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Washington, D. C. ▼ June, 1926

STRUCTURES USED IN DRAINING AGRICULTURAL LAND

By

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Bureau of Public Roads

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INTRODUCTION

A system for the drainage of agricultural lands requires a variety of structures in addition to the tile or ditches. To permit cleaning underdrains, manholes are used at connections with laterals and at changes in alignment. Lamp holes may be installed to facilitate inspection. In soft ground and at crossings under railroads and canals, cradles and other foundations are used. Open drains subject to erosion require checks, drops, and bank protection.

In the installation of such structures care should be taken to select suitable material, to prepare standard plans and specifications, to obtain proper locations, and to coordinate the structures with the rest of the system. Improper design and location of structures introduce defects in drainage systems which decrease their effectiveness.

A wide variation exists in the design and cost of structures serving identical purposes. This bulletin describes the principles of design indicated by practice and experiment to be the most satisfactory in reduction of cost and of maintenance expenses and in increase in the efficiency of drainage systems.

STRUCTURES FOR USE WITH UNDERDRAINS

MANHOLES

On some tile drains more sand or silt finds its way into the drain than the water can carry. If the drain is to be kept open, it is necessary that this material be intercepted at suitable intervals and later removed. This can be done by building a manhole of suitable size. It should be so proportioned that there will be an appreciable loss of velocity as the water passes through it and consequent deposition of the sand or other material that the water has in suspension. Manholes are not required on all drainage systems; and, unless it is clear that their use is necessary, they should not be installed as they increase the cost of the drainage and there is always danger that débris may get into the manholes and obstruct the drains.

When their use is necessary they should be located at points where a reduction in gradient occurs, at sharp angles, at connections with main laterals, and at special crossings. Usually it is not best to construct them at frequent intervals on tangents. The cost of installing them near enough to each other for efficient use of sewer rods is prohibitive, and they are of but little use except in the special circumstances mentioned.

The depth of the silt basin below the bottom of the outlet tile should be not less than 18 inches; 2 feet is preferable. For farm drains not over 8 inches in diameter, in firm ground, a 30-inch manhole with a depth of 2 feet for the silt basin should be the minimum size. Where the size of the drain is the only governing factor, the diameter of the manhole should be not less than 18 inches plus the diameter of the outlet, and 36 inches should be the minimum diameter for district systems. High velocities, existence of a long tile line above the manhole, junctions with laterals, and the probability of infrequent cleaning, require larger sizes.

Loss of head occurs at manholes, and for this reason a drop should always be provided between the inlet and outlet. Ordinarily a drop equal to the velocity head in the pipe will be enough, but the loss may amount to 50 per cent more than this in manholes at sharp angle points. The minimum drop should be 1 inch. Surface inlets should not be connected with manholes, as the falling water may prevent the deposition of silt and defeat the purpose of the manhole.

Where the lower part of the manhole is located in gravel, hardpan, or stiff clay formation, a floor is not necessary; otherwise timber or concrete must be used. In soft ground provision against settlement must be made by the use of gravel or piling. In fine silty material the joints in the lower part of the structure must be made tight.

Elevation of the top depends upon the kind of material used in the cover and the location of the manhole. When it is located on a fence line the elevation makes little difference, but if in a field the top must be strong enough to support farm machinery and stock or the structure must rise above ground. The latter is sometimes objectionable to the farmer. A cast-iron top and frame similar to but lighter than that used in sewer practice is an excellent type (fig. 1). Heavy reinforced concrete covers are satisfactory, provided the diameter of the top of the manhole is not over 24 inches and it is not located in a road. Locks on covers prevent unauthorized persons from opening them but are a source of trouble where the top is flush with the ground surface, especially in freezing weather. Probably it is better to make the covers very heavy or otherwise hard to lift.

Manholes are made in various shapes and of different materials. A jug-shaped structure is the most desirable, but some materials can not be made into this shape. Wooden manholes have the lowest first cost, but their life is short. Figure 2 shows a wooden manhole so designed that earth pressure will hold it in place after the failure of the nails.

A very good type of manhole for small drains can be made from clay or concrete pipe. Large sizes are heavy and very difficult to transport and handle. Plate I, A, shows a concrete-pipe manhole made up of 1-foot sections 36 inches in diameter, reinforced with heavy wire mesh. When used on large tile lines the lower part of the structure is made of brick.

Galvanized corrugated pipe has been used to some extent. It is light in weight and very easy to install. Customarily the top extends above ground and has a cone-shaped cover of the same material. (See pl. 1, B.) The metal should not be lighter than 14 gauge.

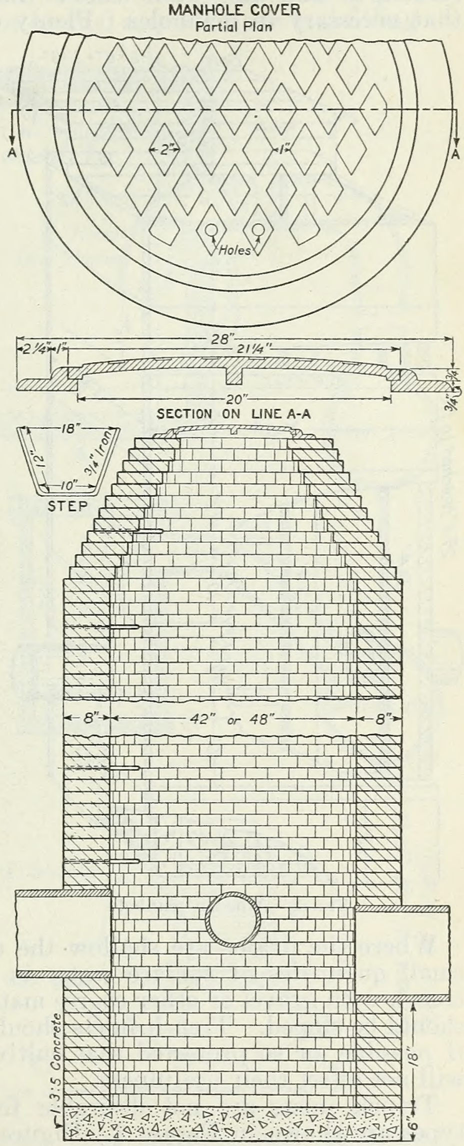


Fig. 1.—Brick manhole with cast-iron cover

Excellent manholes are made of concrete with 6-inch walls. They are usually rectangular in form. Concrete blocks have not been found very satisfactory. Figure 1 shows a brick manhole with cast-iron top. This type is considered good. It is easier to construct than the monolithic concrete manhole.

Drops, sometimes called "well holes," may be needed in underdrains. These should be built like a manhole. Small ones may be made of heavy pipe, but concrete should always be used in large structures and the walls should have a greater thickness than that necessary in manholes. Plenty of depth below the outlet tile must be provided to form a cushion for the falling water.

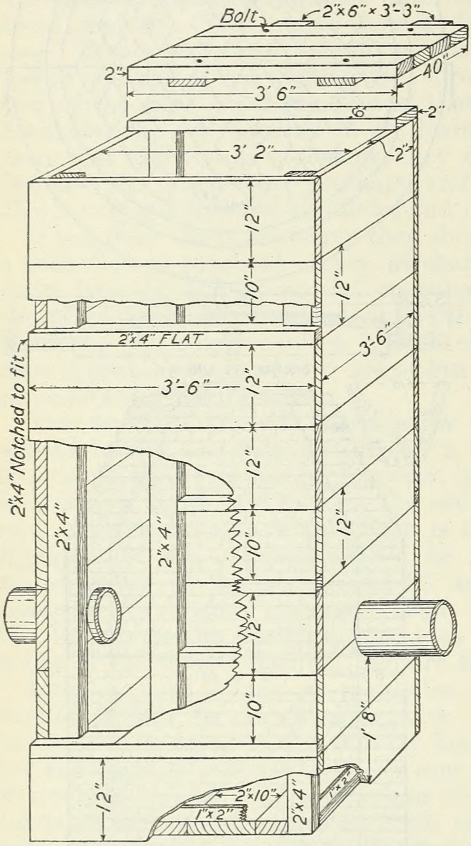


Fig. 2.—Wooden manhole

SURFACE-WATER INLETS

Often where tile drains are used provision must be made for rapid removal of surface water caused by heavy rains or the accumulation of waste water from irrigation on low areas. Such accumulations pass slowly into dense soils, delaying cultivation or even destroying crops. If the soil is porous this water may break into and damage the drain. Sometimes a separate system of shallow ditches is constructed to care for this water, but often it is more satisfactory and economical to admit the water directly into the drains. Surface water inlets have not been used extensively in the drainage of irrigated lands except in Yakima Valley, Wash., and a few other places, but they will be found advantageous if properly installed and maintained.

Where the drains are shallow the cheapest method of admitting small quantities of surface water is to fill a short section of the trench with gravel or other coarse material. The sides of the trench should be sloped. Trench inlets should be located along fence lines, if possible, or so protected that cultivation and trampling of stock will not affect their usefulness.

Trench inlets are not desirable for deep drains. Three other types are shown in Figure 3. Figure 3, C illustrates a type useful where the grades throughout the system are good; but care should be taken in using it on a line that is dry part of the time, since earth and débris falling in during such dry periods may choke the drain. The connecting pipe may be brought up vertically instead of on a slope as illustrated. In this case precautions should be taken to prevent settlement which might break the tile at the point of connection. This type will also serve as a lamp hole. The riser pipe may be made of any size, but the top opening should never be less than 12 inches in diameter. For very large inlets the upper section of the vertical riser pipe is sometimes of larger diameter than the lower sections and is connected with a concrete ring. Where the soil freezes to considerable depth, a more substantial riser pipe may be made by placing a large pipe around a smaller one and filling the

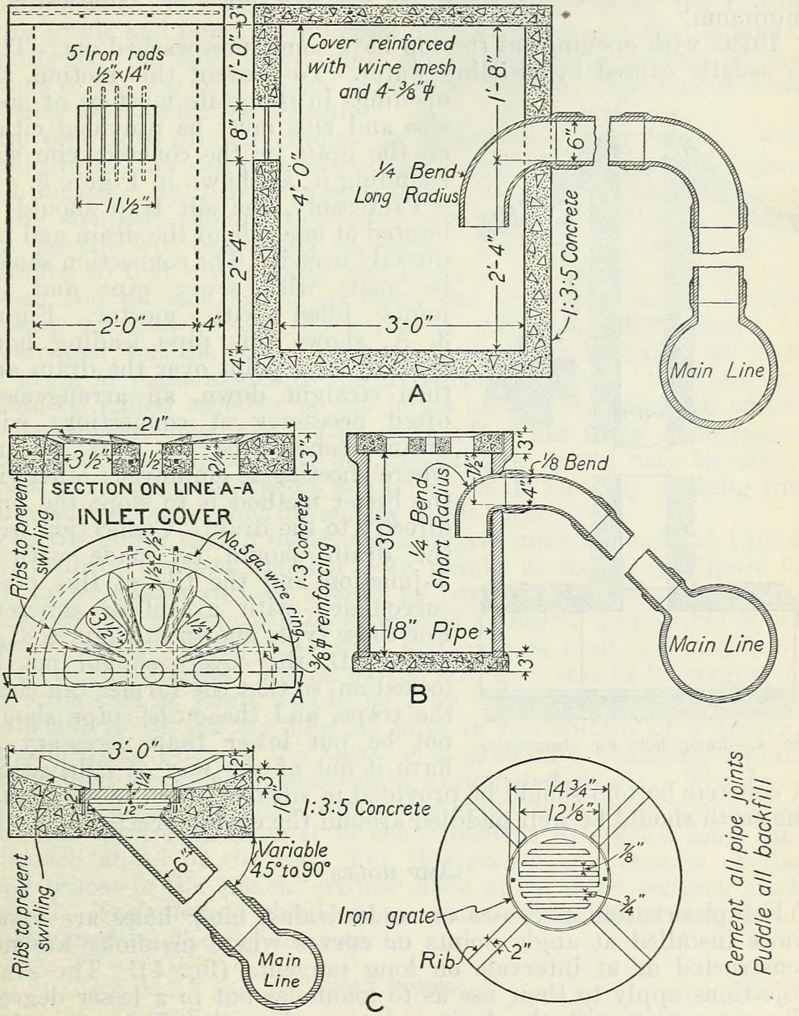


Fig. 3.—Types of surface water inlets for closed drains

intervening space with concrete. The entrance may be protected by a cast-iron grate of the type illustrated in Figure 3, C, or one made in the form of the frustrum of a cone may be substituted. The latter type is more expensive but will provide greater area of opening. The grate should be secured against removal.

