustable by means of sliding or swinging division boards.

Generally the flow is divided on the basis of proportional width over a control crest (figure 25). Reasonable accuracy may be expected on this basis if the openings are not too greatly different in width and approach and downstream flow conditions are similar for each part of the flow. To obtain uniform approach conditions, the structure should be long enough so that the lines of flow are smoothed out before reaching the control crest. If the divisions are disproportionate, the larger opening is likely to be favored when the velocity of approach is not reasonably uniform. If the control point is at the upper edge of the structure, the uniformity of approach flow will be influenced by the shape and direction of the ditch above. Different condi-

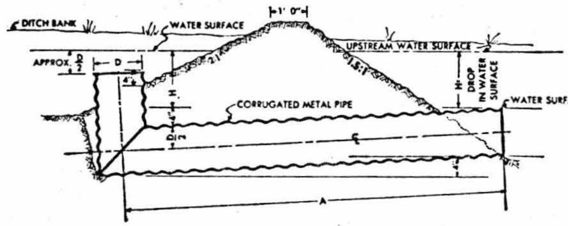


Figure 24 — Cross-section showing setting of steel pipe drop. Heavy riprap or other protection should be placed around lower end.

tions of "get away" will result in disproportionate discharges. Theoretically a 50-50 division should give good results but when the proportions are 10 and 90, results are questionable. A division into more than two parts is not likely to prove satisfactory with the ordinary type of divisor.

Divisors can be tested for accuracy by measuring the flows from each side. Such a test should be made over a quantity range as relationships frequently change with the amount of water being divided. A fixed divisor is shown in figure 26. A design for an adjustable divisor —based on work done by V. M. Cone in 1916 at Colorado A & M College*—is shown in figure 27.

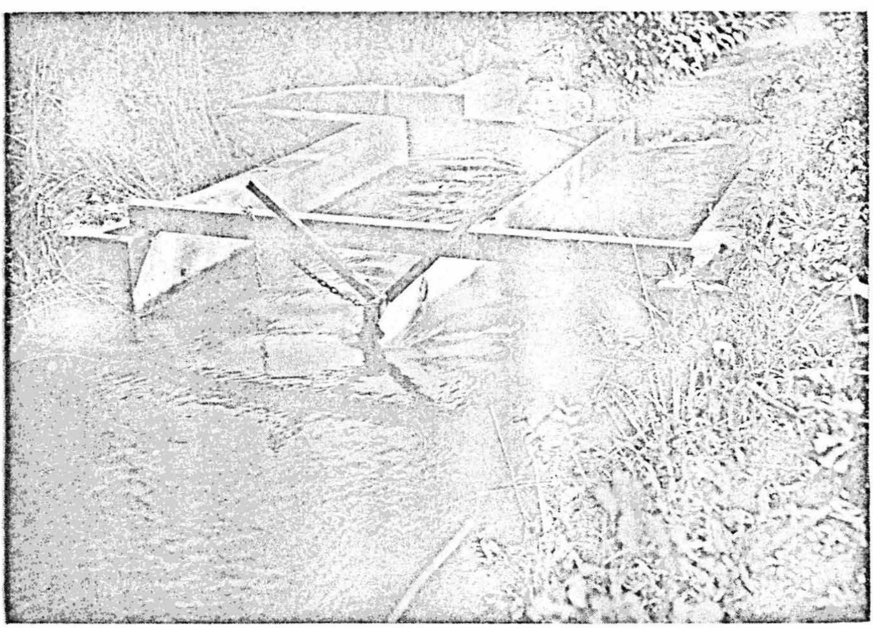


Figure 25—An adjustable divisor. This is faulty in two respects. The upper control is at the upper edge of the structure and downstream conditions favor the right-hand channel.

*Cone, V. M., Divisors, 1917, Bul. 228, Colorado A and M Experiment Station.

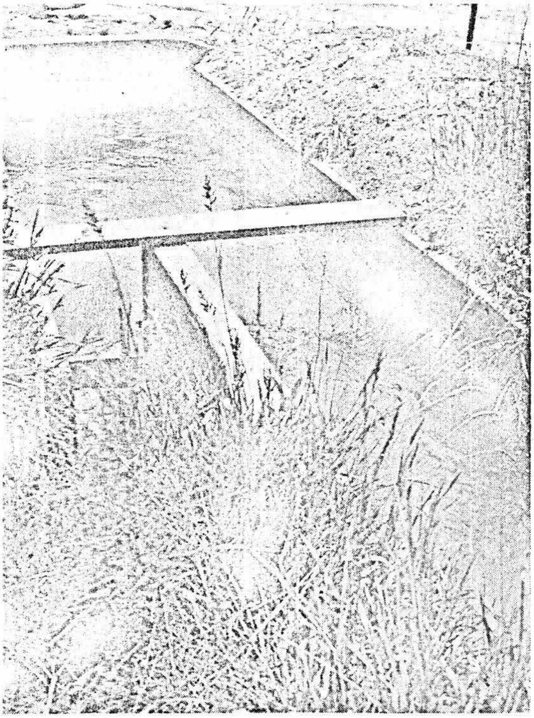


Figure 26—A fixed proportion divisor. The approach and downstream conditions are good even though there is no control point.

To provide the proper conditions upstream, the control crest is placed well downstream from the entrance to the structure. The control crest should be high enough to reduce the approach velocity to less than two feet per second and also to reduce the effect of different downstream conditions. A free overpour would be more desirable to accomplish this but the rise in the water surface above the structure might be too great.

The "splitter" should be thin (such as a metal plate) and, of course, should be kept free of trash. An adjustable "splitter" is shown in figure 25. By moving the L-shaped section, the proportions of flow can be changed as desired. One objection to this type is the leak from one channel to the other that may occur under the movable board. Another type of adjustable "splitter" is a metal sheet hinged at the downstream end. There are two objections to this type—it changes the entrance conditions and leakage can occur under the plate.

The Cippoletti weir can be used as a divisor and is perhaps better adapted for a three-way division than other types. The sides of this weir have a slope of four vertically to one horizontally which automatically corrects for side contractions. Divisor plates should be placed to split the flow vertically, not horizontally.

Flumes

Flumes or inverted siphons are required for crossing drainage ways. A choice between the two can be made only after a cost study. For deep, wide depressions, the inverted siphon may be more economical than a flume crossing. Timber or steel are ordinarily the materials used for open flumes. Steel pipe is becoming very common for these structures.

The kind of wood, the character of exposure and the amount of stress have an important bearing on the life of timber flumes. If it were not for the warping and change of dimension due to wetting and drying, lumber would be entirely satisfactory. Schemes for preventing leakage from timber flumes include lining with roll roofing or light weight steel sheeting. By using ship lap or driven-tongue joints and two-inch fir lumber, a fairly tight structure can be built. In small flumes, the sides carry the load between supports. When made of 2 by 12 inch lumber, this distance is limited to 14 feet if the width is less than 2 feet and the water depth does not exceed 8 inches. The span can be increased to 16 feet if the width is only 12 inches. Center supports from below are expensive and cause channel obstruction. They may be avoided by using a truss such as shown in figure 28.

Flume capacity is influenced by entrance conditions unless the area of flow through it is about the same as the connecting ditch. If the flume is very much less in area, the velocity must be increased by increasing the slope. A fall must be created at the entrance to attain the new velocity. To avoid overflow at this point, the sides may have to be higher than the other parts.

A rectangular flume with a cross-sectional water area of two-thirds square foot on a slope of 6 inches per 100 feet will have a capacity of about 2.3 cubic feet per second. This capacity would be for a flume one foot wide with a water depth of eight inches. Doubling the width would increase the capacity to 5.8 c.f.s. In the latter case, the velocity would be about 4.4 feet per second. If the ditch approach velocity is assumed at two feet per

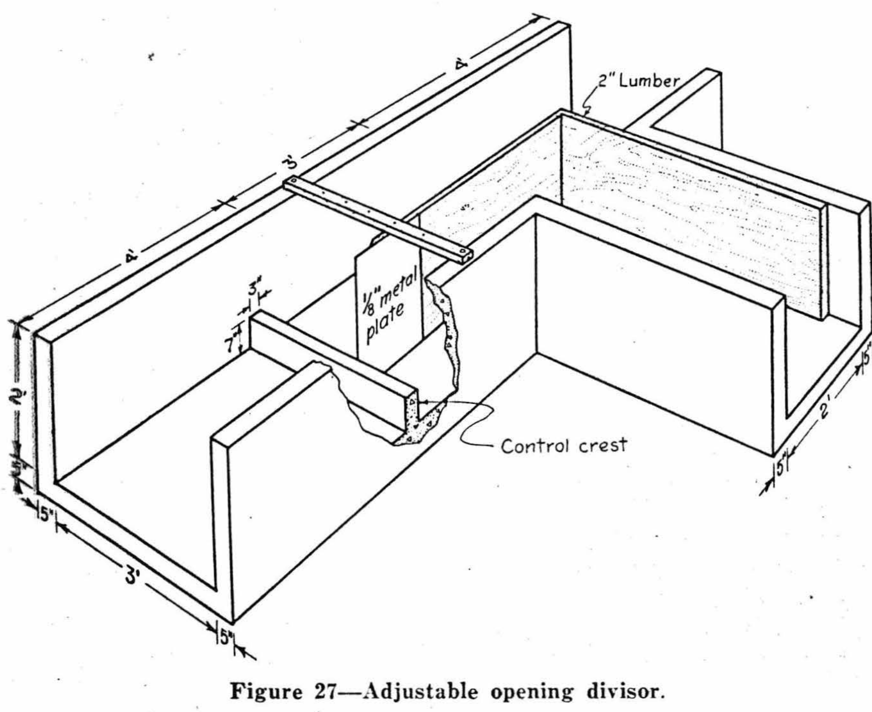


Figure 27—Adjustable opening divisor.

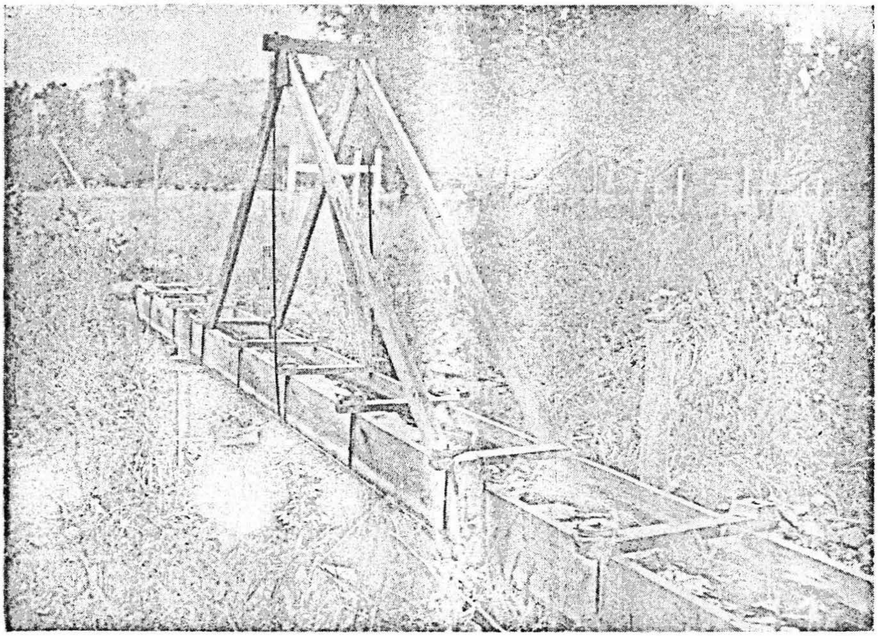


Figure 28—Timber flume with A-frame truss.

Figure 29—Metal flume on timber supports.

second, a fall in the water surface of about three inches must be provided for at the entrance.