A type of inlet which will prevent débris from dropping into the tile line is shown in Figure 3, B, but the entrance of water at the top stirs up the silt and much of it passes through the connection. The silt traps, of 18 or 24-inch sewer pipe, have a concrete cover provided with openings (pl. 1, A).

A type more expensive but better adapted to exclude silt consists of a concrete box which permits the water to enter on grade with the outlet (fig. 3, A). This is an important part of the design, since the disturbance of the water in the box must be reduced to a minimum.

Inlets with openings at the top have sometimes washed out. This is usually caused by swirling water. To prevent this motion, the openings in the grate must be of good size and ribs must be provided either on the grate or the concrete rim surrounding it, as shown in Figure 3.

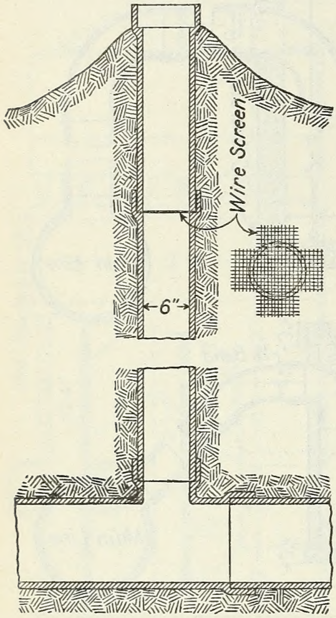


FIG. 4.—Lamp hole for observation

Preferably, the silt trap should be located at one side of the drain and not directly over it. The connection should be made with sewer pipe and the joints filled with mortar. Figure 3, A, shows this pipe leading horizontally to a point over the drain and then straight down, an arrangement often necessary at connections with drains constructed in soft ground where sheeting is employed; otherwise the better method is to slope the pipe directly to the drain. Connection with the drain should be made with a T-junction and the tile at this point surrounded with gravel or concrete. For those types shown in Figures 3, A, and 3, B, the covers should not be locked on, so that the farmer can clean the traps, and the outlet pipe should not be put lower than necessary to have it out of the way of cultivation. A concrete bottom should be provided in silt traps, and in every case the earth should be well puddled around the entire structure.

LAMP HOLES

For observation purposes on underdrains, lamp holes are sometimes installed at angle points or curves where manholes are not constructed or at intervals on long tangents (fig. 4). The same objections apply to their use as to manholes but in a lesser degree. The connection with the drain is best made with a T-junction, but may be made by cutting a hole in the top of the tile and extending a 6-inch pipe from this to a point about 1 foot above ground. The earth around the riser should be puddled and a bank thrown up around that part above ground. If possible they should be out of the way of farm machinery. If necessarily installed in fields a protecting post should be set by each.

A lock-fastened lid is likely to be unsatisfactory, but a wire screen across the first joint below the top will keep out rubbish and small animals. Heavy galvanized wire with meshes of one-third or one-fourth inch will exclude everything but fine débris, and the tile line can be inspected readily by reflecting light toward the bottom with a mirror.

CRADLES

In soft ground some means must be provided for holding the tile in alignment. The best method consists of excavating the trench below grade and tamping in gravel until a firm foundation is made. Boards may be laid under small drains where the bottom of the trench is not too soft. They should be fastened together at each joint by short strips underneath.

In very soft ground cradles on piling may be required. For small drains they can be made of two parallel 2 by 4 inch stringers held together by 1-inch cross boards. The upper inside corners of the stringers should be beveled, and they should be so spaced that the tile will bed firmly on them. The cross strips should be arranged so that overlapping will occur at each joint. At the upstream end of each set of stringers the crosspiece should extend at least 6 inches beyond the stringers, with the grain parallel to the stringer, but the other two crosspieces should be nailed on with the grain at right angles to the stringers (pl. 1 C). The sections should be nailed together at the joints and to the piles, on which the crosspieces must rest. This work often has to be done under several inches of thin mud; but the nails or spikes may be easily driven if inserted in a short section of small pipe, by striking the nail head with a rod that fits snugly in the pipe.

For tile larger than 8 inches the stringers must be made of 4 by 4 inch timbers fastened together with planks as shown in Figure 5. The upper inside corners should be beveled, and they should be spaced so that the tile will be supported as nearly as possible at its quarter points. When pipe with bell ends is used, notches must be cut in the timbers. Joints of the stringers should be staggered and cross sills at joints should be 2 by 6 inch planks. Usually it is difficult to cut off the tops of piles in the bottom of a trench, but sometimes piles of the same or a gradually changing length may be used where conditions can be anticipated closely. The driving may then be stopped at the proper point to support the cradle.

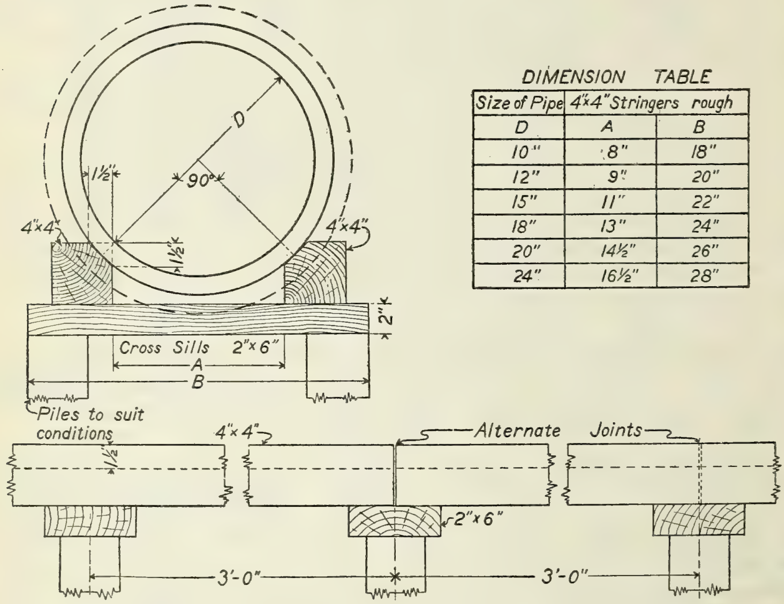
In difficult construction it is not expedient to open a long line of trench ahead of the tile. For this reason and because of the many braces in the trench, cradles made up in short sections must be used. Their length should have some relation to the length of the sets used in sheeting the trench.

ANGLE BOXES

At angle points on main drains, not sharp enough to call for a manhole, an angle box should be made of a pipe somewhat larger than the diameter of the tile, extending from a point a few inches below the bottom of the tile to the ground surface; and a small drop should be provided between the inlet and outlet. A corrugated iron pipe is desirable for this purpose. Angle boxes are sometimes made of large sewer pipe at the bottom, above which is placed a reducer and then a stack of 8 or 12-inch pipe extending to the top, which can be made as for a lamp hole or like the top of the surface water inlet shown in Figure 3, C. Elimination of the expensive reducer may be accomplished by use of a concrete ring placed in the bell and having its inside diameter the same as the interior of the small pipe used above. (See pl. 1, A.) For large lines, manholes had best be used.

LATERAL CONNECTIONS

Main lateral connections should be made with manholes, but for small connections angle boxes will serve the purpose. On a system having a great many closely-spaced farm laterals, it probably will be necessary to eliminate these structures and simply make a hole in the upper part of the main lateral to receive the end of the small farm lateral. This joint should be well surrounded with pieces of



DIMENSION TABLE

Size of Pipe	4"x4" Stringers rough	
D	A	B
10"	8"	18"
12"	9"	20"
15"	11"	22"
18"	13"	24"
20"	14½"	26"
24"	16½"	28"

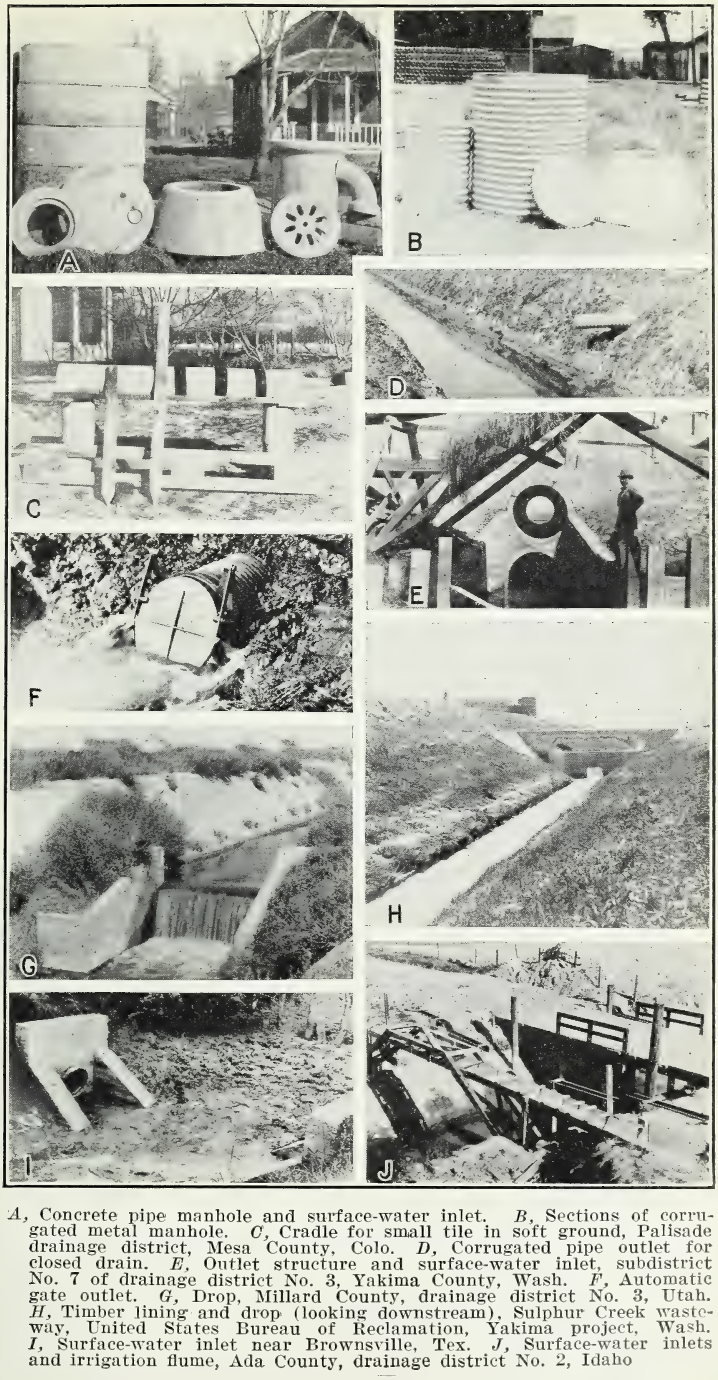
FIG. 5.—Cradle for supporting large tile in soft ground

broken tile and gravel or concrete. The elevation of the top of the small lateral should be near that of the top of the line to which it is connected. If possible, branch lines should be provided where numerous small farm laterals are needed, as it is not advisable to connect these with main trunk drains.

OUTLETS

Structures are usually necessary at outlets of underdrains to prevent injury from frost and to afford protection of adjacent banks. For drains with diameter of 16 inches or less a continuous section of wood box or corrugated pipe will be satisfactory (pl. 1, D). This should be from 14 to 20 feet long, depending upon the slope of the bank and nature of the material. A tight box made of 2 or 3-inch lumber will prove economical. However, boxes are likely to be

PLATE I



A, Concrete pipe manhole and surface-water inlet. *B,* Sections of corrugated metal manhole. *C,* Cradle for small tile in soft ground, Palisade drainage district, Mesa County, Colo. *D,* Corrugated pipe outlet for closed drain. *E,* Outlet structure and surface-water inlet, subdistrict No. 7 of drainage district No. 3, Yakima County, Wash. *F,* Automatic gate outlet. *G,* Drop, Millard County, drainage district No. 3, Utah. *H,* Timber lining and drop (looking downstream), Sulphur Creek wasteway, United States Bureau of Reclamation, Yakima project, Wash. *I,* Surface-water inlet near Brownsville, Tex. *J,* Surface-water inlets and irrigation flume, Ada County, drainage district No. 2, Idaho

destroyed where weeds on the banks of the main drain are burned, and in such places heavy corrugated pipe must be used. The outlet end of such conduits should protrude a short distance from the bank so that the water in the channel will make a cushion for the outflow of the drain.

For large drains, concrete bulkheads, wing walls, and an apron for the falling water should be provided (fig. 6). Modification of the wing walls is required where the drain enters the channel at a sharp angle. Reinforcing must be used for large structures, and for all structures if in very soft soils. The main considerations should be stability and prevention of undermining or cutting around walls. To prevent damage from floods in the main channel, the structure should be set well into the bank. Failures may be caused by surface water flowing over or around the outlet, to prevent which surface-water inlets should be provided with the lower end of the pipe passing through the head wall of the concrete outlet structure at one side of or just above the drain, as shown in Plate 1, E. This type is particularly desirable where the outlet is just below a road. If frequent heavy floods are anticipated the structure must be designed as a check or drop similar to that shown in Plate 1, G, with the underdrain outlet in the lower part of the breast wall.

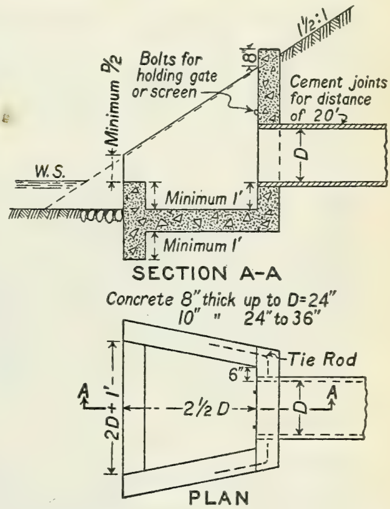


Fig. 6.—Outlet structure for closed drains

Where outlets of underdrains are at times completely submerged, it is advisable to provide flap gates to prevent water from backing up the drain. These valves may be made of lumber, but under many conditions an automatic iron gate will prove very satisfactory, as shown in Plate 1, F. For small drains they may be attached to the end of a corrugated iron pipe, and for large drains they should be installed on the head wall of the concrete outlet structure. Drains not submerged may require a flap gate made of rods to keep out small animals.

CROSSINGS UNDER RAILROADS AND CANALS

Where underdrains cross under railways and canals, pipe with bell-and-socket joints should be used and the joints made tight with mortar. Pipe of extra strength should be used immediately under the fill or canal. A concrete foundation usually envelops the lower half as shown in Figure 7, and the pipe is laid before this concrete has set. This foundation should extend not less than 6 inches below the bottom of the pipe and its total width should exceed the outside diameter of the pipe by not less than 8 inches. In trenches with exceptionally soft bottoms, gravel should be tamped in before the concrete is placed.

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For canal crossings three cut-off walls should be constructed as shown in Figure 7. The minimum height and width of these should be 4 feet. Under some canals it may be desirable to use, on the lower side, only one cut-off wall extending to the top of the embankment instead of two small ones as shown. Should the top of the pipe coincide closely with the bottom of the canal, the whole section between the two upper cut-off walls should be cased in concrete.

Railway crossings are similar to canal crossings except that cut-off walls are omitted.

LUMBER BOX DRAINS

Box drains are chiefly used where cost of transportation prohibits use of tile. The life of a wooden structure is reasonably long if it is always wet; but failure, especially of the top, may occur in a few years where alternate wetting and drying take place. The boxes

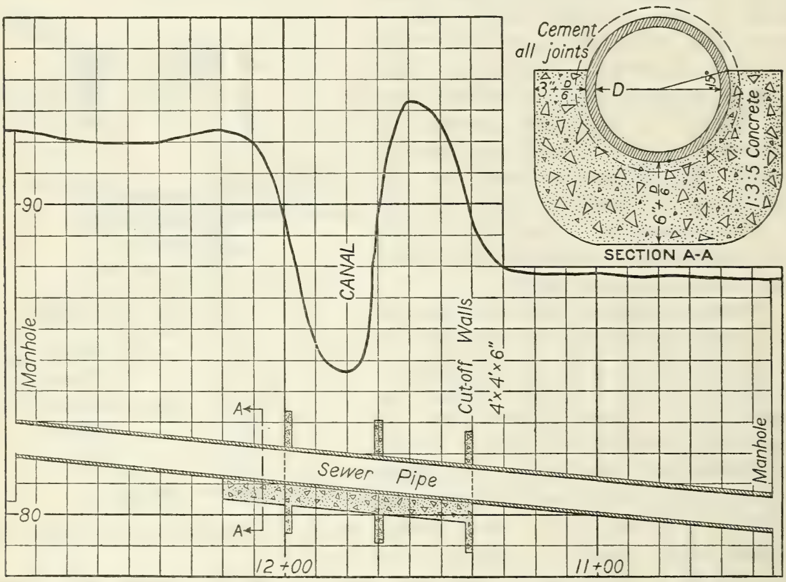


Fig. 7.—Closed drain crossing under canal

should be built to retain their form after failure of the nails, which will happen soon if alkali is present. Shoulders milled in the lumber effect this; they are cut cheaply by passing each end of the top and bottom boards over a circular saw set to cut a rabbet as deep as the thickness of the saw and as wide as the thickness of the side planks (fig. 8).

The type shown in Figure 8, A may be used for small sizes where cheapness is desirable. The lumber runs with the box and long sections may be made. The bottom is held from the sides by short pieces of lath separated to admit the water. The widest boards should not exceed 8 inches for 1-inch lumber and 12 inches for 2-inch lumber. Lumber for the top and bottom of larger drains should run crosswise, with the ends milled to provide shoulders (fig. 8, B). Decay is likely to be the most rapid at the top, which should be 2-inch material. One-inch lumber will do for bottoms except in fluid soils where an upward pressure is exerted. The top pieces should fit tightly together, but the bottom pieces should be separated from one-fourth to one-half inch to admit water. Such boxes should not be over 24 inches in width nor over 14 inches in height. In larger sizes 3-inch lumber should be used for the top, with the sides made up of short pieces and arranged so that the joints interlock as shown in Figure 8, C. The larger sizes should be built in short sections and arranged so that joints can be fastened together.

Trenching covers a large percentage of the total cost of deep drainage, and it will usually prove better economy in the long run to use durable material even at a greater first cost.

STRUCTURES FOR OPEN DITCHES

DROPS AND CHECKS

To prevent injury to canals from excessive velocities, drops are installed to concentrate the excess fall at one or more points. Plate 1, G shows a type used for small discharges. In design, drainage

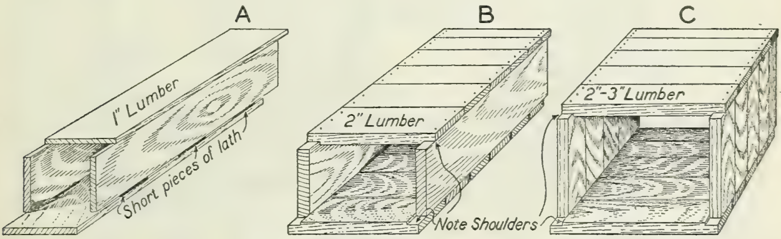


FIG. 8.—Types of lumber box drains

drops are not different from those used in irrigation practice with the exception that in most cases they should be able to withstand the destructive action of discharges considerably in excess of the normal flow of the canal.

The primary purpose of many open drainage systems is to carry seepage water, and to provide drainage this flow may occupy only a small part of the cross-sectional area of the channel, which may have steep grades without danger of erosion. However, floods or breaks in irrigation systems may produce high velocities and consequent damage. This may be overcome by (1) reducing the grade and installing drops; (2) using checks to retard flood flows but also permitting the passage of the normal flow without checking; or (3) a combination of these two methods. Figure 9 and Plate 1, H show a combination check and drop which may be made to serve equally well for any one of the three methods by the variation of certain dimensions. The breast-wall or overflow weir should be made as long as possible and the opening for normal flow as large as conditions will permit.

Factors to be considered in the design of such a system are: (1) Quantity of normal flow, its depth, and minimum velocity permissible; (2) the volume and maximum allowable velocity of the flood discharge; and (3) the cost of structures and excess excavation where drops are used. If the canal be deep, the flood discharge moderate, and the cost of structure low, then checks without drops should be used. When very large flood discharges are to be cared for the canal must be constructed on a grade flat enough to prevent

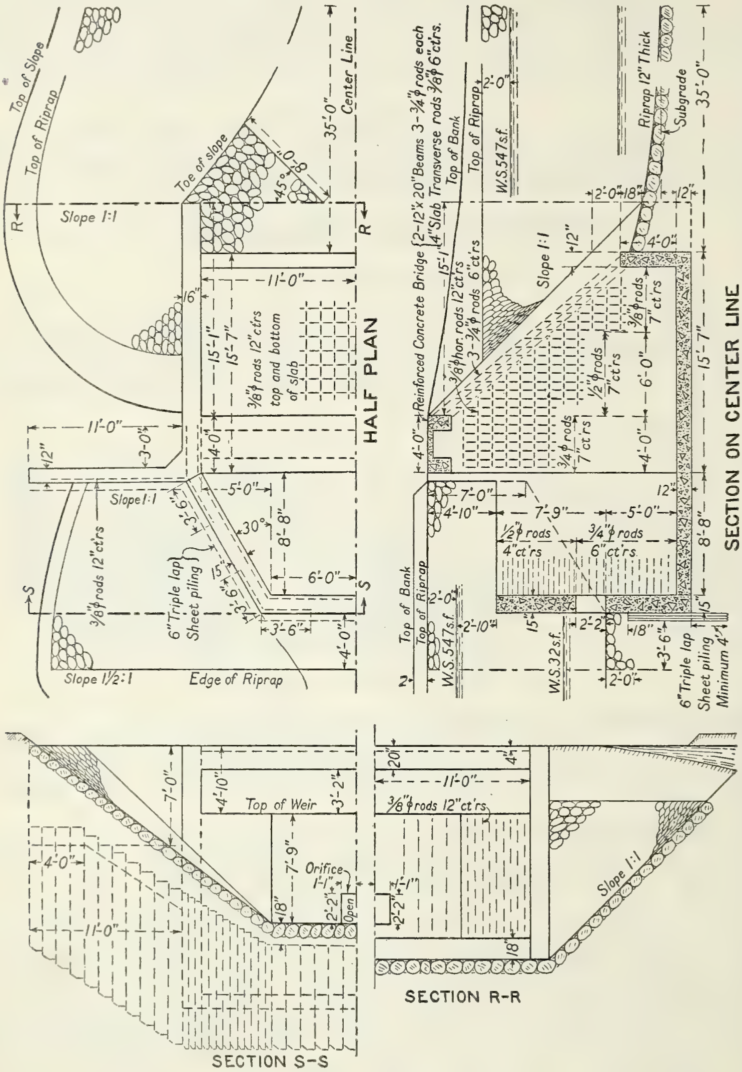


Fig. 9.—Drop on Sulphur Creek Wasteway, United States Bureau of Reclamation, Yakima project, Washington. This wasteway also serves as an outlet for several large drainage systems

excessive velocities and the structure used only as a drop. For some combinations of the factors mentioned it will be found economical to design the system to use a combination check and drop.