Supports for flumes should be placed on concrete mud sills that extend above the ground line in order to prevent rotting of the timbers. If the supports are 10 feet or more in height, cross bracing is needed to prevent side sway from wind pressure. Bearing timbers should rest on top of supports or be bolted to them when the supports are used as sides. If the bottom is made of two or more pieces, yokes must be used between supports. Entrance and exit structures should be made of concrete, should have considerable length and should be well secured to the flume ends. Any failure at these points usually spells disaster.

Steel flumes are preferred to timber flumes. They can be made practically water tight and they will remain so during their useful life. To attain long life, they should be carefully put together and the supporting structure should be well designed. Since they are a commercial product, information and advice on construction and capacity should be obtained from the manufacturer. Flumes of any size are obtainable. One of about 10 c.f.s. capacity is shown in figure 29.

Steel pipe flumes are rapidly replacing other types for small flows. They can be quickly installed and some of the dangers of overflow are eliminated. For protection against plugging which will cause overflow in the approach ditch, a spillway for the escape of excess water should be provided. This spillway should not be adjacent to the structure. There are three types of pipe flumes. One requires outside continuous support such as used with open steel or timber flumes, the second is cable suspension and the third is a pipe with sufficient wall thickness to be self supporting. The three types are illustrated in figures 30, 31 and 32.

To obtain the full capacity of a pipe flume, its top should be placed a foot below the water surface at both ends. The concrete at the entrance should be bell shaped to reduce the head loss at this point. Smooth welded pipe should be chosen for flumes rather than corrugated pipe (such as is shown in figure

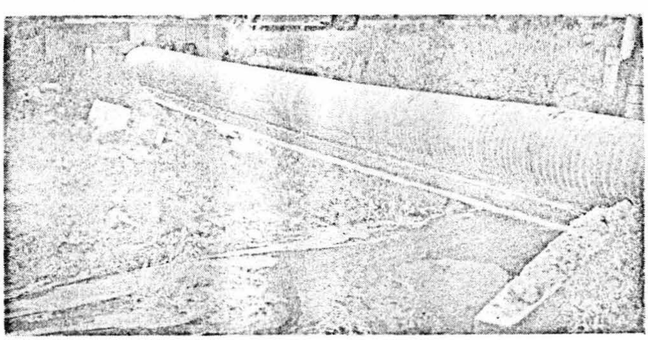


Figure 30 — Corrugated steel pipe flume supported on framed steel beams.

Figure 31—Unsupported plain steel pipe flume.

30) since it has about twice the capacity for the same nominal diameter. Table 3 estimates the pipe size and wall thickness for a given span and quantity of water. The fall indicated is the difference in elevation between water surfaces at each end, not the pipe ends, and is for a length of 100 feet. For shorter lengths, the fall required will be proportionately less. The additional losses indicated are those occurring at the entrance and velocity head. These are approximate and are constant regardless of pipe length. The manufacturer should be consulted on the details before a purchase is made.

Chutes

When water is to be conveyed down a steep slope, there is a choice to be made between a succession of drops, an open lined

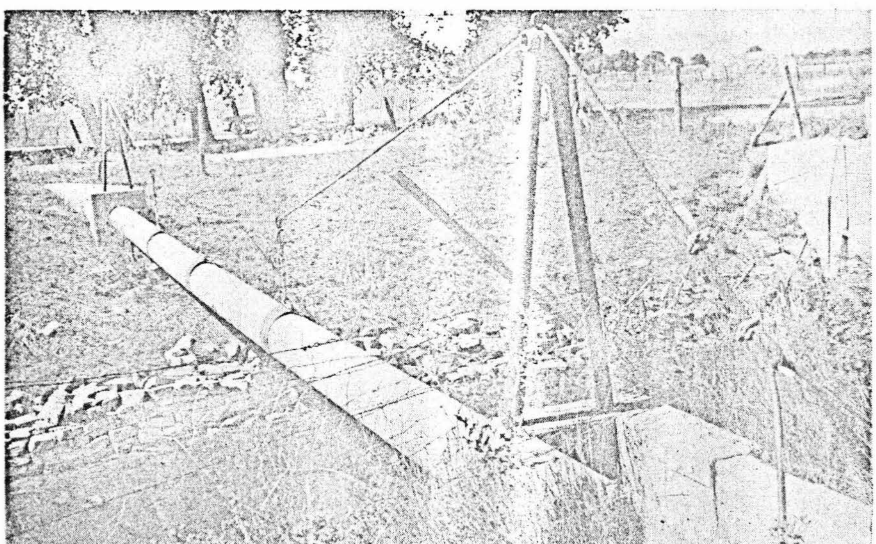


Figure 32—Cable suspension support for plain steel pipe flume.

canal or a pipe line. The cost of all should be investigated. Often the lined canal or pipe line will prove less costly and will have definite advantages over drops.

In such situations the velocities in canals and pipe lines are usually very high and may lead to difficulties. This is particularly true if a chute contains a turn or if the flow has to be diverted part way down the slope. When high-velocity water is slowed down to a low velocity for turning into a lateral, there is a sudden increase in depth through what is known as an hydraulic jump. If the height of the walls is not increased to provide for this depth, overflow will take place. The added height can be computed mathematically but, because of its technical nature, will not be discussed here.

Use pipe to divert water on its way down a steep slope. The outlet in this case could be controlled by means of a gate valve. If the pipe is concrete, gates installed in concrete risers would provide the control. The high velocities would be dissipated within such risers. Ordinary, agricultural concrete pipe should not be subjected to water pressures exceeding eight feet. Caution must be exercised in the use of valves on such lines (see page 47).

Culverts and Bridges

For road crossings across small ditches, a steel or concrete pipe culvert is the simplest and most satisfactory answer. Corrugated steel is the best material for these culverts because of its flexibility, low cost and strength to resist earth pressure. Plain steel pipe does not have nearly the strength of corrugated steel

TABLE 3—Capacity and spans for welded plain steel pipe flumes.*

Pipe Size	Maximum span length	Wall Thickness	Fall per 100 feet**	Add for additional losses	Discharge
inches	feet	gage	inches	inches	c.f.s.
10	17	14	2	1	1.1
	30	12	3	1½	1.4
12	22	12	2	1½	1.8
	34	10	3	2	2.2
16	21	10	1	1	2.6
			2	2	3.8
			3	2½	4.6
20	14	10	1	1	4.6
	23	7	2	2	6.7
24	10	10	1	1½	7.5
	16	7	2	3	10.8
30	11	7	1	1½	13.4
			2	3½	19.2

*Span lengths from Handbook of Welded Steel Pipe, 1950, by permission Armco Drainage and Metal Products, Inc.

**Multiply by four if corrugated pipe is used.

pipe to resist external loads. Corrugated steel pipe can be salvaged and can be taken up for use at another location. Extra-strength concrete pipe is obtainable from some manufacturing concerns for use as culverts. In these pipes the concrete is poured into the forms rather than dry tamped.

Velocities through culverts should be rather high (not less than 2½ feet per second) to avoid deposition. To determine the size pipe to use, divide the flow in cubic feet per second by the velocity to get the area in square feet. By changing this to square inches, dividing by 0.79 and then extracting the square root, one obtains the diameter.

Example: For 3 cubic feet per second and a velocity of 2.5 feet per second, what will be the pipe diameter? Divide 3 by 2.5 and the result is 1.2 square feet. To change this to square inches, multiply by 144. The square root of this quantity (173 square inches) is 13.2 inches. The next smaller pipe size—12 inches—would be the size of pipe to choose.

If smooth pipe is used, allow about an inch for friction (four inches for corrugated pipe) plus another inch for entrance loss as the difference in elevation between the upstream and downstream water surfaces when both ends are completely submerged. The upstream submergence should be at least five inches for either kind of pipe. This may mean placing the pipe below ditch grade. The ends should be finished with a head wall to prevent traffic damage to the pipe ends and to maintain the useful full length of the culvert. The earth foundation should be shaped to fit the lower one-third of the pipe. Backfilling should be thoroughly tamped around and over the pipe. The covering should not be less than 1 foot for corrugated metal and 18 inches for concrete.

A bridge constructed of timber may be considered if a culvert cannot be used. The principal difficulty will be that of obtaining timber of the proper dimensions to carry the heavy loads often imposed upon farm bridges. The farmer usually is dependent upon salvaged material, but there is also the possibility of obtaining dimension lumber on order from local sawmills. Salvaged telephone poles and railroad switch ties offer possibilities.

Decking should not be less than three inches thick in order to spread the load over more than one stringer. Foundations should be made of concrete and should extend into firm earth. A bridge design using 6 by 12 stringers on a 14-foot span and capable of carrying a load of 13,000 pounds on one axle is shown in figure 33. Telephone poles 12 inches in diameter could be used in place of the dimension lumber. Old but sound railroad ties similarly placed would be safe on a six-foot span.

Trash Racks and Screens

Trash racks are necessary at every pipe entrance. These should be built so they can be easily cleaned and removed. They also should be fire proof. The best materials are round rods, pipe or flat bars welded to cross pieces. For ease of withdrawing from a groove or to facilitate sliding on a flat surface, a rail should be welded to the cross pieces. If rods or pipe are used, they should have a nominal diameter of three-quarter inch. If bars are used, the dimensions should be three-sixteenths by one inch. Spacing between bars should be about four or five inches. For convenience in cleaning, the top part of the supporting structure should be close to the top of the rack so that trash will fall onto the ground surface during removal. A trash rack is shown in figure 34.

Screens are required for gated pipe as well as for sprinkler systems. Screens for gated pipe need not be fine mesh. For gated pipe, coarse debris such as twigs, leaves and corn cobs must be screened out. This requires a screen of about three-quarters inch mesh or rabbit fencing. Ahead of such a screen, a coarser screen of about 1½ or

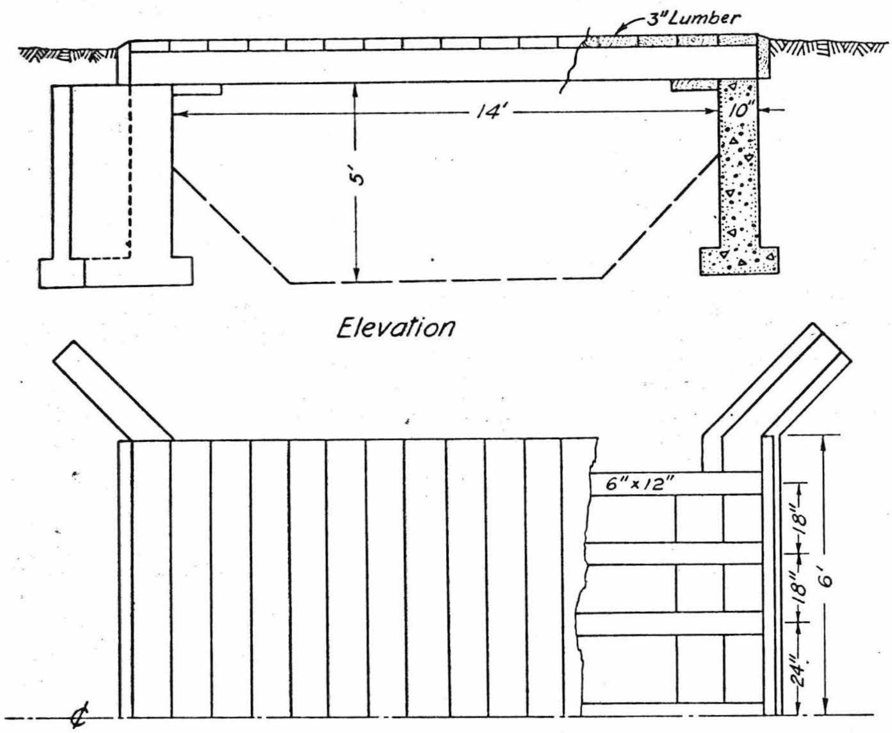


Figure 33—A timber bridge designed for a single axle load of 13,000 pounds.