TIMBER LININGS IN OPEN DITCHES

In saturated soil frequently it is impossible to dig a ditch to proper depth or to keep it open after excavation, in which event timber linings are employed to prevent sloughing in of soft material. These are usually constructed without a bottom. They should be designed as simply as possible. Usually they are regarded as temporary structures which will not require replacement after the water table has been lowered and the slope of the banks has become stable. Unless a bottom is needed they should be made as wide and low as possible, so that after they have decayed little or no smoothing of the banks will be required. Careful placing is necessary to insure that such structures will remain in alignment, both vertical and horizontal. Although sometimes necessary, cross braces on the top

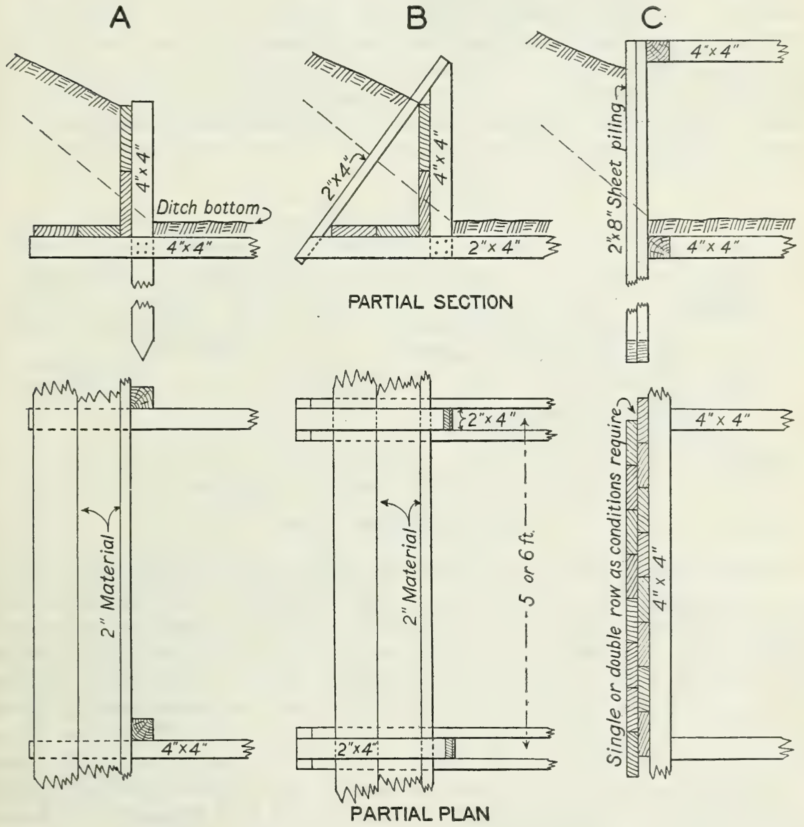


FIG. 10.—Types of cunettes

usually are objectionable, particularly where large weeds are apt to blow in. If such braces are used, they should be placed well above the surface of the normal flow.

Three types are shown in Figure 10. (See also pl. 1, H.) The type shown in Figure 10, B does not require piles and may be used where the bottom is firm and there is no difficulty in maintaining horizontal alignment. The design in Figure 10, A calls for piles at intervals of 5 or 6 feet. In case these can not be driven into firm material, a top cross brace or a side brace as shown in Figure 10, B will be required. The loading boards on the outside help to keep out the soft material and to prevent the structure from floating.

In exceptionally soft ground a bottom may be needed, or at least one or two planks on each side, to prevent material from being forced up into the ditch. When a bottom is planned, either the piles should be very firm or extra width should be given the loading boards to prevent lifting. Figure 10, C shows a design by which bottom planking may be avoided. It consists of sheet piling driven deep enough to prevent pressure of the banks from forcing the material up into the ditch.

These structures are expensive and are to be avoided whenever possible. In some districts drainage ditches in soft material have been dug in successive stages; in other instances excavation has been carried as far as possible and the ditches sluiced to completion by use of large heads of water. Using a flat side slope is sometimes cheaper than the methods described above, and often the trampling in of brush and weeds will prove effective. Russian thistles have been used successfully for this purpose.

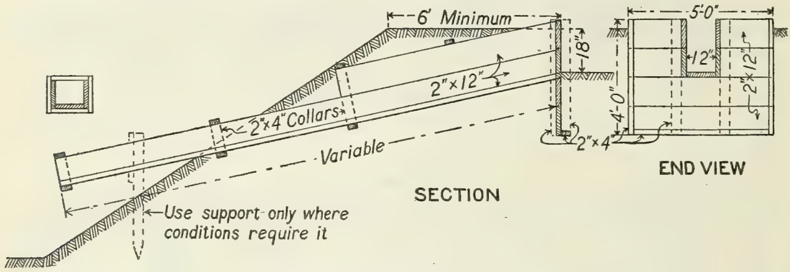


FIG. 11.—Surface water inlet for open drains

SURFACE-WATER INLETS

Surface inlets are installed on open drains to permit entrance of water wasting from irrigation and run-off from heavy rains, without injury to the banks. For irrigation waste the most common and cheapest form consists of a short wooden flume secured at the upper end with a cut-off wall and extending out over the bank of the canal, so that the inflow will discharge upon the water passing down the drain. (See fig. 11; pl. 1, J; and pl. 2, H.) These are sometimes destroyed by fire. A more permanent type consists of a corrugated metal pipe and a concrete cut-off wall, the length depending on the slope of the bank and the nature of the ground. In loose-grained soils, easily eroded, the cut-off wall should be located further from the edge of the bank than shown in Figure 11. Where maintenance may require the use of heavy machines operating from the bank of the canal, the upper end of the pipe or flume and cut-off wall should not extend above the surface of the ground. Where banks are not subject to erosion by water in the main canal, and cobblestones are handy, satisfactory inlets have been constructed by excavating small chutes and lining them with cobblestones in cement mortar.

Plate 1, I shows a type used to admit the run-off collected by shallow road or farm ditches in sections having heavy rainfall. In the case shown, where the inlets are located opposite each other on a narrow canal, a concrete apron extends across the entire bottom. For single inlets the outlet structure should be similar to that shown in Figure 6. A pipe is connected with a concrete cut-off wall or other form of intake structure at the upper end. Where concrete culverts or bridges with concrete abutments and wing walls or other structures are near such inlets, the lower end of the pipe should pass through these walls to obviate the necessity for a special structure at the pipe's lower end. If the pipe is to be made up of short sections, usually it should be incased with concrete.

STOCK GUARDS

Where fence lines cross open drains subject to wide variations in discharge, stock guards should be so constructed as to offer but little restriction to flow at high stages. Such a guard can be made in the form of a wooden gate pivoted at each side of the channel, so that the bottom will swing downstream about a horizontal axis.

SLUICEWAYS AND TIDE GATES

Lands affected to some extent by tides or subject to occasional overflow from rivers are protected by levees or dikes. After periods of flood the interior water or part of it may be discharged by gravity through sluiceways of various materials, such as wood, concrete, and iron pipe. Reinforced concrete usually is best for large outlets, which are similar in design to large culverts in soft formations. They are usually located near the outlets of large sloughs which have been cleaned out and used to store and convey the interior water to the sluiceway. The structure should generally be located on the bank at one side of the slough where a sump may be excavated by a dredge, obviating in many cases the necessity for cofferdams and also affording better foundation material. After the structure is completed channels for inlet and outlet may be excavated.

Gates hinged at the top and placed at the discharge end of the sluiceway are better adapted to ordinary practice. In this arrangement each sluice should be not more than 5 feet in height by 6 or 7 feet in width, and often smaller dimensions are preferable. To provide sufficient waterway several conduits or boxes may be built together, and except for small farm installations there should never be less than two openings.

The length of the sluiceways will depend upon the width of the embankment at its location. For greatest efficiency the elevation of the sluiceways should be such that the gates will be submerged at all stages of the water. Substantial head and wing walls must be provided at each end and the outlet end protected against erosion, drift, or ice. Grooves or guides should be provided for emergency gates to cut off the water and permit the sluiceway to be drained by pumping, inspected, and repaired, and for use in case of damage to the tide gate. A trash screen should guard the interior end.

It has been necessary to support many of these structures with piling. Frequently, however, the material under the sluiceways settles under the weight of the adjoining levee, and when piling is used an opening is left under the floor through which water is very likely to pass even though good cut-off walls have been installed. Some engineers build these structures without foundations with the expectation that they will settle somewhat. The sluiceways are designed to withstand the strain of such movement, and an effort is made to weight them so that the settlement will be uniform. This method appears to be satisfactory.

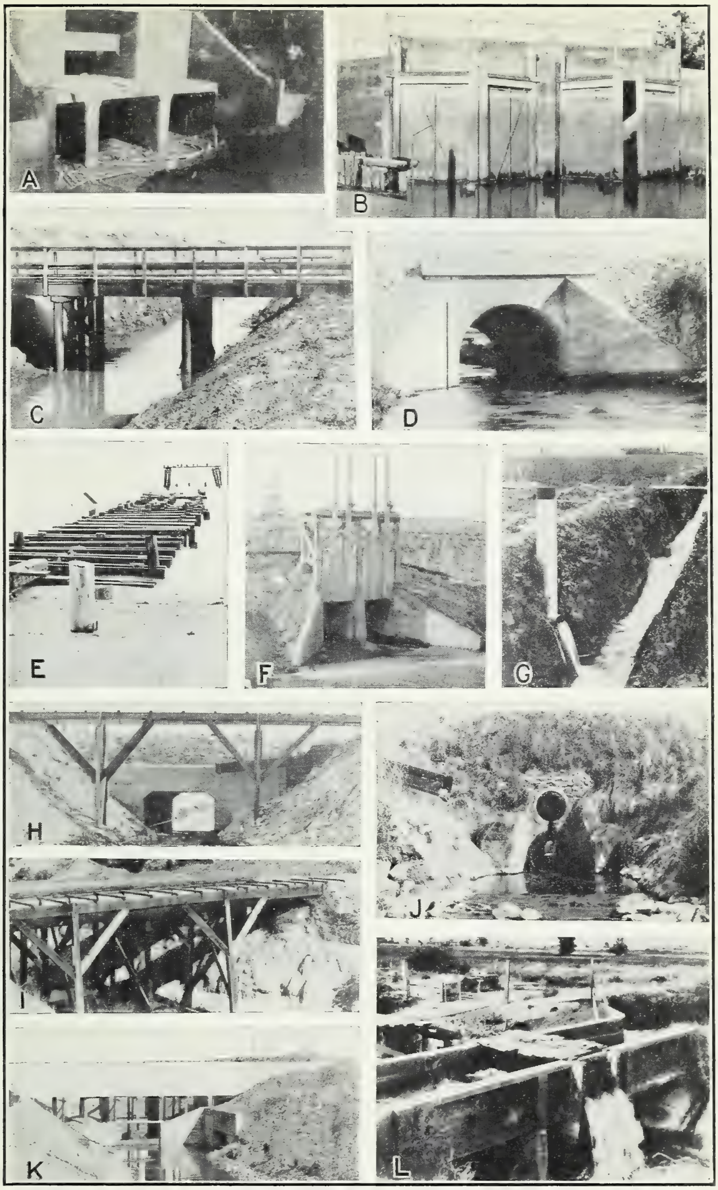
Cut-off walls are an important part of all such structures. Not less than two lines should extend crosswise under the bottom, up the sides and well out along the line of levee. Where piles are not employed care should be used that portions of the cut-off walls do not reach into firmer material and prevent uneven settlement; it may be necessary to depend upon a greater number of lines of short-length sheet piling. Head walls and cut-off walls are equally necessary where pipe is used for conduits.

Iron tide gates, machined to provide close seating, in many cases have been highly satisfactory. Where chemicals in the water may corrode iron, bronze or wooden gates should be installed. Wood gates have had wide use and where properly constructed and continuously submerged have given excellent service. Figure 12 shows a wooden flap valve made up of a double thickness of 2-inch material cross lapped and well bolted together, with an angle iron frame on the outside. Three-inch material embedded in concrete forms the seat. This particular gate is suspended from two trolley rails, which readily permit it to move outward. This gate will operate under very low heads and was designed especially for districts in the vicinity of Portland, Oreg.

Many types of hinges have been designed to meet particular conditions. A short single-pin hinge is not desirable; better balance and action will be obtained from a double-pin hinge connected with a long link or hanger bar and fastened to the gate about one-third the distance from the top. The lower part of the gate should be arranged so that weights can be attached or removed readily, and adjustments made after the gate is in place so that it will operate under a very low head. The seat should incline from the vertical slightly, but not more than 18°, so that the gate will seat tightly at low water. Careful and accurate construction should insure this.