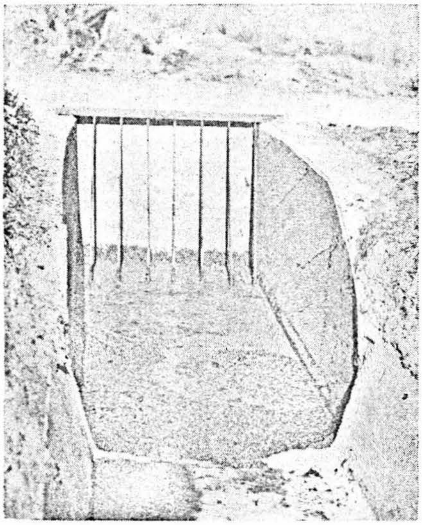


Figure 34—Steel trash rack at intake of pipe line.

2-inch mesh is desirable. In the fall, leaves become the greatest source of trouble. All leaves stop on the screens and, to avoid constant attention, the screen area should be great. Ordinarily this cannot be accomplished by a screen set transverse to the flow. Set them parallel to the flow in a supporting structure so that the clear water may be taken off at the side. There should always be two screens so that trash will not get by when one is removed for cleaning. A self-cleaning trash screen is shown in figure 35. Horizontal trash screens such as this must be of fine mesh (fly screen) to facilitate the wiping operation.

When part of the water can be bypassed, the screening problem is greatly simplified. With the extra water, a large proportion of trash can be floated past the screens. Since finer screens are necessary for sprinklers (one-eighth to one-tenth inch), a fly screen set horizontally has been found satisfactory. By using a large area screen, equivalent to about 30 gallons per minute per square foot (thus producing a low downward velocity), most trash will float on past. Such fine screens can be cleaned with a broom instead of by removal of the screen.

Sand Traps

There are numerous schemes for removing the bed load of sand and small gravel from canals by means of traps. These traps often are constructed depressions in the bed of the canal covered by a grating and dependent on a transverse sluicing action to move the trapped load.

For small canals—under ten feet bottom width—the simple

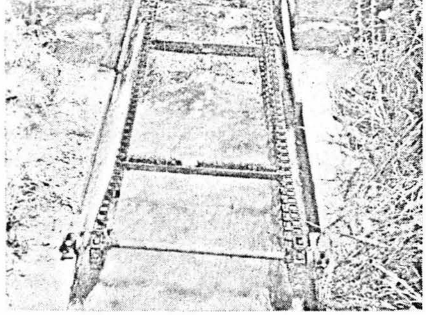


Figure 35—Self cleaning trash rack. Power is supplied by paddle wheel.

vortex tube developed by the Colorado A and M Experiment Station is quite effective. Such a tube is shown in figure 36. It is of little or no value for removing suspended material. Sufficient grade must be available to discharge the sand-laden water back to the river. The tube therefore should be placed near the headworks of the canal.

The velocity of the water over the tube must be great enough to supply the energy necessary to cause rotation of the water in the tube. Usually a velocity of four to six feet per second is required. Four feet per second is about right for depths less than one foot. Sand drops into the tube, the rotation keeps it agitated and the longitudinal flow in the tube transports it to the outlet. The outlet end should be equipped with a slide gate for control of the flow since it does not need to be fully open to function. The gate adjustment is governed by the minimum opening needed to induce the required action in the tube. A discharge of from five to ten percent of the total flow may be necessary for proper functioning.

Although action can be obtained when the tube is placed at right angles to the canal, an angle of 60 degrees with the canal axis produces much better results. The simple tubes should not be more than 15 feet long. The action becomes uncertain if

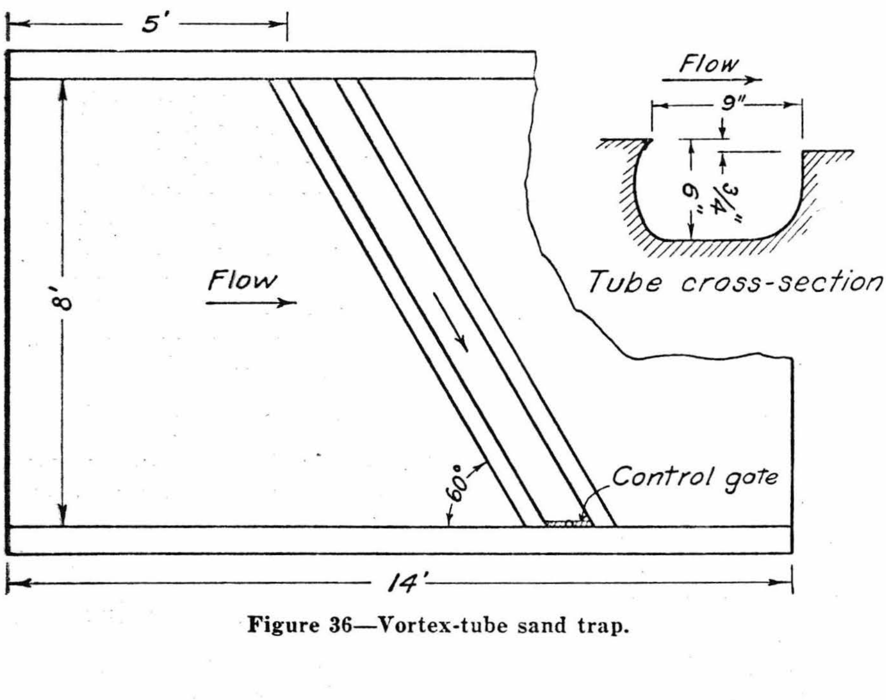


Figure 36—Vortex-tube sand trap.

they are longer. Ordinarily the tube is shaped from about 16 gage galvanized steel. The horizontal approach piece should not be rigidly fixed to the tube since this section wears faster than other parts and may need replacing sooner. For a length of about four feet, a nominal diameter of four inches is sufficient. But for a tube 12 feet long, the diameter should taper from 6 inches at one end to 8 inches at the discharge end.

Since proper conditions of flow are essential for a successful installation, it is recommended that such problems be referred to the Experiment Station for solution.

PIPE LINES

The large capital investment involved in the extensive use of pipe for irrigation requires much careful thought on the part of the investor. Expensive disappointments are numerous through the wrong choice of materials, lack of capacity, short life or defective construction. Where pipe line installations involve large sums of money, it is wise to seek competent technical assistance. Besides the ordinary situations requiring the use of pipe, it can be used in place of open ditches and flumes.

Water used in irrigation often carries a burden of soil, sand or gravel. In this respect, pipe lines are subjected to different conditions than municipal pipe lines or lines carrying clear well water. To prevent the deposit of materials within the pipe, a sufficiently high velocity of flow must be maintained. A velocity of two feet per second will keep fine sand moving but three feet per second is required for fine gravel.

Choice of Materials

The materials used in agricultural pipe lines are vitrified clay, concrete and steel. Clay was very commonly used many years ago and is still used extensively in drains.

The choice of materials is dependent on the conditions under which the pipe is to operate. If, for instance, the water is carrying much gravel, concrete or clay may be better than steel unless the steel is paved with erosion-resistant materials. Where soils contain salts in quantity, a chemical analysis should be made to find out what salts predominate. If sulphates run high, concrete should be avoided. Should chlorides predominate, the life of steel will be shortened unless it has a special protective wrapping. When either concrete or clay pipe is laid with cement mortar joints, the line is very rigid. If in the frost zone, breakage of the joints will be common due to the earth movement. Steel is flexible and will withstand considerable movement. For pressures in excess of eight or ten feet, steel should be chosen instead of concrete unless concrete pipe of high quality is laid below the frost line and has special joints. Steel should be chosen if the line is likely to be subject to water hammer.

Clay Pipe

As far as durability is concerned, vitrified clay pipe will last practically forever in nearly any kind of environment. Under low heads, second-grade pipe —pipe refused for municipal sewers—is entirely satisfactory and cheaper. Hard-burned clay pipe without bell ends is frequently used in drainage but is not suitable for conveying irrigation water. Since the bell joints are made rigid when filled with cement mortar, each length should be placed on original or well-packed soil to avoid unequal settlement and subsequent breakage.

Concrete Pipe

Plain concrete pipe is usually cheaper than vitrified clay and, when not exposed to adverse conditions, is entirely satisfactory for irrigation work. It may be either hand or machine made or wet poured. The last two kinds are denser and stronger. Specimens of concrete pipe are shown in figure 37. Further strength is gained from steel reinforcement but such pipe is seldom

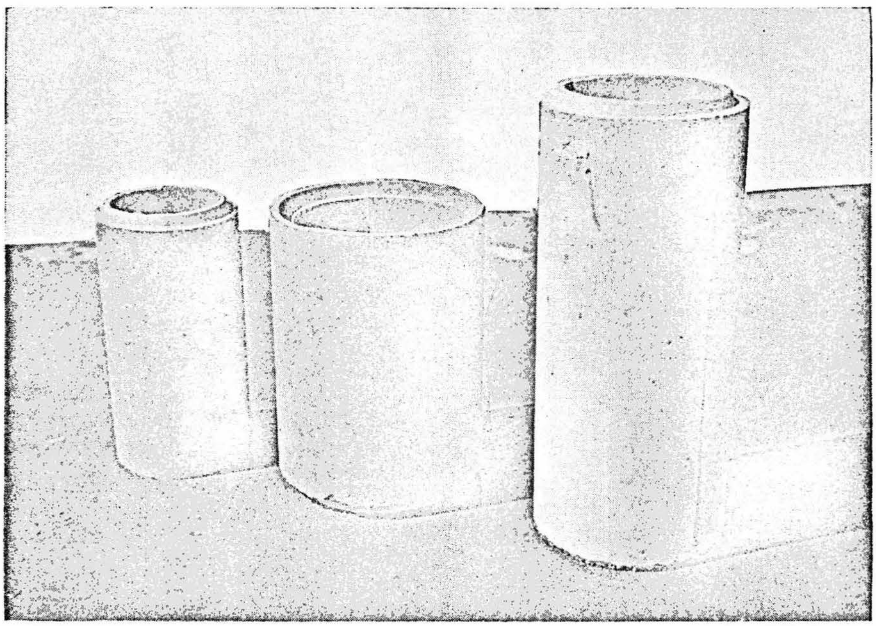


Figure 37—Handmade concrete pipe with tongue and groove joints. The section at the right is wet poured. The other two are hand tamped.

used in irrigation practice. Concrete quality has a very important bearing on durability, hence good quality aggregate and water must be used in pipe manufacture.

The usual concrete pipe is made with tongue and groove joints which are filled with cement mortar. Each section should be laid on firm, undisturbed soil and the line kept reasonably straight. As each new section is pushed into place, the excess mortar in the joint is pushed out. A swab is pulled along inside the pipe to remove and smooth out the excess mortar. A shallow depression to admit a workman's hands is made in advance below each pipe end.

After about three lengths have been laid, a band of cement mortar is hand placed around a joint. Banding at a distance of three lengths back prevents band injury while a new pipe section is being placed. A strip of paper is placed on top of the band to prevent loss of moisture. The line should be covered with a few inches of moist earth soon after banding to provide protection against movement and also to prevent too rapid drying of the joint mortar. Open ends are closed to stop circulation of air. Danger of longitudinal line breakage is greatly reduced if dry pipe is well wetted before laying. No disturbance of the line should be permitted for at least 24 hours after laying. The construction of concrete pipe lines is fully described in a publication of the Portland Cement Association*.

Openings in concrete pipe lines at standpipes or boxes are permitted by omitting a section at such structures. Slide gates usually are used to control the flow. Lateral line and riser connections can be made by chipping holes in the pipe over which the lateral or riser pipe is placed and cemented (see figure 38). Several moderately priced valves are available to control the flow at openings. An alfalfa valve for a concrete pipe riser

Figure 38—Placing a riser pipe on a concrete pipe line.