Plate 2, A shows the land end of a reinforced concrete sluiceway. This particular structure has a superimposed culvert and a platform on the interior end to provide for the installation of an electrically driven chain-lift pump the use of which may be required occasionally when the gravity discharge is not sufficient.

Where tidal range permits and much water is to be passed, sluiceways with wide gates hinged at the side are used. These gates are the so-called " barn-door " type which has had successful use in certain sections of the Southeast. The bearings supporting the gate should be bronze or some other noncorrosive material. The frame should be wood, which best absorbs the shock occurring when the gates close against each other. The gate panels may be steel as in Plate 2, B. When closed the gates should be at an angle of from 18° to 23° with a line connecting their points of support. The bottom of each gate fits against an offset on the concrete floor of the structure.



A, Sluiceways for tide gates, Wahkiakum County, Wash. *B,* Sluice and tide gates combined with highway bridge, near Savannah, Ga. *C,* Highway bridge over drain, United States Bureau of Reclamation, Rio Grande project, N. Mex. *D,* Concrete-arch culvert, Ada County, drainage district No. 2, Idaho. *E,* Ocean outlet, Oxnard drainage district, Ventura County, Calif. *F,* Flood gates, diking district No. 2, Pend Oreille County, Wash. *G,* Relief well connection, Livermore Valley, Alameda County, Calif. *H,* Concrete culvert and small flume, Ada County, drainage district No. 2, Idaho. *I,* Flume and farm crossing, United States Bureau of Reclamation, Rio Grande project, N. Mex. *J,* Culvert and connection for flushing open drain, drainage district No. 2, Yakima County, Wash. For plans see Figure 5. *K,* Concrete flume and structure for diverting water from drain for irrigation, United States Indian Irrigation Service, Yakima project, Wash. *L,* Concrete flume with waste gate for flushing drain, Boise Valley, Idaho

Where occasional floods pass from high lands down the main drains, water must be prevented from backing up in laterals across flat bottom land. The type of structure used is similar to an ordinary sluice gate hinged at the top, except that the gate is placed

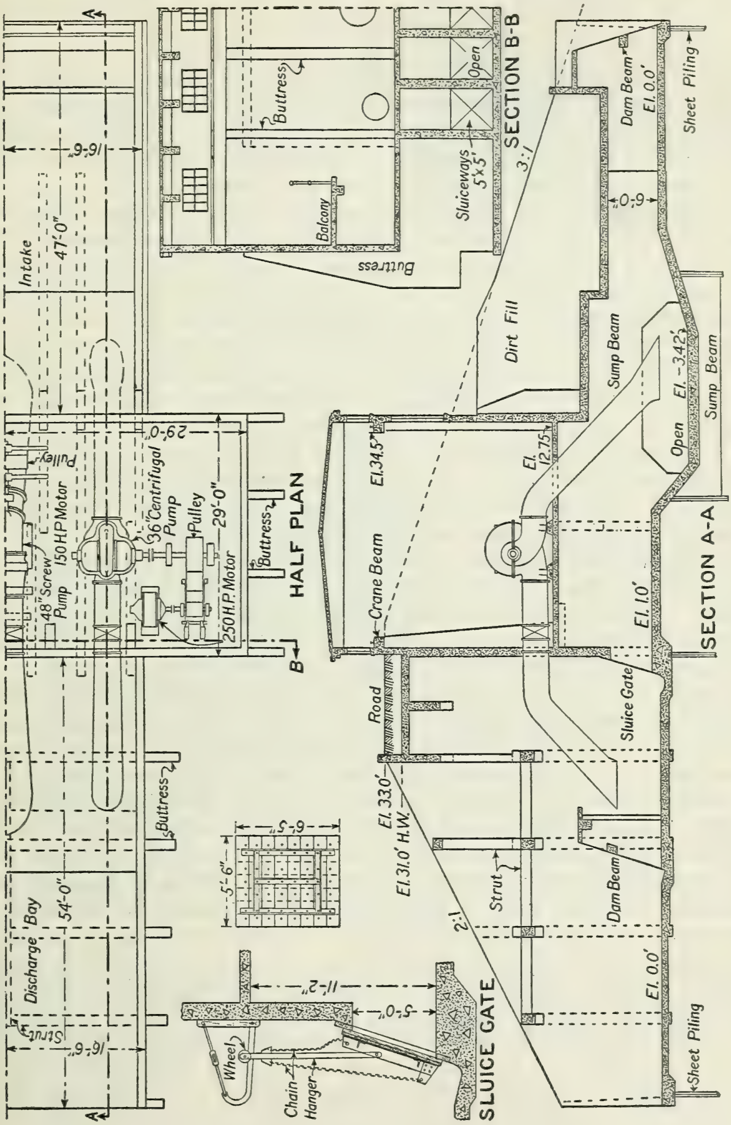


Fig. 12.—Structure for pumping plant, Multnomah County, drainage district No. 1, Oregon

at the inner instead of the outer end and a manhole is over the gate to permit of easy inspection and for making repairs.

Plate 2, F shows a sluiceway with hand-operated gates. At the location of these gates there is no tidal action, but they protect part of the interior area from river floods. The structure is under a railway embankment near the outlet of a stream draining the back area. The gates are made of heavy timber, but the structure itself consists of two concrete sluiceways each 7.5 feet wide, 10 feet high, and 85 feet long, these large openings being necessary to permit passage of logs. This sluiceway is supported with piling.

OCEAN OUTLETS

Some drainage districts are so situated that their outlets must discharge directly into the ocean (pl. 2, E). Such structures are continually subject to wave action intensified at times by storms. The profile in Figure 13 shows the conditions existing at the outlet of the Oxnard drainage district, Ventura County, Calif.

Tide records and the tide tables of the United States Coast and Geodetic Survey should be studied in planning ocean outlets. The mean rise and fall of spring tide varies from 5.1 feet at San Diego, Calif., to 7.7 feet at Astoria, Oreg., with extreme variation several feet more than this. The elevation of mean lower low water is 2.9 feet below mean sea level at San Diego and increases to 4.6 feet at Astoria. The elevation of the invert of outlet end of sluices will depend upon the elevation of land to be protected, tidal range, and difficulties of construction, but it should usually be below mean lower low water. The elevation of the Oxnard outlet is 4 feet below mean lower low water or 6.9 feet below mean sea level, United States Coast and Geodetic Survey datum. The extreme low tides of the year go below this, but usually the full ebb does not.

All possible information should be obtained regarding the permanence of the shore line and the soil through which the outlet pipe will pass. After the installation of the Oxnard outlet the loose formation at the outer end was shifted by wave action, with the result that the piling and outer end of the pipe were washed away.

The end of the pipe should be carried out until the invert is about 2 or 2.5 feet above the ground surface. If it is carried out too far the difficulty of holding the structure in place will be increased, whereas too short a distance will permit sand to be washed in.

Because of ease of installation and flexibility, corrugated-iron culvert pipe, heavily galvanized, is well adapted to construction of the outer end; light cast iron has longer life. The sand-covered part of the conduit may be any strong, durable type. Besides the difficulty of holding the outer end in place some trouble may be experienced in making the pipe joints air tight, or as nearly so as is possible. Wave action may cause air and water to flow through weak joints, sucking sand into the pipe or completely uncovering it so that the entire structure may be endangered at high tide. Where corrugated pipe is used the joints at the outer end should be secured with a band not less than five corrugations wide equipped with pull lugs to insure adequate clamping. The safest method of protecting those joints entirely covered with sand is to surround them with concrete.

Figure 13 shows a good design for the supporting structure. Square reinforced concrete piles are used. This form is easily made and offers greater clamping surface for the caps. The wooden caps should be creosoted and the pipe must be slung from the caps. Never less than two pipe lines should be installed, so that if one is damaged the other may operate while repairs are being made. Two lines make possible a supporting structure of greater stability. Provision for breaking the force of waves against the outer end should be made as shown in the illustration.

The gates must of necessity be at the land end. The gate chamber should be reinforced concrete supported with piling and should be divided into as many sections as there are outlet pipes. Grooves adjacent to the outlet pipes are desirable to accommodate flash boards for an emergency gate. Figure 13 shows self-acting iron tide gates, but lumber gates properly balanced might serve very well. The design shown is similar to the Oxnard outlet in that two gates for each outlet pipe are used. Where the outlet pipes are

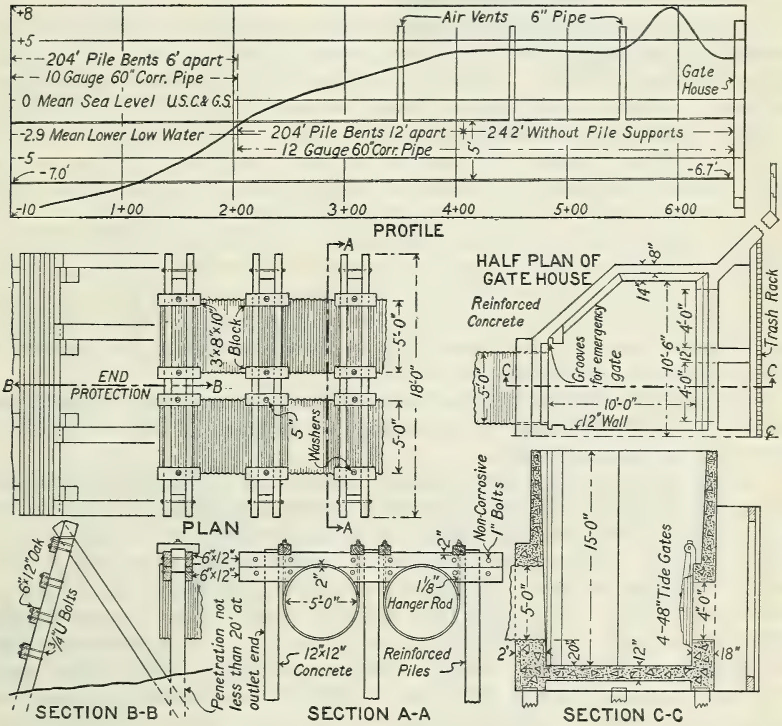


Fig. 13.—Outlet structure into ocean

less than 5 feet in diameter one gate for each, of proper size, will be sufficient. Cut-off walls of sheet piling should extend out a considerable distance beyond the ends of the wing walls, and a trash rack must be provided.

BRIDGES AND CULVERTS

Bridges and culverts are among the most expensive structures used for open drains.

Permanent structures of steel, concrete, or treated timber are required for railway or primary road crossings and must conform to the requirements of the railway or highway system on which they are built. The bed and banks of ditches are subject to considerable erosive action, the extent of which can not be foreseen with any certainty. Location of substructure should allow sufficient unobstructed waterway at time of greatest flow and abutments should be so located as to prevent water seeping behind them after possible erosion of adjacent banks. Foundations should extend below the anticipated erosive effect of the current and never less than 3 feet below the bed of the ditch in material other than rock, hardpan, or clay. Piers or bents should not be placed in the watercourse.

Since they perform the same service, these bridges should afford the same security as those elsewhere on the railroad or highway and should be designed and constructed according to the same principles of permanence as well as economy.

The permanent crossing types are reinforced-concrete box and arch culverts, slab and T-beam spans, steel girders, low trusses, and treated-timber trestles. Where the passage of floating equipment is necessary, spans which can be lifted to one side should be provided.

Most open-drain crossings, however, are for secondary or farm roads where permanent structures are not justified. Extreme flood conditions are seldom provided for in designing bridges of this type. They are generally simple beam spans or timber trestles.

The former are satisfactory for narrow ditches, banks of which suffer little erosion and give firm support to the mud sills or blocks. Short, longitudinal mud blocks give greater and more uniform bearing area than sills placed directly on the ground. The life of sills and blocks may be increased by embedding them in gravel or broken stone, to drain off the water.

Decay of the stringers at the ends of trestles may result from their contact with the ground. A clearance of at least 12 inches should be provided to prevent this.

Timber trestles (fig. 14) should consist of a channel span over the center of the ditch and approach spans long enough to place the ends of the trestle out of range of ordinary erosion. (See pl. 2, C and pl. 2, I). This arrangement is better than two-span trestles with a bent at or near the center of the ditch, because of the obstruction to flow offered by the central bent. Single-span trestles with timber back walls higher than 2 feet are not desirable because the timber in the back walls is subject to rapid decay, and earth pressure against a back wall on a timber bent tends to push the bent out of place. Longitudinal bracing to prevent this obstructs the waterway.

A timber trestle may be supported on either pile or frame bents. Pile bents should consist of three or more piles and be braced with double diagonal sway bracing. The cap should be drift bolted to each pile and the bracing should be bolted or spiked to the cap and each pile. Under some conditions pile bents are not economical for small jobs, because they can not be driven to good bearing by hand and the cost of pile-driving equipment is not justified for the few piles needed.

Frame bents consist of three or more posts and a cap and sill, which may be placed directly on the ground on mud blocks or on concrete piers or pedestals. They should have double diagonal bracing bolted at the ends to the cap and sill and at intermediate points to the posts. The caps and sills should be dapped to receive the ends

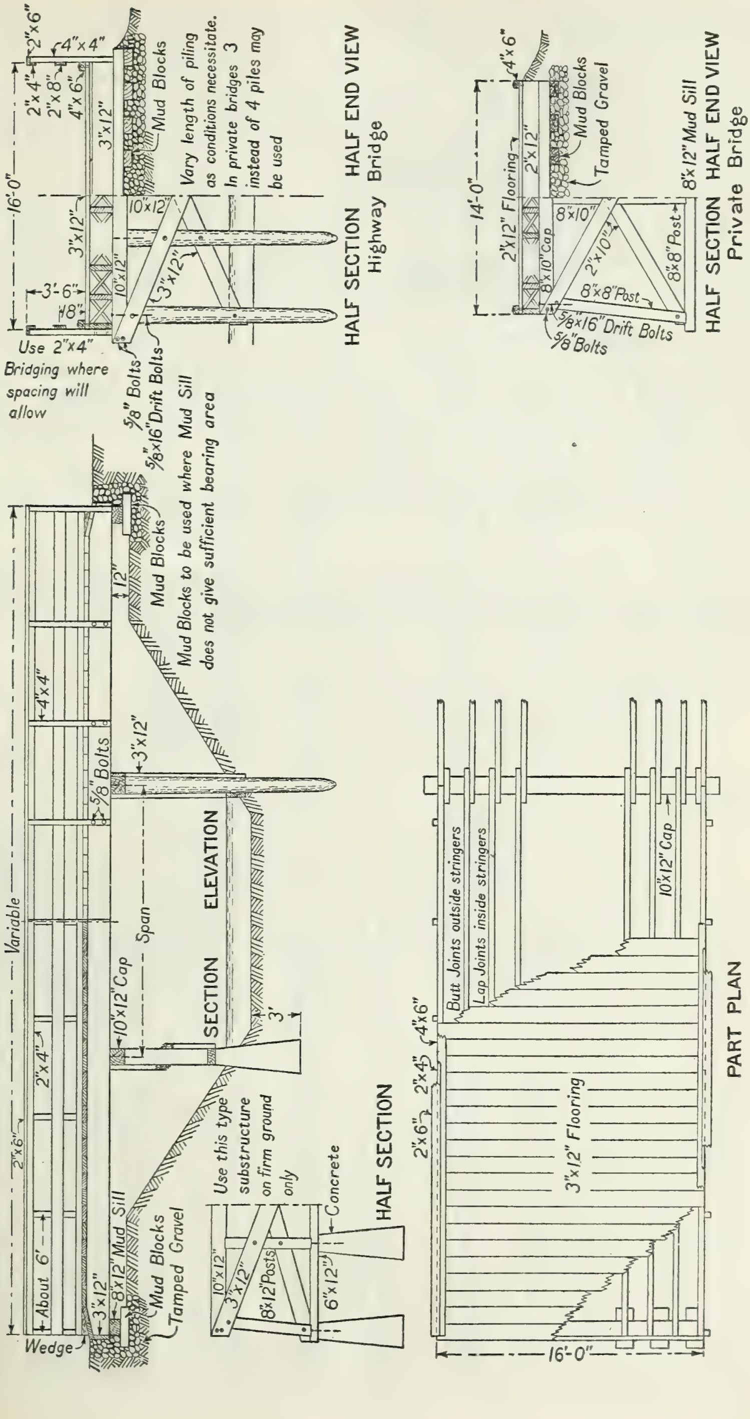


FIG. 14.—Timber bridge suitable for crossing drainage ditch. See Tables 1 and 2 for different assumed fiber stresses and loadings

of the posts, to which they should be securely drift bolted. The sills should be anchored to concrete piers or pedestals by bolts in the masonry and extending into the sill. The provisions to be made against undermining of the foundations by erosion are explained on page 20. Concrete foundations should be high enough to keep the timber sills above the ordinary water level, with such bearing area at the bottom as will prevent settlement.

Spacing between stringers should be not more than 27 inches center to center, preferably between 18 and 24 inches. Inside stringers should have full bearing on the caps, and should be separated at the laps to avoid retention of moisture between them. The outside stringers may be placed end to end over the center line of the cap. Double 2 by 4 inch bridging should be used when the width of stringer is less than one-third of the depth. The number of lines used should depend upon the span, as follows: Spans under 15 feet, 1 line; spans from 15 to 20 feet, 2 lines; spans above 20 feet, 3 lines. Tables 1 and 2 show sizes and number of stringers for various spans, allowable unit stresses, and widths of roadway.

Floor planks, spiked to each stringer, should be not less than 3 inches thick for public highway crossings and 2 inches for private crossings, but preferably 3 inches for a 5-ton loading.

TABLE 1.—*Size and number of stringers for timber trestles using Western larch, Pacific post oak, bur oak, bald cypress, mountain region Douglas fir, or redwood for which a fiber stress of 1,200 pounds per square inch is assumed*

[Truck load 80 per cent on rear axle, axles spaced 12 feet, wheels spaced 6 feet impact 30 per cent]

Span	16-foot roadway			14-foot roadway					
	10-ton truck			5-ton truck			3-ton truck		
	Stringers required		Lumber in stringers per lineal foot of bridge	Stringers required		Lumber in stringers per lineal foot of bridge	Stringers required		Lumber in stringers per lineal foot of bridge
Feet	*Number*	*Inches*	*Feet b. m.*	*Number*	*Inches*	*Feet b. m.*	*Number*	*Inches*	*Feet b. m.*
10	12	4 x 12	48.0	11	3 x 10	27.5	10	2 x 10	16.7
	9	4 x 14	42.0	8	3 x 12	24.0	7	3 x 10	17.5
12	11	4 x 14	51.3	13	3 x 10	32.5	12	2 x 10	20.0
	9	4 x 16	48.0	9	3 x 12	27.0	8	3 x 10	20.0
14	13	4 x 14	60.7	11	3 x 12	33.0	10	3 x 10	25.0
	10	4 x 16	53.3	8	4 x 12	32.0	7	3 x 12	21.0
	9	6 x 14	63.0						
16	11	4 x 16	58.7	12	3 x 12	36.0	11	3 x 10	27.5
	10	6 x 14	70.0	10	4 x 12	40.0	8	3 x 12	24.0
18	13	4 x 16	69.3	13	3 x 12	39.0	13	3 x 10	32.5
	11	6 x 14	77.0	11	4 x 12	44.0	9	3 x 12	27.0
	9	6 x 16	72.0	8	4 x 14	37.3	7	4 x 12	28.0
20	13	6 x 14	91.0	12	4 x 12	48.0	10	3 x 12	30.0
	10	6 x 16	80.0	9	4 x 14	42.0	8	4 x 12	32.0
				7	4 x 16	37.3			
22	14	6 x 14	98.0	13	4 x 12	52.0	12	3 x 12	36.0
	11	6 x 16	88.0	10	4 x 14	46.7	9	4 x 12	36.0
	8	6 x 18	72.0	8	4 x 16	42.7			
24	12	6 x 16	96.0	11	4 x 14	51.3	13	3 x 12	39.0
	10	6 x 18	90.0	9	4 x 16	48.0	10	4 x 12	40.0
				8	6 x 14	56.0	8	4 x 14	37.3
26	14	6 x 16	112.0	13	4 x 14	60.7	12	4 x 12	48.0
	11	6 x 18	99.0	10	4 x 16	53.3	9	4 x 14	42.0
	8	8 x 18	96.0	9	6 x 14	63.0			
28	12	6 x 18	108.0	13	4 x 14	60.7	13	4 x 12	52.0
	12	8 x 16	128.0	11	4 x 16	53.3	10	4 x 14	46.7
	9	8 x 18	108.0	9	6 x 14	63.0	8	4 x 16	42.7

TABLE 2.—*Size and number of stringers for timber trestles using tanbark oak, white oak, Cuban pine, longleaf pine, coast region Douglas fir, and shortleaf pine (treated) for which a stress of 1,600 pounds per square inch is assumed*

[Truck load 80 per cent on rear axle, axles spaced 12 feet, wheels spaced 6 feet, impact 30 per cent]

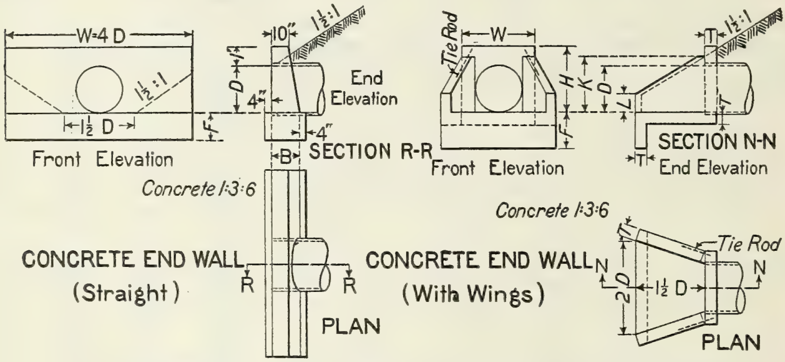
Span	16-foot roadway			14-foot roadway					
	10-ton truck			5-ton truck			3-ton truck		
	Stringers required		Lumber in stringers per lineal foot of bridge	Stringers required		Lumber in stringers per lineal foot of bridge	Stringers required		Lumber in stringers per lineal foot of bridge
Feet	*Number*	*Inches*	*Feet b. m.*	*Number*	*Inches*	*Feet b. m.*	*Number*	*Inches*	*Feet b. m.*
10	12	3 x 12	36.0	12	2 x 10	20.0	8	2 x 10	13.3
	9	4 x 12	36.0	8	3 x 10	20.0			
12	11	4 x 12	44.0	10	3 x 10	25.0	9	2 x 10	15.0
	9	4 x 14	42.0	7	3 x 12	21.0			
14	13	4 x 12	52.0	11	3 x 10	27.5	11	2 x 10	18.3
	10	4 x 14	46.7	8	3 x 12	24.0	7	3 x 10	17.5
	8	4 x 16	42.7						
16	11	4 x 14	51.3	13	3 x 10	32.5	12	2 x 10	20.0
	9	4 x 16	48.0	10	3 x 12	30.0	9	3 x 10	22.5
				8	4 x 12	32.0			
18	13	4 x 14	60.7	11	3 x 12	33.0	10	3 x 10	25.0
	9	6 x 14	63.0	8	4 x 12	32.0	7	3 x 12	21.0
	10	4 x 16	53.3						
20	10	6 x 14	70.0	12	3 x 12	36.0	11	3 x 10	27.5
	14	4 x 14	65.3	9	4 x 12	36.0	8	3 x 12	24.0
	11	4 x 16	58.7	7	4 x 14	32.7			
22	12	4 x 16	64.0	13	3 x 12	39.0	12	3 x 10	30.0
	11	6 x 14	77.0	10	4 x 12	40.0	9	3 x 12	27.0
	8	6 x 14	64.0	8	4 x 14	37.3			
24	13	4 x 16	69.3	11	4 x 12	44.0	14	3 x 10	35.0
	11	6 x 14	77.0	9	4 x 14	42.0	10	3 x 12	30.0
	9	6 x 16	72.0				8	4 x 12	32.0
26	13	6 x 14	91.0	13	4 x 12	52.0	11	3 x 12	33.0
	10	6 x 16	80.0	10	4 x 14	46.7	9	4 x 12	36.0
	8	6 x 18	72.0	8	4 x 16	42.7			
28	14	6 x 14	98.0	11	4 x 14	51.3	12	3 x 12	36.0
	11	6 x 16	88.0	8	4 x 16	42.7	10	4 x 12	40.0
	9	6 x 18	81.0	7	6 x 14	49.0			
	9	8 x 16	96.0						

Handrails should be secured to the outside stringers by at least two bolts, spaced as far apart as the depth of the stringer permits. The usual type of handrail has one rail spiked to the top of posts and two side rails, one at the top of the post, the other midway between the floor and the top of posts. A wheel guard should be on each side of the roadway and be wide enough to prevent contact between vehicles and handrails.