*Irrigation With Concrete Pipe. Portland Cement Association, 33 West Grand Avenue, Chicago 10, Illinois.

is shown in figure 39. Hydrants may be attached to such valves for turning water into distribution pipes (or hose) as shown in figure 40.

Steel Pipe

Pipe made from sheet steel is available either galvanized and riveted or black welded. Both types are asphalt dipped and may be further protected by an asphalt impregnated paper wrapping. The minimum diameter of such pipe is four inches. Ordinarily it comes in 20-foot sections for convenience in shipping and installing. The simplest field joint for moderate pressure is that which is driven while the asphalt coating at the joint is hot. Dayton and Dresser couplings (figure 41) are used often as they are moderate in cost and easily installed. These couplings act as expansion joints when lines are exposed to temperature extremes.

Figure 39—An alfalfa valve being set on a concrete riser pipe.

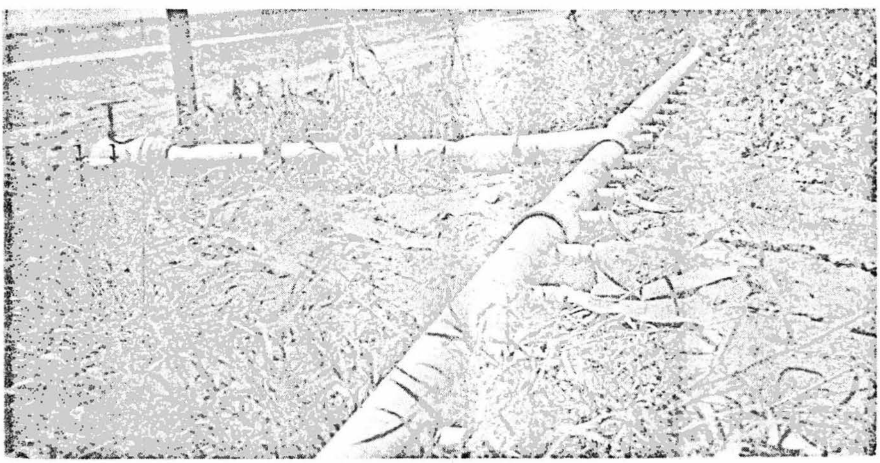


Figure 40—Portable hydrant mounted on alfalfa valve to which either surface pipe or canvas hose may be attached.

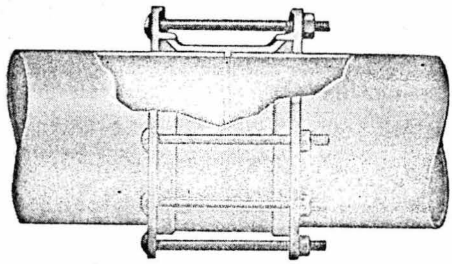


Figure 41—A Dayton coupling.

Asphalt-dipped black steel in the lighter gages may have a life of 20 or more years depending on the exposure. Thickness of metal is one of the determining factors but, when galvanized and dipped, a longer life can be expected. In some situations electrolysis may ruin a line in a very short time, making cathodic protection necessary. Cathodic protection consists of imposing an electric current between anodes buried in the soil and the pipe line. Another method uses a magnesium block as an anode. Technical advice is necessary for any such installation.

Steel pipe should be chosen whenever tightness, high pressures (over ten feet of head) or water hammer are involved. Steel pipe should be considered as an alternative to an open flume for crossing depressions, either on grade or as a so-called inverted siphon. True siphons are seldom used except to connect wells in a battery system. For this purpose, tightness and strength against collapse are very important and standard-threaded pipe usually is preferred.

Thin, plain steel pipe should not be subjected to high external pressures nor internally to below-atmospheric pressures. Pipe lines should be placed well below the ground surface at roadways or where heavy loads may pass over them. The larger diameters of thin wall pipe are especially vulnerable to collapse if the end valve at a high point is closed before there has been an opportunity for the line to drain out. For automatic protection against collapse due to closure of an end valve, an air relief pipe (see figure 42) should be installed in the pipe line back of the valve.

Pipe Line Design

In the solution of pipe line problems, some familiarity with resistance to flow and some oth-

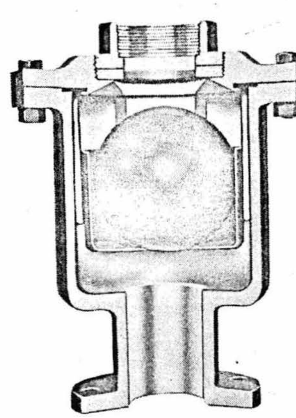


Figure 42—A pipe line air relief valve.

er features is necessary. This resistance is caused mainly by friction along the pipe walls. Other factors such as bends, valves and changes in size also add to resistance. In some types of problems, especially those involving short pipes, the loss at the entrance is more important than wall friction. Friction in pipe varies with velocity and is expressed in feet of head per 100 or 1,000 feet of length. Friction can be shown in tables or diagrams. Other losses have to be determined independently. It is obvious that the smoother the pipe interior, the less will be the head loss. Thus, the head loss in plain welded pipe is less than in concrete pipe with its numerous, somewhat rough joints and far less than corrugated steel pipe.

Some people find pipe problems difficult to solve. For that reason, four examples are given in which the use of tables 4 and 5 is shown.

Example 1. How much fall (difference in head) will be required to transport 900 gallons per minute through a 10-inch welded steel pipe line 925 feet long that enters a reservoir flush with the head wall? Enter table 4 in the left hand column under g.p.m. at 900. Follow horizontally across to the column under 10-inch diameter and find 5.09 feet. This is the head loss or difference in head in 1,000 feet of pipe. For 925 feet, it will be $\frac{925}{1,000} \times 5.09 = 4.71$ feet. The water in this case is delivered under no pressure at the outlet.

Besides the loss of head because of pipe friction, there is also a loss at the entrance and the energy loss (expressed as velocity head in feet) required to speed up the water to pipe line velocity. It is necessary to compute the velocity in the pipe and this can be done by applying the formulas in the addenda (page 60). In this example, the loss of head at the entrance and the velocity head amount to 0.1 and 0.2 foot respectively. The total loss, therefore, becomes 4.7 plus 0.3, or 5.0 feet. All losses mentioned are illustrated in figure 43.

Suppose the water quantity is 975 g.p.m. This is three-quarters the difference between 900 and 1,000 g.p.m. So three-quarters of the difference between 5.09 and 6.17 is to be added to 5.09. The result is computed thus: $(6.17 - 5.09) \times \frac{3}{4} + 5.09 = 0.81 + 5.09 = 5.90$ feet. The entrance loss and velocity head amount to about 0.4 feet. The final result is $\frac{925}{1,000} \times 5.90$ plus $0.4 = 5.46 + 0.4 = 5.86$ (use 5.9) feet.

Example 2. A welded steel pipe line is needed to convey 1,200 g.p.m. across a ravine, the fall between water surfaces at each end being 6 feet and the distance along the line, 1,150 feet. The first step is the computation of the slope in terms of fall in 1,000 feet. Divide 6 by 1,150, which gives the slope per

TABLE 4—Loss of head in feet per thousand feet of new welded steel pipe.*

Cubic ft. per second	Gallons per minute	Outside diameter 14 gage steel, inches									
		4	6	8	10	12	14	16	18	20	24
.22	100	7.54	.97								
.28	125	11.93	1.53								
.33	150	16.30	2.09								
.39	175	22.39	2.87	.67							
.44	200	28.17	3.62	.85							
.56	250	44.53	5.72	1.35	.44						
.67	300	62.58	8.03	1.91	.62						
.78	350	83.62	10.74	2.55	.84	.34					
.89	400	107.3	13.78	3.28	1.07	.43					
1.00	450	135.7	17.21	4.07	1.33	.54					
1.11	500	165.5	20.99	4.97	1.63	.66	.31				
1.34	600		30.11	7.12	2.34	.94	.44				
1.56	700		40.09	9.50	3.13	1.25	.58	.30			
1.78	800		51.45	12.21	4.00	1.62	.75	.39	.22		
2.01	900		64.69	15.38	5.09	2.03	.96	.49	.27		
2.23	1000		79.14	18.75	6.17	2.48	1.16	.60	.33	.20	
2.67	1200		111.3	26.98	8.68	3.48	1.63	.84	.47	.28	
3.12	1400			35.41	11.60	4.67	2.19	1.13	.63	.37	
3.56	1600			45.58	14.90	5.99	2.82	1.45	.81	.48	.20
4.01	1800			57.13	18.80	7.55	3.53	1.82	1.02	.61	.24
4.46	2000			69.90	23.30	9.14	4.30	2.23	1.24	.74	.30
5.57	2500			106.7	35.30	14.09	6.60	3.40	1.90	1.13	.46
6.68	3000				49.10	19.89	9.32	4.79	2.67	1.59	.64
7.80	3500				66.35	26.73	12.49	6.44	3.58	2.14	.87
8.91	4000				85.41	34.67	16.11	8.28	4.61	2.74	1.11
10.03	4500					42.99	20.17	10.38	5.77	3.44	1.40
11.14	5000					52.81	24.61	12.66	7.06	4.22	1.71
13.37	6000					74.52	34.85	17.92	10.00	5.95	2.42
15.60	7000						46.66	24.03	13.39	7.99	3.23
17.82	8000						60.13	30.98	17.26	10.26	4.18
Factors to apply to figures in columns above to obtain approximate head loss for other pipes of that nominal diameter.											
Riveted steel (I.D.)		0.98	1.04	1.08	1.09	1.11	1.12	1.13	1.14	1.14	1.15
Corrugated steel				4.5	4.3	4.2			3.8		3.6
Concrete—dry mix			1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.4

*From Armco Handbook of Welded Steel Pipe by permission. Computed from Scobey's formula, $K_s = 0.32$.

foot, and multiply by 1,000 thus: $1{,}000 \times (\frac{6}{1{,}150}) = 5.21$ feet. On the line opposite 1,200 g.p.m. in table 4, follow to the right until the first number is found less than 5.21. This will be 3.48 feet under the 12-inch pipe column which means that this pipe is slightly larger than needed. The 10-inch with 8.68 feet is too small. An 11-inch pipe would be about right, but this is not obtainable commercially so 12-inch must be chosen. This pipe will not be flowing full at the upper end under the circumstances.

Suppose that because of the money saving in using the 10-inch pipe, one wanted to know how much water that size would convey. One follows this procedure: Under the 10-inch pipe column, follow downward until a number is found less than 5.21, which in this case is 5.09. This corresponds to 900 g.p.m. The correct capacity lies between 900 and 1,000 g.p.m. and is found by interpolation. The difference between 6.17 and 5.09 is 1.08. The proportion of 0.12 to 1.08 is $0.12 \div 1.08 = 0.11$. This same proportion applies to the capacity difference between 900 and 1,000 g.p.m. which is $0.11 \times 100 = 11$ g.p.m. Add this to 900 and the correct capacity is found to be 911 g.p.m. for the 10-inch pipe.