For small drains, or large ones where the discharge is not excessive or subject to considerable increase, a culvert is more economical than a bridge; but in deciding between them it must be remembered that a culvert must be capable of passing more than the normal flow, otherwise weeds and debris may clog the intake. Pipe culverts should never be less than 15 inches in diameter. Except for very shallow fills, two parallel lines are not recommended, because of their cost and the greater possibility that the waterway may become obstructed. On many drainage ditches, culverts can not be used because of floods which occasionally greatly exceed the normal flow, and in some districts because small motor boats are used in maintenance work.

Corrugated-metal pipe is easily installed and on farm crossings it may be used without end walls. Very good small culverts can be made of concrete or vitrified clay pipe. They require good foundations. For corrugated-metal pipe, the coefficient of roughness, n in the Kutter formula, ranges from 0.019 for the 12-inch size to 0.023 for the 30-inch size. For the same sizes of vitrified clay pipe, n ranges from 0.010 to 0.013. For large sizes the reinforced box will be more nearly permanent (pl. 2, H) or where good natural foundations exist arch culverts of plain concrete may be used (pl. 2, D).

Concrete end walls should be used on most types of culverts except wood. (See pl. 2, D, and pl. 2, J.) Figure 15 gives designs for two



DIMENSIONS AND ESTIMATED QUANTITIES FOR ONE END WALL

STRAIGHT						WITH WINGS												
D	B		F		Cu. Yds.	W		H		F		K		L		T	Cu. Yds.
in.	ft.	in.	ft.	in.		ft.	in.	ft.	in.	ft.	in	ft.	in.	ft.	in.	in.	
12	1	2	1	0	0.54												
15	1	2	1	2	0.76												
18	1	3	1	3	1.04	2	11	2	3	2	0	1	9	0	8	8	0.55
24	1	4	1	4	1.62	3	2	2	10	2	0	2	4	0	10	8	0.90
30	1	6	1	6	2.49	3	11	3	6	2	0	3	0	1	0	8	1.25
36	1	8	1	8	3.60	4	9	4	2	2	6	3	6	1	2	10	2.42
42	1	10	2	0	5.20	5	3	4	10	2	6	4	1	1	4	10	3.08
48	2	1	2	0	6.85	5	9	5	6	2	6	4	8	1	6	10	3.80

FIG. 15.—Concrete end walls for culverts

types, with dimensions and estimated quantities for various sizes of pipe culverts. These may also be used for box culverts. The **U** type is not recommended, since it requires approximately the same quantity of concrete as the type having wings set at an angle and is less efficient in reducing entrance loss than either of the two types shown. To reduce entrance losses, rounding the entrance to the pipe is more important than the type of structure used, as it will increase the capacity of a pipe culvert from 10 to 13 per cent. For this reason the bell end of clay or concrete pipe should be placed upstream. In soft soils the bottom of the canal should be paved with riprap for a short distance below the structure outlet.

Drainage crossings under large canals also require culverts. The material should be more permanent than wood. Where pipe made up of short sections is used, a good foundation must be provided and the joints surrounded with mortar. (See fig. 16 and fig. 7.) End walls should be similar to those shown in Figure 15. Water must be prevented from finding its way along the sides and bottom of the structure, and cut-off walls must be provided as shown in Figure 7. In some soils it will be necessary to pave the section of the canal passing over the culvert with concrete.

FLUMES AND INVERTED SIPHONS

Drains frequently cross irrigation or other canals, necessitating the construction of flumes. These are commonly used in irrigation to carry water across natural depressions. but because the cross sec-

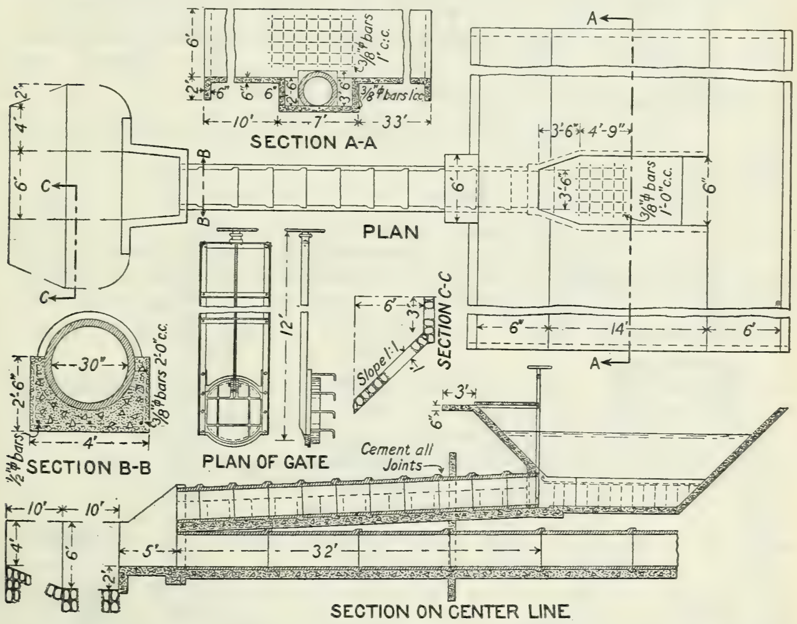
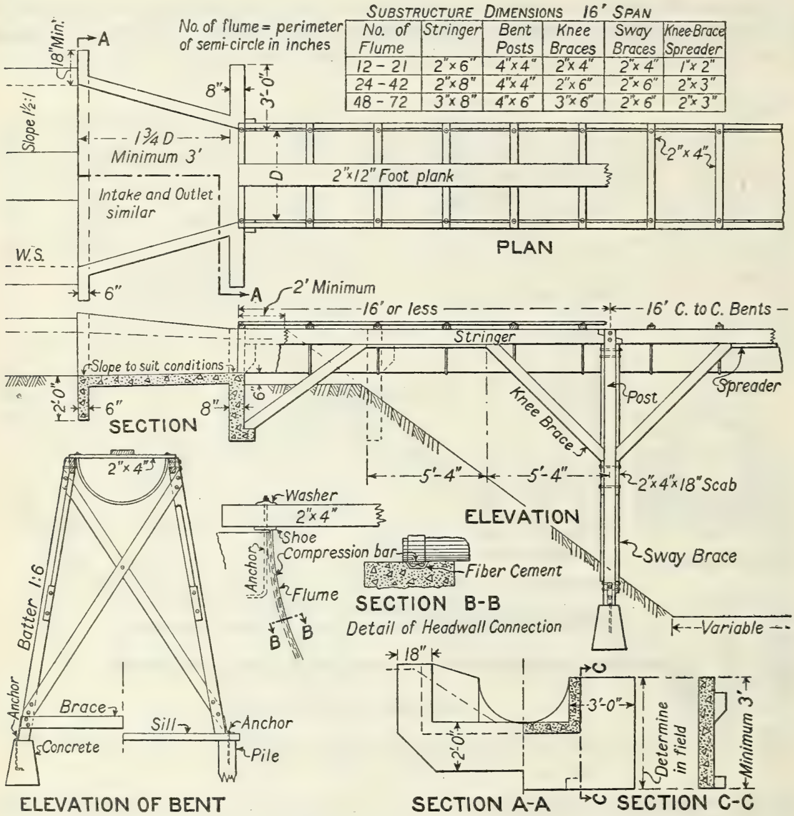


FIG. 16.—Culvert under canal and connection for flushing open drain, drainage district No. 2, Yakima County, Wash.

tion of a drainage ditch is very apt to change, greater care is necessary in the design of substructure, and intake, and outlet structures than is common for irrigation requirements. A design for small metal flumes is shown in Figure 17 and Plate 2, H and I. Intakes and outlets can usually be made similar in form. Figure 17 shows a design suitable for sizes to and including No. 72. If desirable the wing or transition walls for large flumes may be warped. The slope of the intake and outlet floors will depend upon available slope and change in cross section of the ditch. Usually the fall available in such cases is not great and flumes with large cross section will be required. For small flumes such structures should be made as simple as is consistent with correct hydraulic design. Many failures are caused by washing and undermining due to seepage. To provide against this and erosion in very loose sandy soils, it may be necessary to line the canal for a short distance beyond the structures. For size No. 24 and smaller in good soils a straight wall may do, but the end of the flume should extend back farther than for other types.

Figure 17 shows connection between metal flume and end structures. The end of the metal sheet should not be turned into the concrete. The flume, when filled with water, sags at bottom and the opening in the head wall must be shaped approximately to correspond to this form. The bars across the top may be omitted from small sizes of some types. This is desirable where large weeds may



SUBSTRUCTURE DIMENSIONS 16' SPAN

No. of Flume	Stringer	Bent Posts	Knee Braces	Sway Braces	Knee-Brace Spreader
12 - 21	2"x6"	4"x4"	2"x4"	2"x4"	1"x2"
24 - 42	2"x8"	4"x4"	2"x6"	2"x6"	2"x3"
48 - 72	3"x8"	4"x6"	3"x6"	2"x6"	2"x3"

FIG. 17.—End connections and substructure for metal flumes

cause overflow. In all cases a liberal free board should be provided.

Creosoted wood-stave flumes are coming into favor and it is believed that their cost of maintenance will be low. The substructure required is in some respects similar to that for metal flumes.

Where the bottom of the drain is very soft or the structure may be endangered by floods, trusses similar to those in Plate 1, J, are recommended for small flumes. Corrugated pipe, requiring no support, is a convenient means of carrying small laterals across narrow ditches. Reinforced concrete is desirable for large flumes. (See pl. 2, K, and pl. 2, L.)

As a general rule it is economy to make the drain deep enough to obviate necessity for inverted siphons. When this is impossible the inverted siphon should be used on the canal carrying least water, and possibility of flood discharges must be considered. A screen should be provided at the inlet structure to keep out weeds and trash. This screen should be inspected and cleaned frequently, otherwise it may become so badly clogged with trash that it will obstruct the flow and endanger the canal bank.

MISCELLANEOUS STRUCTURES

PUMP HOUSES

Pumping from wells is being resorted to in some localities to drain lands damaged by irrigation seepage. Figure 18 shows a type of pump house used in Salt River Valley, Ariz., which is a suitable shelter for electrically-driven, direct-connected plants. The lower part of the derrick, which is essential in pulling the pump for repairs, forms a part of the framework of the building. At the top is a removable hatch, and a section of the roof and wall over the door is also removable. A weir is desirable, but for small plants a cheaper arrangement brings the discharge pipe above the floor and carries it out to a less elaborate stilling pool and weir in the ditch. A concrete floor is provided, drop siding is used on the walls, and the top is covered with asbestos roofing. Belt-driven pumps will need longer housing, and where engines are used galvanized corrugated iron is recommended for covering walls and roof.

On levee districts where gravity outlets are not available the location of the pumping plant is often determined by topographic conditions; but it should be such that pumped water will be conveyed as short a distance as possible. Stable foundation material should be present, and transportation of heavy machinery and fuel or power should be handled easily.

The most common form of pumping plant consists of a structure supported on piling, with discharge pipes passing through or over the levee and suction pipes leading to a sump in the rear of the building. This requires long pipes with attendant friction losses, to overcome which sumps may be placed under the pump house and the structure located in the levee where the foundation alone or both the foundation and wall must serve as a dam. This requires careful design but permits economical operation and sometimes also involves cheaper construction than other arrangements, except perhaps for small plants with low lifts.

Borings and a very careful examination of the formations at the proposed site must precede the design. Settlement under the floor is an important and difficult problem to handle. In some soils, where the pump is located some distance back of the levee, subsidence due to drainage may occur, and where located in the levee, settlement due to weight of adjacent fill must be anticipated, making it essential to construct carefully designed cut-off walls.

Often where the lift is low the pump-house floor may be placed at an elevation such that flooding the motors or engines is not likely in case of accidents or forced suspension of pumping. The suction

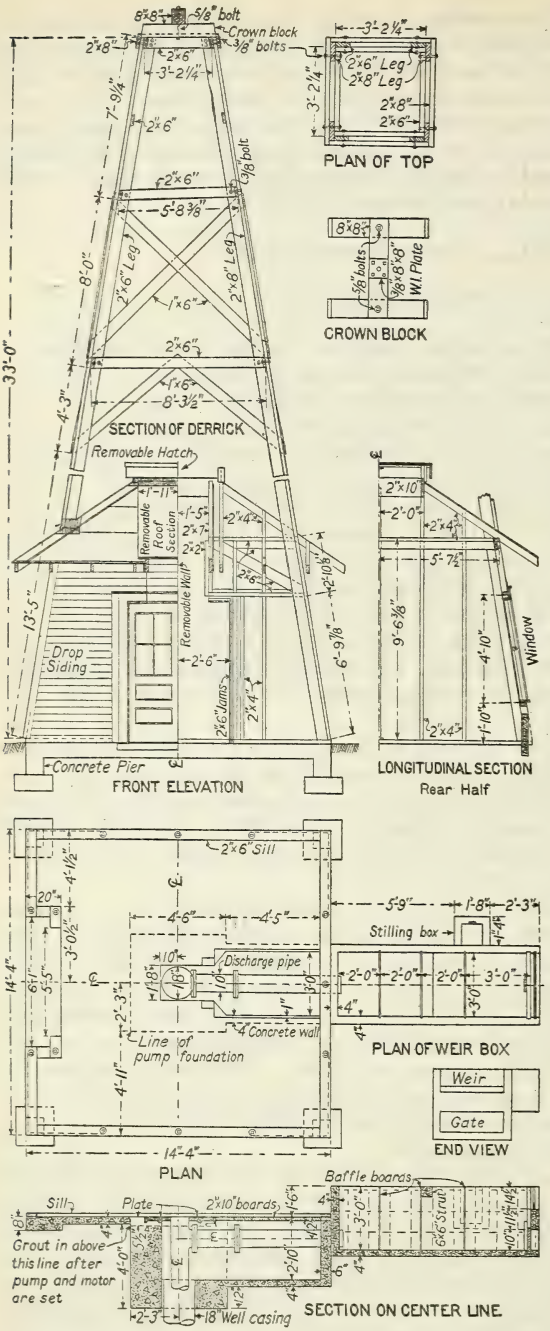


FIG. 18.—Pump house for drainage wells, Salt River Valley, Ariz.

lift should be kept as low as possible, however, this often requiring the walls of the structure to be designed to prevent the entrance of water. A plant in operation on the Sacramento River was designed to withstand a head of water 20 feet above the floor, with walls and floor several feet thick to prevent floating.

The suction bay must have a greater depth than the main canal and a sufficient area to permit movement of the water to the intake pipes at low velocities. A screen must be provided to protect the intake. If the suction bay is not an integral part of the concrete house or foundation, its sides must be well protected with sheet piling; and in case sand boils develop, the sides and bottom must be made of reinforced concrete designed to withstand upward pressure. In fixing the elevation of the floor, allowance should be made for subsidence where muck or peat soils exist.

Where the discharge pipe passes through the levee, extreme care must be taken to prevent seepage by construction of cut-off walls. The discharge bay, made of reinforced concrete, should be substantially protected against washing and undermining, with elevation such that the outlet pipes will be submerged. For some types of pump installations, gates must be provided at the discharge structure. Discharge and suction pipes usually are steel, but sometimes they are reinforced concrete. The diameter should be sufficient to produce a velocity of not more than approximately 5 feet per second, and the intake and discharge ends must be enlarged to reduce losses.

The house should be durable and fire proof. Galvanized corrugated metal is desirable for small plants, but excellent houses have been made of brick. Reinforced concrete is well adapted to large structures and must be used on all plants where there is danger of flooding the machinery. The building should be well ventilated. Reinforced-concrete columns or pilasters must be carried up on the inside of the walls to support rails for a crane, which is an essential part of all except very small plants.

Figure 12 shows the design of a pumping plant installed in Multnomah County drainage district No. 1, Oreg. This reinforced-concrete structure has unusual features in that the wall of the plant is designed to withstand a high head of water, and the entire structure rests on a silty formation without rigid support. It was thought that the earth would settle and thus leave an opening beneath the floor if the structure were otherwise supported, which would be very hazardous particularly during the high-water period which sometimes lasts for several weeks. Five rows of sheet piling were placed beneath the floor. These are only 8 feet in length so that none of them would reach into what appeared to be a hard layer of sand beneath the silt and thus tend to prevent uneven settlement. The entire structure has settled about 3 inches since installation.

The floor was designed against upward pressure, and an effort was made to reduce the pressure to some extent by filling with porous concrete five boxes each 1.5 feet square placed in the down-stream side of the sump. The structure is also provided with five sluiceways having openings 5 feet square for gravity discharge. Automatic gates are used. Emergency dams can be installed easily in case repairs must be made to gates or pipes.

CONNECTIONS FOR FLUSHING DRAINS

Often it is desirable to connect open drains and underdrains with irrigation or other canals for periodic flushing. This is the cheapest form of maintenance work that can be done. Figure 16 and Plate 2, J, show connection to an open drain which passes through a culvert under an irrigation canal. The canal is lined with concrete, and riprap at the lower end of the outlet pipe and culvert prevents erosion of the embankment. The connection is made by an ordinary turnout gate. Use of this connection for sluicing has reduced maintenance cost to a minimum, and has lowered the grade line of the main canal approximately 2 feet for several miles.

Where a concrete box culvert is used, the connection should consist of a small concrete tower with a gate at one side of the upper canal, through which the flushing water may be discharged directly into the culvert instead of at its lower end as in the example shown. At flume crossings a gate may be provided, as shown in Plate 2, L. Unstable soils below such a discharge will require a short paving of concrete or riprap to prevent erosion.

Connections between canals and intersecting underdrains resemble in some respects that shown in Figure 16, but the discharge pipe will be much smaller and its lower end will discharge into a manhole. Usually it will be unnecessary to pave the canal. As a rule special gates and elaborate connections are not needed on underdrains since most properly built mains and laterals have flushing structures at the upper end. Water may be conducted to the tile line from small laterals as shown in Figure 19, the connection being made either with a T-junction or an elbow, depending on whether the line is to be extended. The riser may be tile of the same size as the drain, but usually it does not need to be larger than 6 or 8 inches. In case surface run-off is to be admitted a regular surface-water inlet should be used. Ordinary drain tile may be used for tile ends on farm laterals, but on more important lines bell-end tile to prevent displacement will be preferable. Gravel should be placed around the tile at the connection and the earth should be well tamped or puddled in around the riser. Wherever possible tile ends should be located out of the way of farm machinery, but where such location is impossible the top should be about 16 inches below the ground and covered with gravel. Vitrified clay or concrete stoppers may be used for the cover.

RELIEF-WELL CONNECTIONS

Relief wells of various types are used to conduct ground water under pressure to closed drains or open ditches. Often a large number of small wells are sunk with augur or drill to drain land underlain with water-bearing shale formation. If the tile line reaches into the shale, casing is usually unnecessary; otherwise the well should be cased from the top of the shale to the tile line. This upper part may be cased with tile from 4 to 8 inches in diameter if the adjacent material can be excluded from the joints; otherwise an iron-pipe or wooden-box casing must be used.

Many relief wells flow only at certain seasons, hence they must be located at one side of the drain to keep them free from silt. In shale the small wells should be drilled close to the drain line, to which they should be connected by a hole in the side several inches above the bottom of the tile. The well and the hole should be covered with a large piece of tile, surrounded by small pieces of tile and gravel.

Some drainage systems include deep relief wells of large diameter, cased with iron pipe, as in artesian well practice. Here it is necessary to perforate the lengths extending into the formation under artesian head, the size, shape, and number of these openings depending upon the nature of the formation. Casings should extend above ground and the covers should be secured against removal. T-junctions should be used at connections and the bottom of the outlet opening in the well casing should be several inches above the grade of the tile line into which it discharges. If manholes are near, wells should be connected with them. Gravel pockets which will discharge large quantities of water when tapped are occasionally found below the grade of the tile line. These may be connected to the drain by a structure similar to a small manhole, located at one side of the line.

Relief wells discharging into open ditches must be located and lined in the manner described above. The elevation of the T-junction discharging into the ditch should be that of ordinary high water in the line of the drain (pl. 2, G).

CONNECTIONS FOR DIVERTING WATER

Drainage water is valuable for irrigation if the percentage of alkali is not too high. When water is diverted by gravity from an open drain the required structures will be similar to those used in irrigation practice, consisting of a turnout gate located just above a check as shown in Plate 2, K. The elevation of the water is controlled by flashboards. The gate should be large and low enough to permit diversion with a checked head of only a few inches; otherwise the purpose of the drain will be defeated.

When good fall exists on an underdrain, water may be diverted from it through a pipe having a flatter grade. This pipe must have tight joints and the connection should be made at a manhole and at an elevation slightly less than that of the outlet drain. A slide gate should be fitted on the diversion pipe and a similar gate may be installed on the outlet drain pipe; but the latter should be so constructed that it can not be completely closed unless the diversion pipe has a capacity equal to that of the drain.

As a general rule, any considerable checking of the normal flow of drains is to be avoided. This is particularly true for underdrains and for any type when alkali is present, except perhaps in peat soils where it is necessary to practice subirrigation. In such systems the level of the water in the small open drains is controlled by wooden check gates. If underdrains are used checking may be accomplished by means of slide gates at frequent intervals; these have a stem reaching to the ground surface through a pipe similar to an observation well.

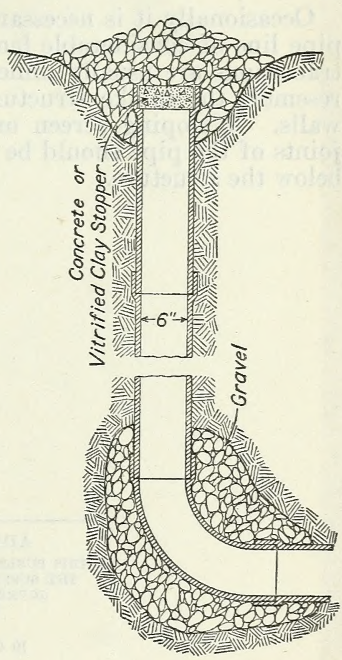


FIG. 19.—Tile end to permit flushing

Pumps on closed drains should be located at manholes with deep sumps, and for small plants on open drains a suitable sump should be provided at one side of the main channel in such a manner as to offer no obstruction to the flow.

WATERING PLACES FOR LIVESTOCK

In some localities special watering places for livestock must be provided on underdrains and on open systems where stock are not permitted to graze on the banks. On open drains the channel bottom should be widened at one side, a flatter side slope excavated for entrance, and a fence so located as to prevent the forming of a bar in the main channel by the trampling of stock. In very soft ground a plank floor will be needed at the lower end of the approach.

Watering places on underdrains should be provided by the installation of a by-pass consisting of a trough situated several feet from and parallel to the main line and connected to it at each end with Y-branches. A coarse screen must be placed at the lower end of the trough, which is located in a sump with sloping sides to permit access by stock. The earth excavated should be spread entirely around the sump so as to exclude surface water.

TRANSITIONS

Occasionally it is necessary for an open drain to discharge into a pipe line of considerable length. Elaborate structures with warped transitions are usually unnecessary. In a general way they should resemble the intake structure of a culvert and have ample cut-off walls. A sloping screen or trash rack should be provided. The joints of the pipe should be cemented for a distance of 20 to 30 feet below the structure.

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