TABLE 5—Loss of head in feet per 1000 feet of common steel pipe, slightly rusted interior.*

	Pipe Size in Inches							
Gallons per minute	½	¾	1	1¼	1½	2	2½	3
1	21							
2	74	19						
3	158	41	13					
4	270	70	21	6	2.6			
5	410	105	32	8	4.0			
6		147	46	12	5.6	2.0		
7		250	62	16	7.4	2.7		
8		380	78	20	9.5	3.3	1.1	
9			97	25	11.8	4.1	1.4	
10			117	30	14.3	5.0	1.7	0.7
12			164	43	20.1	7.0	2.4	1.1
14			220	57	26.8	9.4	3.2	1.4
16			280	73	34.1	12.0	4.1	1.7
18			350	91	42.4	14.9	5.0	2.1
20			420	111	52	18.2	6.1	2.5
25				166	79	27.3	9.2	3.8
30				235	110	38.4	12.9	5.4
35				312	147	51	17.2	7.1
40				400	188	66	22.0	9.1
50					284	99	33.2	13.8
60					396	139	46.5	19.2
70						184	62	25.7
80						237	79	32.8
90						294	98	40.8
100						358	120	49.6
120							168	70
140							223	92
160							290	118
180							357	148
200							431	178

*Hazen-Williams formula, C = 100

If a closer calculation of capacity of the foregoing pipeline is desired, the losses at the upper end must be taken into consideration. By applying the formulas on page 60, the pipeline velocity is found to be 3.81 feet per second. The computed loss of head at the entrance and the velocity head are 0.1 and 0.2 foot respectively. The available head now becomes 5.7 feet instead of 6 feet. Following the method described in the preceding paragraph, the final capacity is found to be 888 g.p.m.

Example 3. Find the pressure above a pump discharging through a 10-inch welded steel pipe line 860 feet long. The water surface at the point of discharge is 28 feet higher than the pump head. The discharge is 850 g.p.m. The pressure will be the lift of 28 feet plus the head loss in the pipe line. The quantity, 850 g.p.m., is half way between 800 and 900 g.p.m. in the left column of table 4. The loss therefore is half the difference between 4.00 and 5.09 feet as shown under the 10-inch pipe column, added to 4.00, or 4.55 feet. This is for 1,000 feet of pipe so the loss for 860 feet will be (860 ÷ 1,000) × 4.55, or 3.91 feet. It is customary to use but one decimal place in such computations and so the figure is taken as 3.9 feet. The total lift then will be 3.9 plus 28 or 31.9 feet. If the line were to be of riveted steel, the friction loss would be 1.09 × 3.9 = 4.3 feet. The factor 1.09 is given at foot of the table opposite riveted steel.

Example 4. A rancher wants to bring in water for his farmstead and for watering 200 cattle from a spring a mile distant. The fall between the two points is 180 feet. He would like to have sufficient pressure to irrigate a small grass plot and supply domestic needs. What size pipe is needed?

The first calculation to be made is that of the amount of water required—either the rate or the total in one day. The cattle will want about nine gallons per head per day — 1,800 gallons. The household use will be computed on the basis of 75 gallons per person per day. Let us assume there are six persons involved so a total of 450 gallons per day will be required for this purpose. The sum of these two quantities is 2,250 gallons per day, which reduced to a rate will be 1.56 g.p.m. A small lawn sprinkler will use about 3 g.p.m. and the least satisfactory pressure for sprinkling or household purposes is about 15 pounds per square inch (33 feet). Storage is required for cattle because they drink at definite periods and a small flow that will provide the necessary total only is necessary. It is evident that the sprinkling will require the highest rate even though it is not used continuously. The pipe line capacity then must be 3 + 1.56 or 4.56 g.p.m.

To provide the desired pressure, 33 feet of the total of 180 feet must not be used up in friction and the net head now becomes 147 feet. The allowable loss per 1,000 feet will be (147 ÷ 5,280) × 1,000 or 27.9 feet. Table 5 is examined for values near 27.9 for quantities between 4 and 5 g.p.m. This occurs under the one-inch pipe, the values being 21 and 32 feet. A trial will be made for 4.56 g.p.m. by multiplying the difference between 21 and 32 by 0.56 and adding the result to 21. Thus, 11 × 0.56 + 21 = 27.2 feet. This is close enough for the choice of one-inch pipe. The only fear to consider is that pipe interiors become rougher with age — depending on the character of the water — and capacity therefore becomes less. To choose 1¼ inch would double the capacity or increase the working pressure to about 140 feet (61 pounds per square inch).

When a pipe line conveys water down slope over undulating terrain, the engineer constructs a scale diagram (figure 43) on cross-section paper showing the position of the pipe vertically. He then draws a line from the upper to the lower water surface. This line will be straight for a line of uniform diameter and character and is called the hydraulic grade line. This line must pass above the pipe at all points or it will not flow at full capacity.

If a given pressure is desired at the lower end, this pressure in feet is measured vertically above the point of use on the diagram and the hydraulic grade line is drawn to this new starting point. By scaling the distance between the hydraulic grade line and the pipe, one obtains the pressure on the pipe at any chosen point.

Pipe Line Structures

Stand pipes or boxes are the most common structures built along pipe lines. They may be used to divert water or limit the

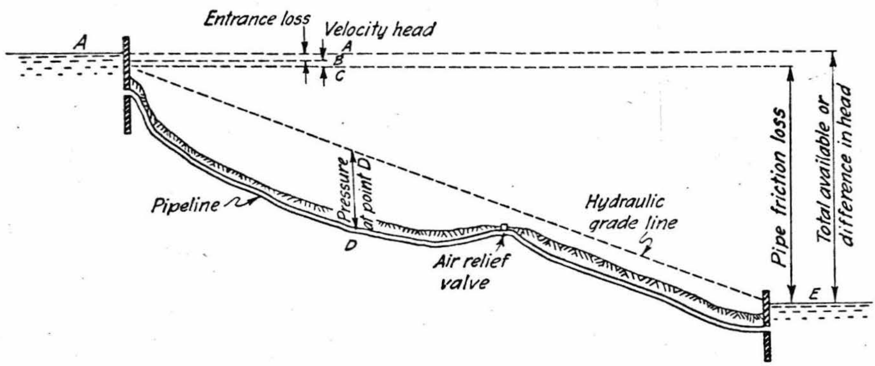


Figure 43—Illustration of the use of the hydraulic grade line. The line starts at a point below the upper water surface equal to the entrance loss plus the velocity head. It ends at the lower water surface. The line will be straight only if the pipe is all the same size and character. It must be above the pipe at all points.

pressure on concrete pipe. Two gates are usually involved in such structures, one for stopping the pipe flow and the other for controlling the diversion. A structure for controlling the pressure along a concrete pipe line is illustrated in figure 44.

In operation, the pressure is normally held to the height of the partition wall, and it cannot exceed the height of the box because it will overflow if a gate is accidentally left closed. The gate in the partition is left open when not required, thus preventing an overpour which results in air entrainment in the pipe below. An air vent such as a two-inch pipe should be located two feet or so downstream from the structure. The air vent is needed because trapped air will reduce the capacity and may cause pulsating flow. A control box can be made of two vertical pipes side by side with connected openings at the top, thus permitting water to spill from one to the other. Where no pressure control is needed, the center wall can be omitted and the gate placed on the outlet pipe. A gate for this purpose is shown in figure 45.

The walls of concrete boxes and standpipes should be about six inches thick. Steel reinforcing for strength is not needed for boxes less than three feet square inside and when the water depth is not over five feet.

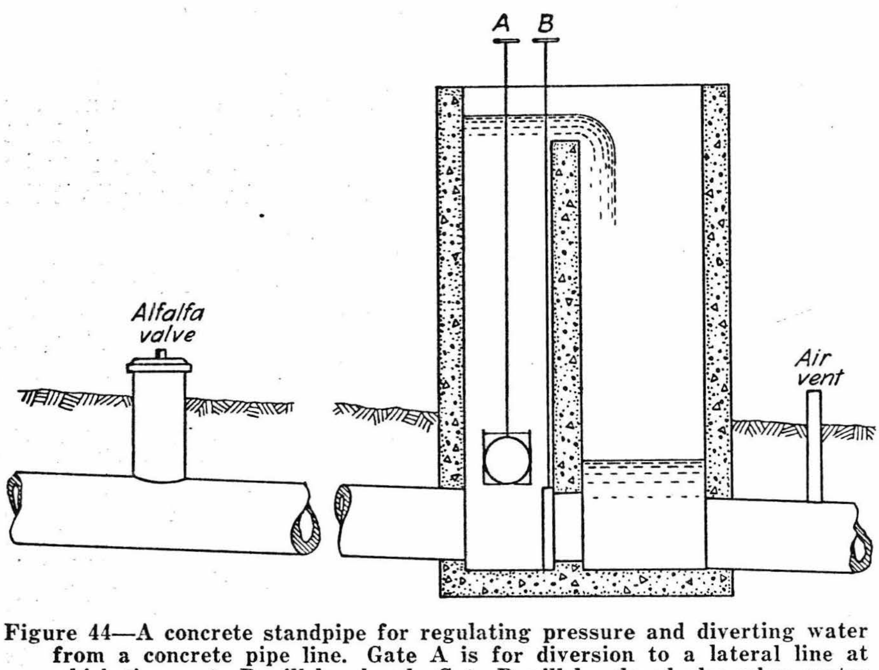


Figure 44—A concrete standpipe for regulating pressure and diverting water from a concrete pipe line. Gate A is for diversion to a lateral line at which time gate B will be closed. Gate B will be closed also when water is drawn from alfalfa valves above. Gates similar to that shown in figure 45 would be satisfactory for this purpose.

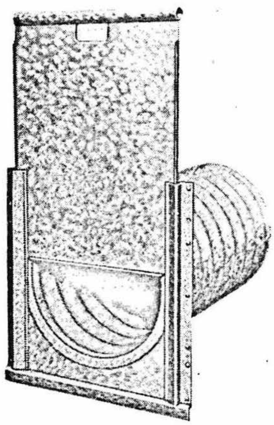


Figure 46—Sheet steel gate on end of short section of corrugated steel pipe.

However all such boxes should contain a minimum reinforcing of three-eighths inch bars on 12-inch centers to prevent cracks due to various causes. For pressures of five to ten feet, the horizontal bars should be nine inches apart.

Disk valves called alfalfa valves (figure 39) permit diversions along the pipeline and are obtainable in a wide variety of sizes. Their cost is reasonable. For steel pipe, the seat is either riveted or welded onto a riser. If alfalfa valves are to operate under much pressure, they should be boxed-in to prevent washing away of the surrounding soil.

The so-called inverted siphon offers no special problem and often is a more desirable method of crossing a low place than an open flume. The velocity through such pipe lines should be sufficiently high that silt and sand will not be deposited in the siphon. A drainout valve is required at the lowest point. The valve should be sufficiently large to permit flushing out of any deposits. The inlet and outlet ends should be submerged. A water depth of two or more feet is desirable at the inlet end to provide for entrance loss of head and to avoid entrance of air. Trash racks are necessary at the upper end. When not in use, both ends should be closed to keep out animals. A safety spillway to care for accidental excess flows is advisable.

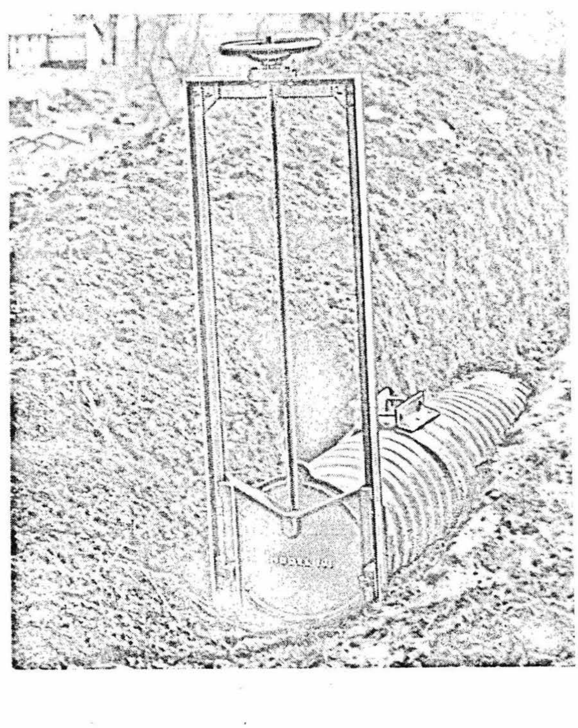


Figure 45—Cast iron gate in steel frame for low pressures. This gate may be attached to steel pipe or placed against a wall. It also is usable on the sloping face of a dam.

Pipe lines laid over undulating terrain should contain air relief vents at the high points. If the pressure is not great at these points, an open vent such as a pipe can be used. If, however, the pressure is so great as to require an unreasonably tall pipe, a ball-type air relief valve —such as that shown in figure 42—must be used. The cost of these valves is reasonable.

PUMPING-PLANT STRUCTURES

Turbine pump installations should be provided with a shelter. Vertical electric motors mounted directly on the pump head are weather proof and the controls can be attached to a short pole. These can be left open to the weather. A shelter, however, helps prevent entry of the larger dust particles and trash into the motor. If belted, a shelter must be provided. A shelter also provides storage space for lubricating oils and small tools. Shelters may be small as indicated in figure 47.

Frame construction is desirable since a shelter must be detachable from its foundation in case the pump has to be removed for repairs. Long power wire lead-ins should not be attached directly to the shelter because of the strain imposed by high winds or ice loads. There is also the danger of inadequate head clearance in the direct wiring method. A stub pole should be placed within a few feet of the shelter and the lead-ins brought down the pole vertically in conduit (figure 47).

A fine shelter for a diesel-driven plant is shown in figure 48. All engine drives should be housed. During the winter, some operators give the engine additional protection from dust with a canvas cover. It may not be possible to move a large shelter in order to remove the pump. In

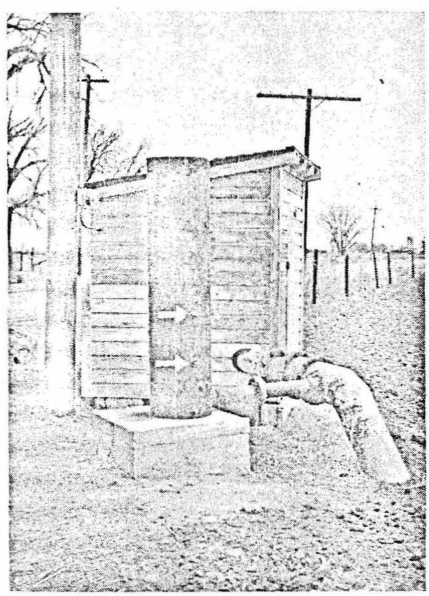


Figure 47—Pumping plant discharging into pipe line in which a check valve and air chamber are involved. Two pet cocks (arrows) are located in the lower third of the air chamber. Note location of stub power pole and conduit into shelter.

such a case the building should be constructed with removable side panels and roof sections. Ample ventilation must be provided.

The discharge from a pump should never be turned directly into an earth ditch. The erosion in such instances is very great. The resulting large-diameter hole is unsightly and makes work around the pump inconvenient. There also is a possibility of damage to the well from downward leakage. A splash box of concrete is shown in figure 49. Walls five or six inches thick are satisfactory. No reinforcing is necessary but bars across the top add considerable strength. If water is to be diverted in more than one direction, steel slide gates or a double set of stop boards can be installed. In most cases, the discharge pipe should come into the box just below the water surface. However, if other water is passing the plant, the pipe should come in just above the surface or the end provided with a flap valve (figure 50) to prevent entry of water. All discharge pipe ends should be protected with some sort of end cover and, if children play in the vicinity, it may be necessary to have a locking cover. Stones thrown into the pipe can easily pass on down the pump column, lodging in the impeller and causing considerable damage.

Pumps discharging directly into pipe lines—especially long ones runnnig up hill—often present serious problems when check valves are involved. When the pipe is exposed, two factors must be considered. One is the change of length, a change which can amount to one inch per 100 feet for maximum temperature range. The other is water hammer. For relatively thin exposed pipe, expansion joints are needed. Such couplers as the Dayton or Dresser, figure 41, will take up change in length and can be used as expansion joints. Pipe placed underground suffers much less change in length. The supporting earth prevents lateral movement and the stress is absorbed by the metal. To prevent any change in length which would move the pump on its foundation, a concrete restraining block is sometimes cast around the pipe near the pump.

Water hammer occurs on the sudden stoppage of flow. It usually takes place upon closing of a check valve installed to prevent back flow. The potential for water-hammer intensity increases with pipe length, difference in elevation and delay in valve closing. If the delay in closing is great, reverse velocity builds up and water hammer can become very severe. Pipes may burst, separate at a joint or the line may lengthen sufficiently to move a pump on its foundation. Very slow hand closing of a gate valve will reduce water hammer to a minimum but such operation permits the line to be emptied if the pump stops accidentally. Closing of a gate valve

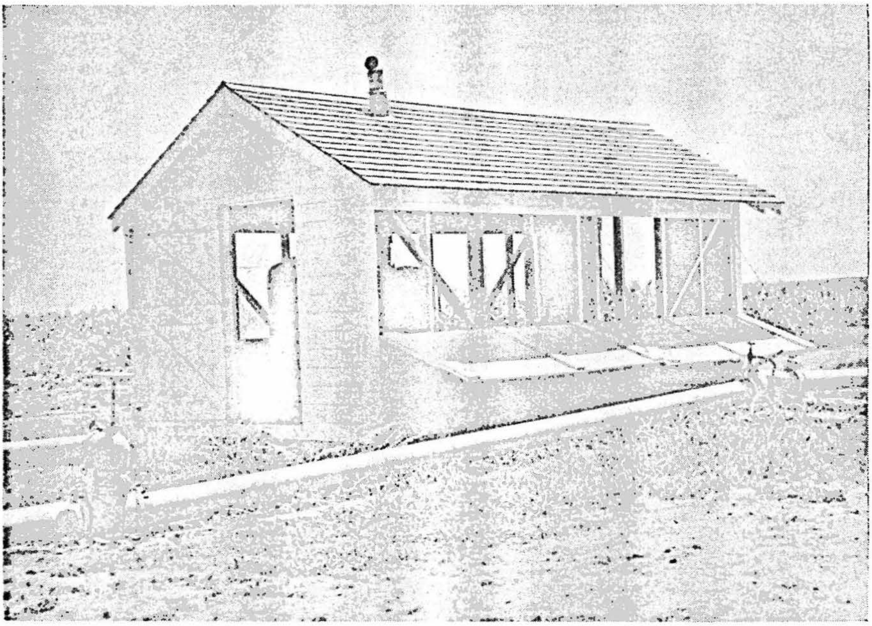


Figure 48—Shelter for diesel engine pumping plant.

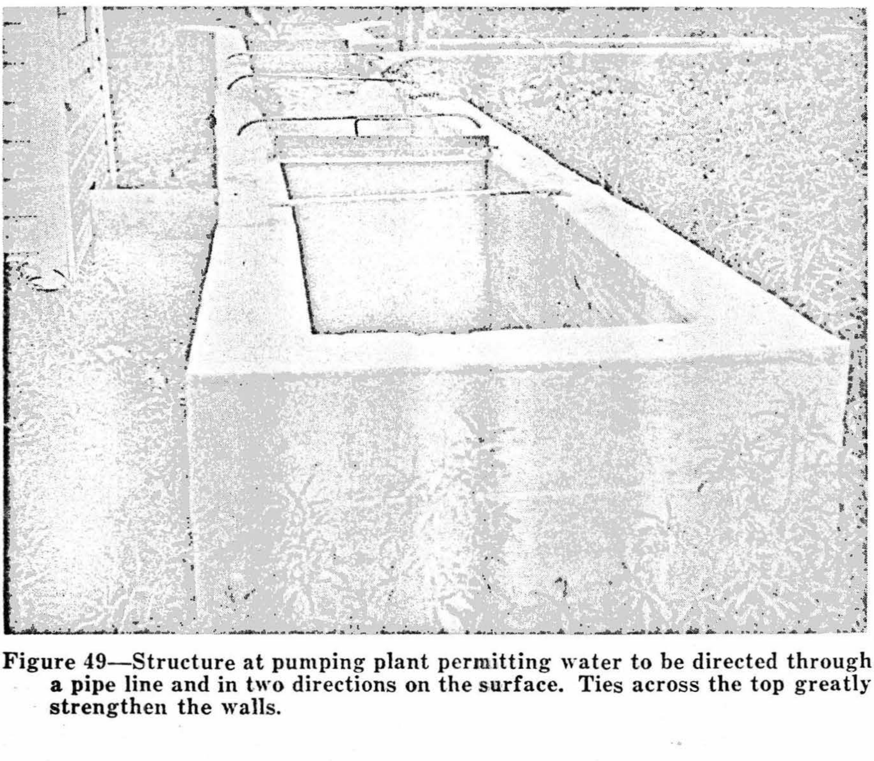


Figure 49—Structure at pumping plant permitting water to be directed through a pipe line and in two directions on the surface. Ties across the top greatly strengthen the walls.

while the pump is still running involves no risk and is proper procedure.

To protect against damage by water hammer where the lift is not great, an open concrete standpipe similar to that shown in figure 44 can be used. An open vertical pipe rising directly from the pipe line and of the same or slightly smaller size is also satisfactory. In the case of the open concrete standpipe, an end flap valve (figure 50) may be used as a check whereas a line check valve (figure 51) will be required in the open vertical pipe case. With a pipe line 400 feet long, the rise in the water surface due to the sudden closing of a check valve in a stand pipe of the same diameter would be about 1.8 feet if the back velocity were one-half foot per second. If the velocity were one foot per second, the rise would be 3.6 feet. The rise occurs above the water level in the stand pipe at the moment the valve closes. This level is somewhat lower than the level while the pump is operating.

It is seen that the actual pressure rise due to a valve closing

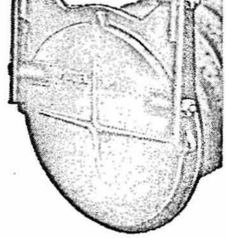


Figure 50—Flap valve for pipe end.

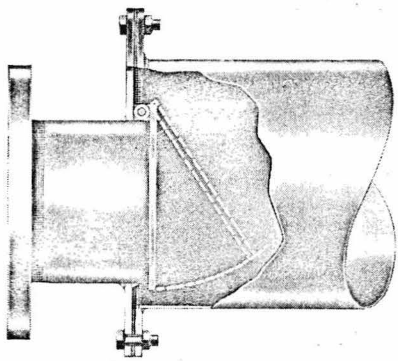


Figure 51—Line check valve.

with reasonable promptness is not very great. If the valve does not close promptly, the potential increase of pressure may be six times the operating pressure. Actually a stand pipe is more likely to overflow on a start against a full pipe because of the momentum that must be overcome in starting flow. To prevent overflow, the pipe must be three or four feet higher than is necessary for elevation and friction combined. Because of their capacity, large concrete boxes need not be built with as much freeboard as those of pipeline size in order to prevent overflow.

When the pressure conditions are such that a stand pipe will be too tall, an air chamber may be used. Such a chamber must have a sufficient volume of air to cushion the water-hammer shock. The pipe leading to the air chamber should be short and not smaller than one-half the diameter of the line pipe. The action of flowing water resulting in water-hammer conditions is rather complex, involving several assumptions before a mathematical solution of the air chamber design can be determined.

In order to gain some idea of the quantities likely to be encountered, the following example is given: A 12-inch steel pipe line is 1,000 feet long and the difference in elevation is 10 feet. The limit of pressure is to be 50 feet and the backward velocity is assumed to be 2 feet per second as the check valve closes. With these data, an air volume of 6.3 cubic feet is indicated. This is equivalent to 8 feet of 12-inch pipe. The volume varies as to the pipe line length, its area and the square of the closing velocity. Therefore, if the pipe line length was 750 feet, the air volume would be 4.7 cubic feet, or if it was an eight-inch pipe line, the volume would be 4.5 cubic feet, or 3.2 cubic feet if the closing velocity was one foot per second.

Air may disappear in an air chamber under continuous operation by dissolving in the water. When frequent starts are the rule, some air will be entrapped each time. To be sure that an air pocket exists, pet cocks (see figure 47) for testing are needed.

Siphons between wells in a battery system are quite common in Colorado when a turbine type of pump is used. The size of pipe to be used is determined according to the formula used in the pipe problems shown on page 39. In order to obtain as much drawdown in the outlying wells as possible, friction must be kept at a minimum. The theoretical limit of drawdown is reached when the distance between the horizontal run of pipe and the water surface in the pumped well reaches atmospheric pressure. This is equivalent to about 27 feet of water at an elevation of 6,000 feet and 29 feet at 4,000 feet. For several reasons, the theoretical limit must be reduced about six feet for practical operation. If the limit is exceeded, the water column in the siphon will separate and the siphon will lose its prime. If the drawdown in the main well is such that the siphon limit would be exceeded, a siphon still can be made to function. This is accomplished by fastening a bucket to the end of the pipe in such a manner that the distance from its top to the horizontal run is within the siphon limit.

Siphon pipes are primed before the pump is started and, in order that all air will be withdrawn, the horizontal run should slope upward to one of the wells (usually the main well). A riser pipe is brought to the high point of the ground surface and the priming pump is attached to this pipe. A globe valve with its tight side down is installed below the priming pump. Siphons must be air tight. When properly constructed, siphons will retain their prime for an entire season.

DAMS AND RESERVOIRS*

Dams in Colorado higher than 10 feet, water impounded in excess of 1,000 acre-feet or a reservoir having a surface area in excess of 20 acres cannot be constructed without the approval of the State Engineer. Aid from qualified experts is necessary to construct earth dams exceeding 15 feet in height. This does not mean that lower dams can be built in a haphazard manner. The following items should be carefully considered.

Foundation

The foundation should meet strength and water-tightness requirements. The dam may be built directly on rock or on suitable earth. If built on creviced rock, grouting may be necessary. Plastic materials, swampy, gravelly or sandy areas and springs should be avoided. Remember that a foundation which may be strong when dry may not be strong when wet. Well-graded material is best. Table 6 shows suitable materials for the impervious section of a dam. It is also satisfactory for determining foundation materials.

Springs in the downstream portion of the foundation, if small, may be drained to the downstream toe. A French drain of graded rock and gravel around a tile is preferable for this purpose. Springs in the core or upstream areas usually preclude use of the site. If the foundation soil is pervious, the core may be extended to rock or impervious stratum or an upstream impervious blanket may be provided. Before construction is started, all topsoil, organic material and debris should be removed and the area moistened and compacted, preferably with a sheeps-foot roller. A wheel tractor with high traction ribs is acceptable in place of a sheeps-foot roller.

Earth Fill

Watertightness and strength are important considerations in dam construction. Two types of materials often are used, placing the more impervious materials toward the center and the higher strength pervious materials

TABLE 6—Typical material suitable for impervious section of rolled-fill dams.

Description	Percentage by weight					
	Cobbles (greater than 50 mm)	Pebbles (5.0 mm to 50 mm)	Gravel (1.0 mm to 5.0 mm)	Sand (0.05 mm to 1.0 mm)	Silt (0.005 mm to 0.005 mm)	Clay (less than 0.005 mm)
Coarsest limits	28	38	14	15	2	3
Finest limits	0	0	0	46	24	30
Medium fine	0	0	20	50	10	20
Medium	0	22	23	30	15	10
Medium coarse	0	48	16	20	8	8

*The material under "Dams and Reservoirs" was provided by Dean F. Peterson, Head, Civil Engineering Department, Colorado A and M College, and is taken largely from the Extension Service County Agents Manual, 1952.

near the outside. Other considerations are:

1. Add about five percent to total height to adjust for settlement.
2. Allow two feet freeboard after settlement above maximum high water if pond does not exceed a length of 1,000 feet and, if longer than this, more than two feet.
3. The downstream slope should be protected by heavy gravel or rock riprap against rainfall erosion. Sod provides erosion protection if the rainfall is sufficient to grow and maintain grasses. Rock riprap also prevents burrowing by rodents.
4. If a pond is empty part of the time, the drying of soil high in clay content will result in cracking. Such cracking probably would not be dangerous except to small structures with thin shells.
5. The best protection against erosion by wave action is a fairly heavy riprap of rock or cobbles on a bed of gravel.
6. Place free-draining material in toe to prevent saturation and sloughing.
7. Top width should be seven to ten feet.
8. For heights less than 15 feet, the upstream slope should be 2½ to 1 and downstream 2 to 1.

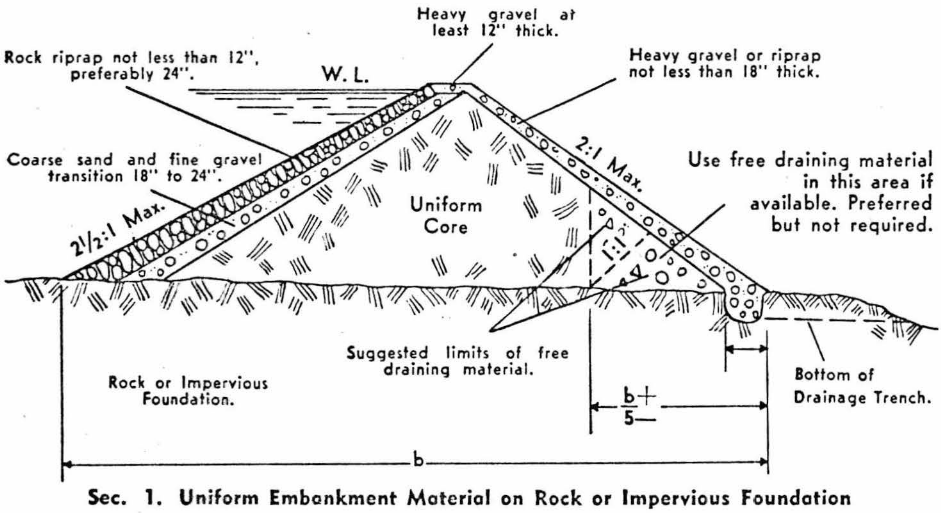
Construction

The cross-section of two types of earth dams is shown in figure 52. If a core trench is used, it should be kept unwatered. The least permeable material is placed in six-inch layers and rolled (six to ten passes) with a sheeps-foot roller or weighted rubber-tired tractor. If the latter is used, each course should be harrowed before placing the next layer. The soil must be reasonably moist, moist enough to form a cast when squeezed in the hand but not sticky. The freer-draining soil (that placed to either side of the core) can be rolled in 12-inch layers and compacted as wet as possible. If the foundation material is permeable, the core material should be extended upstream to the upstream toe. Riprap can be dumped directly from trucks. If hand placed, the stones should be placed with their long dimension at right angles to the slope.

Spillways

Spillway capacity is dependent on many widely varying factors. Soil type, vegetation and slope all affect runoff rates. There will be a different quantity involved if the maximum storm likely to come in a 25-year period is considered rather than in a 100-year period. For a square mile area, the 25-year storm is estimated to produce a peak flow of 500 c.f.s. on plains area range land and about 1,100 c.f.s. on very steep foothill slopes. For areas exceeding a square mile, advice should be obtained from an expert.

The spillway capacity will be less than the peak flow because of storage capacity. Thus, it would be reasonable to estimate a spillway capacity one-half that of the peak flow. Often the spillway crest consists only of a concrete slab and a grass waterway to let water down to the stream channel. Use the least possible slope, especially near the crest or near the dam. If



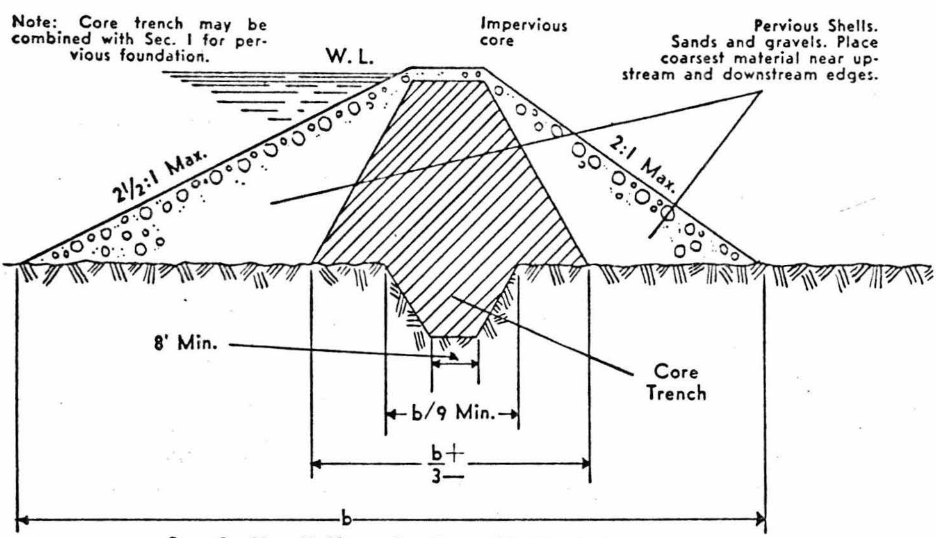


Figure 52—Cross-sections of two types of earth dams.

concrete is used for paving, engineering advice should be obtained. The spillway should be well removed from the dam structure so the structure will not be endangered. For simple spillway crests, an approximation of the discharge can be made assuming that a depth of one foot will provide a discharge of 3 c.f.s. per foot of length; 2 feet, 7 c.f.s.; and 3 feet, 15 c.f.s. Thus, the length of crest for 500 c.f.s. flow mentioned above would be ½ × 500 divided by 15 (if a depth of 3 feet is permissible)—a crest length of 157 feet. Engineering advice should be sought in such matters, especially in computing spillway capacity. It is possible to compute the effect of storage and substantial savings in materials might be made.

Outlets

The capacity of the outlet tube should be that of maximum demand at low stages in the reservoir. The problem of pipe size is solved by using table 4 on page 40. In this case, one estimates the pressure head available at a low stage and takes this as the loss over the length of the tube. To this is added the entrance loss which is about one-half a velocity head. Examples beginning on page 39 may be found helpful in determining the required pipe size.

Cast iron, steel or high strength concrete pipe are the usual materials used for outlets in their order of excellence. Steel, however, is most commonly used and for good reasons. It is much less costly than cast iron and superior to concrete since a slight settlement will not result in a crack. Corrugated steel pipe is much stronger in resisting external pressure than plain pipe, but remember, it is of considerably lower capacity for the same nominal size. If concrete pipe is used, it should be of superior construction with particular attention given the joints. Pipe should not be placed in a fill but in solid earth trimmed to fit the lower one-third of the circumference. Cut-off collars of concrete are to be placed about 20 feet apart in the upper section to prevent seepage following the pipe. These collars are six to eight inches thick and extend about two feet in all directions from the pipe.

Gates should be on the upstream side of the dam. Then if anything happens to the tube, the dam is not endangered and repairs are easily made. A type of gate for this purpose (low heads) is shown in figure 45. It can be installed either vertically or on a slope.

Seepage Control

Frequently the loss of water from a reservoir by seepage is quite great and a means must be found to correct it. Soils heavier than sandy loam may be puddled by forcing stock to trample over the surface when in a very wet condition. This will tend to seal the surface to some extent. Certain colloidal clays, especially those containing sodium salts, can be applied as a blanket and rolled while moist. To be effective, such blankets should be four to six inches thick.

Bentonite, either in the crude or processed form, is very effective. It should be incorporated in the soil surface by discing. The processed variety is more efficient and therefore less is required. The usual amount is 100 pounds per 400 square feet, worked in to a depth of 1½ to 2 inches. The lighter soils respond to bentonite treatment more efficiently than the heavier types.

Common salt can be effective on the clay-type soils if they are of the correct chemical content. Soils that contain a large amount of lime or gypsum may not yield much benefit and any benefit may be of short duration. Samples of the soil should be sent to a soils laboratory for analysis. Salt is worked into the soil much the same as bentonite and in similar quantities. Its effectiveness is increased by rolling when some moisture is present. Rains are helpful previous to filling. The first filling should be only partial. The cheapest form of salt (sodium chloride) should be used.

USE OF THE FARM LEVEL

The farm level is essentially a telescope containing low power lenses, cross wires, a bubble tube rigidly attached to the telescope and a second bubble tube at right angles to the telescope. Many have a horizontal plate divided into degrees of a circle for measuring angles. In some, the telescope is mounted on a horizontal axis for viewing points on the ground nearby. Others may have a compass needle. Leveling screws are provided in the base. Directions for operating the equipment are furnished with the instrument but the principles of field use may not be included. A short description of field use is given here.

To begin with, one should visualize a string placed horizontally by a carpenter's level. There is a certain point under the string that is to be used as a base. The farmer wishes to find out how much a second point is below or above the first point. He would first measure *up* from the base point to find out how high the string was above it. This would obviously be a *plus* quantity because one must add the measurement to the elevation of the point. The next step is that of measuring *down* from the string to the second point. The height of the string is known, and a measurement *down* to any other point would have to be subtracted to find its elevation. The distance has to be subtracted so it is considered a *minus* quantity. The numerical difference between the two measurements is the amount the second point is below or above the base point. If the minus quantity is greater numerically, the second point is below the base point. The same line of thinking can be applied to instrument leveling.

The levelman must visualize the telescope of his level as replacing the string. It does the same job. To find out how high the telescope is above his starting point he sights at a rod held on it. The reading is *plus* as it was in case of the string. The rod held on any other point would give the distance down from the telescope and the reading would be *minus*. If the two points were so far apart that they both could not be seen from one setting, the levelman would have to move the level and repeat the operation.

The procedure is illustrated in figure 53 in which the problem is to determine the difference in elevation between the water surfaces X and Y. The instrument is set up at A at a distance such that graduations on the rod show plainly. This will be about 150 feet for many farm levels. The rod may be equipped with a target, a necessary accessory if the markings are light lines. It may be graduated in feet, tenths and hundredths or in feet, inches and fractions as shown in figure 54.

In leveling the instrument, aim the telescope and one pair of leveling screws in the direction of the rod by rotating the plate. By means of the leveling screws, bring the bubble pointing in that direction towards the center. Now do the same with the opposite pair of screws. A more precise centering of the bubble is next made on the first set of screws followed by adjustment with the second set. This procedure is repeated until both

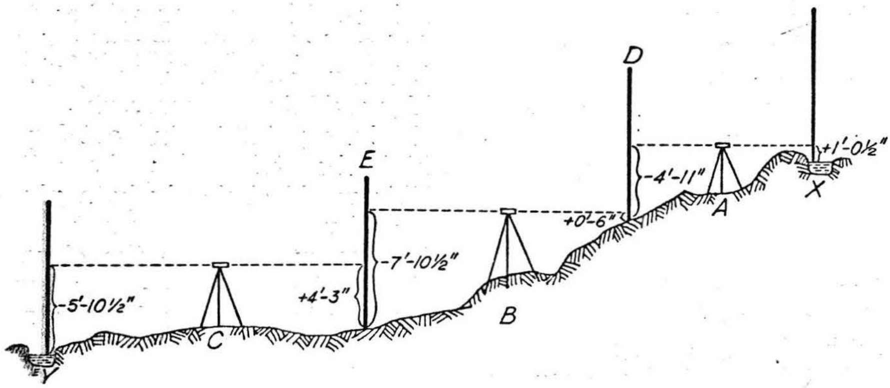


Figure 53—Method of using farm level to obtain difference in elevation between two points.

bubbles will stay reasonably centered as the telescope is moved. The thread pressure on the leveling screws should never be so great that they cannot be moved easily with thumb and fingers.

A sighting is made on the rod which is set on the starting point. The sighting is read directly, or if a target is being used, the rodman is signalled to move it up or down. Now check the bubble as it may have moved away from center. If not centered, adjust with the leveling screws again and make a second sighting. Assume the rod reading to be one foot, one-half inch. Record this as a plus quantity on note paper. It is plus because the elevation of the telescope is higher than the starting point. The height of the instrument is now known.

The rodman now proceeds to D, stepping it off so it is the same distance from A as when he was at X. This is important — even with an instrument slightly out of adjustment, the readings equally distant from the instrument are very nearly correct. On a hillside, one should avoid gaining greater distance down hill just because he is able to read a longer rod. The rodman places the rod on some substantial object — a stake or a firm rock — and the telescope is sighted as before. Assume the reading to be 4 feet, 11 inches. This will be a minus reading because the point being determined is below the telescope. The instrument is now picked up and set up about 150 feet farther along. The rod is again held on point D and a reading of 0 feet, 6 inches made. This will be a plus reading. The process is repeated until point Y is reached.

There will be an equal number of plus and minus readings. Arrange the plus and minus quantities in separate columns and add. Subtract one sum from the other and the result will be the difference in elevation between the two points—12 feet,

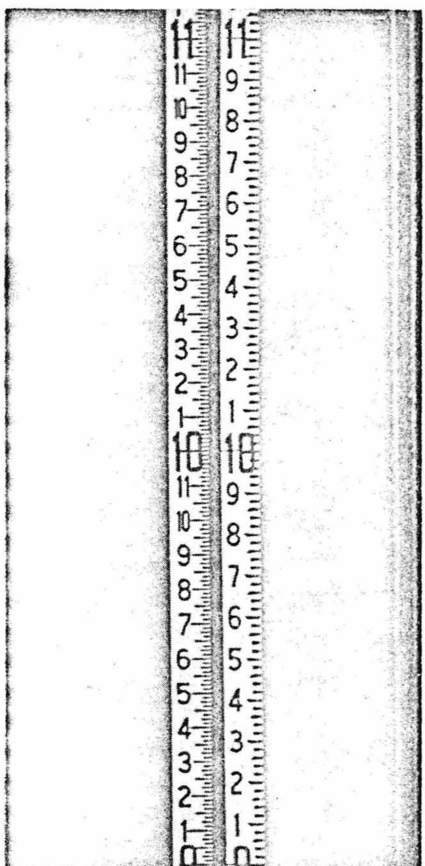


Figure 54—Level-rod graduations. At left—feet and inches; at right—feet, tenths and hundredths.

10½ inches. An engineer would keep a form of notes but such would not be used ordinarily by a farmer. It should be emphasized that the rod must be held plumb for all readings. This is accomplished by balancing it while it is held loosely with the fingers.

In staking out a ditch, another procedure is followed. Make a decision on the ditch grade. A guide to this decision will be found under the subject of ditches. Suppose the grade selected is three inches (0.25 feet) per hundred feet. Calculations are always made from the water surface and other features are based on it. Thus, if the water depth in the ditch is 12 inches, the bottom will be 12 inches below the computed water surface.

The instrument is set up along the line of the proposed ditch and about 150 feet from the starting point or station 0 (see figure 55). The rod is held at the water surface at station 0 and the reading or target setting noted. The water surface may be that in the supply ditch or the proposed water surface in the new ditch. A third man is needed if a measuring tape is used. Otherwise the rodman can step off the distance. If ground is rather uneven, it may be necessary to place stakes as close as 50 feet apart. This would require a fall of 1½ inches between stakes. Assume that the water depth is 12 inches and the ditcher makes a trench 10 inches deep. You want to find a point on the ground where the water surface in the new ditch will be 1½ inches lower than the starting point. If the starting rod reading was 3 feet, 2 inches, then 50 feet away the rod reading on the future water surface would be 3 feet, 3½ inches. But the ground surface would be 2 inches lower (12 inches minus 10 inches) and the correct rod reading would be 3 feet, 5½ inches. If the rod has a target, it is set at this reading.

The rodman then moves up or down hill, keeping at a distance of 50 feet from the starting point. The correct position is found and a stake is driven where the telescope cross wire bisects the target. The target is now *raised* 1½ inches to read 3 feet, 7 inches and the rodman proceeds to station 1 and repeats the process. When station 3 is reached (rod reading 4 feet, 1 inch), it will be time to move the instrument, hence more care should be exercised in locating the point

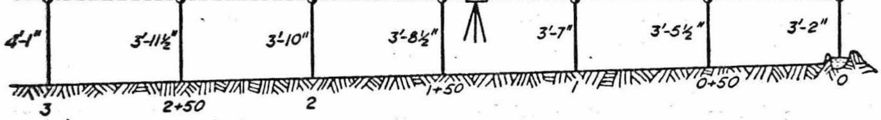


Figure 55—Procedure for locating a ditch with a farm level.

for station 3. The rodman stays at station 3 while the instrument man goes ahead. When ready, a new reading is made on station 3. Suppose it is 4 feet, 5 inches. The rodman notes this reading, *raises* the target $1\frac{1}{2}$ inches to read 4 feet, $6\frac{1}{2}$ inches and proceeds to station 3 + 50. The procedure is repeated until the end of the ditch is reached.

Often a full-length lath is used for stakes or, if the ground is bare, a short stake driven through a sheet of paper makes a good marker. The stakes are now in their correct positions for the ditch but they may be in very crooked alignment. By making minor adjustments, a smoother arrangement of curves can be effected. If moved too far uphill, it may be necessary to dig deeper with the ditcher at such places. If too far downhill, more bank will be required.

COMMON MISTAKES TO AVOID

It is not unusual to find carelessly built or neglected irrigation structures on farms. A good workman takes pride in his work even though it may not be exposed to public view. So often just a little more effort spent with a form for a concrete structure will produce a good looking and functioning job. Prevent bulges by adequate bracing. Use boards that are reasonably straight and, if reclaimed, see that their strength is not gone. See that walls are plumb so that a stop board will fit well at any position. Finish the top with a trowel, and for real neatness, use an edger. Air pockets in concrete which expose the aggregate are easily avoided by spading.

Finish the job. Do not wait to place bank protection around a structure when you are almost certain some protection will be necessary.

Do not allow trees to grow up around a structure. Their roots will eventually push in the walls.

Culverts without end walls will suffer broken or bent ends. This omission not only shortens their lives but also impairs their carrying capacity.

If a ditch is to be concrete lined with the plastering method, make the excavation neat and straight. Invent a scheme for striking the concrete to a neat-looking surface.

On important construction, obtain competent engineering advice. If it is not available through the Soil Conservation Service, do not hesitate to employ an engineer. Some mistakes can be costly.

ADDENDA

Convenient conversion factors

1 pound (lb.) pressure = 2.31 feet of water
1 foot of water = 0.434 lb. pressure
1 cubic foot of water = 7.48 gallons
1 cubic foot of water weighs 62.4 pounds
1 gallon = 231 cubic inches
1 gallon weighs 8.33 pounds
1 cubic foot per second (c.f.s.) equals:
  38.4 Colorado miners inches
  448.8 gallons per minute (g.p.m.)
  646,317 gallons per day
  1.98 acre-feet in 24 hours
  1 acre-inch in 1 hour
1 acre-foot = 43,560 cubic feet, 325,850 gallons, 12 acre-inches
1 millimeter (mm) = 0.0394 inch (see table 6)

Formulas

Terms used:

Q discharge in c.f.m.
A area (square feet)
V velocity (feet per second)
π 3.1416
g gravity constant (32.2 feet per second)

A for a circle, $\frac{\pi d^2}{4}$

A for a ditch, average of top and bottom width multiplied by depth.

Q = AV

Velocity head, $\frac{V^2}{2g}$

Entrance loss

Loss of head for a pipe end flush with wall, 0.5 $V^2/2g$
Loss of head for a pipe protruding from wall, 1.0 $V^2/2g$
Loss of head for a pipe with bell entrance, 0.1 $V^2/2g$