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MECHANICAL STRUCTURES FOR FARM IRRIGATION[a]

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INTRODUCTION

The water facilities and management practices used by the individual farmer are extremely important factors and have a significant effect upon irrigation water use. Considerable effort is being made to improve irrigation practices by developing better surface irrigation methods and equipment. Mechanized systems with automated control structures enable the farmer to apply water more efficiently and with a minimum of labor. These structures automatically terminate irrigation on one portion of a field or farm and direct the water to another section. It is common practice in many areas to use either 12-hr or 24-hr irrigation sets because it is convenient to change the water only once or twice each day. Often an irrigation of less than 12 hr or between 12 hr and 24 hr is sufficient to refill the root zone. The available water supply can serve a larger area if water can be changed from one set to another at the optimum time without attention. Many farms can use automatic structures without extensive modifications to present systems.

Mechanical, automatic irrigation structures being developed at the USDA Snake River Conservation Research Center do not require an external power source for operation and include simple timer-controlled structures. These are being tested in automatic cutback furrow, conventional furrow, graded border, basin, contour ditch, and recirculating systems.

Surface flooding systems using basins, borders or contour ditches, are easiest to automate because the field topography allows the entire stream of water to become distributed over the soil surface naturally. When furrows are used, however, the irrigation stream must be uniformly divided into many small streams directed into individual furrows. This requires furrow flow

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regulating devices or controls in addition to check and turnout structures. Various means of regulating the flow in furrows for automatic irrigation have been tested. These have included plain and gated furrow tubes, sheet metal devices with various opening configurations and sodded outlets. None, however, is completely satisfactory. The problem is further complicated because soil intake rates often vary from one furrow or corrugation to another. These variations are compensated for under normal irrigation practice by the irrigator who manually adjusts the flow in individual furrows.

MECHANICAL TIMERS

A dependable timer is one of the requirements of semiautomatic timer-controlled structures. Some farmers have used conventional alarm clocks; however, these have disadvantages when used to control irrigation structures. They do not have: (1) A direct reading scale to indicate the time of irrigation set; (2) a built-in trip for releasing the gate; or (3) an escapement release. Furthermore, they are not corrosion resistant, and require attention at least every 12 hr.

A timer with an escapement release is desirable so that the timer and its accompanying structure may be reset anytime between irrigations. A timer so equipped may be preset but does not actually operate until the escapement release is activated by the presence of water in the irrigation ditch. An escapement release also increases the total time period for which a group of structures may be preset because only one timer of a group operates at a time. The total possible time period is the time capacity of one timer multiplied by the number of timers.

A commercial timer having a mainspring windup, direct-reading time indicator, and a tripping mechanism all integral with the same shaft, has been tested. In cooperation with the manufacturer, this timer was redesigned for use with automatic irrigation structures. It was equipped with a corrosion-resistant movement and an escapement release, and was mounted in a sealed enclosure. This experimental timer was used with all of the timer-controlled structures described herein and was made for 2-, 5- or 12-hr periods.

Some timers being field tested were left in the field during the winter months. The weatherproof enclosure appeared to provide adequate protection. However, it is recommended that the timers be removed during nonirrigation seasons if they will be exposed to adverse field weather conditions.

PORTABLE IRRIGATION CHECK

A semiautomatic check for use in lined ditches is shown in Fig. 1. This portable, lightweight unit may be placed at any location in the ditch. It consists of a nylon-reinforced butyl rubber dam supported in a metal frame designed to fit the ditch cross section. In the closed position, the top edge of the flexible dam is supported by a drawstring threaded through grommets. A 1/8-in. plastic-covered steel cable is used for the drawstring. The drawstring is released at the end of the desired irrigation period by the special timer previously described. Schematic sketches illustrating a generalized procedure for designing check dams for various water depths and ditch sizes are presented in Appendix I.

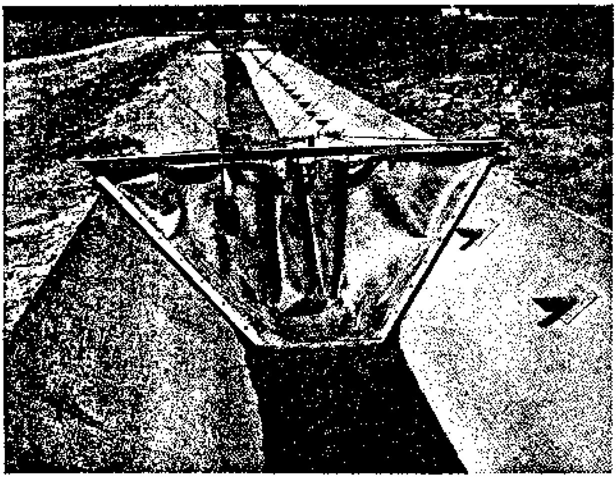


FIG. 1.—PORTABLE, TIMER-CONTROLLED IRRIGATION CHECK FOR LINED DITCHES

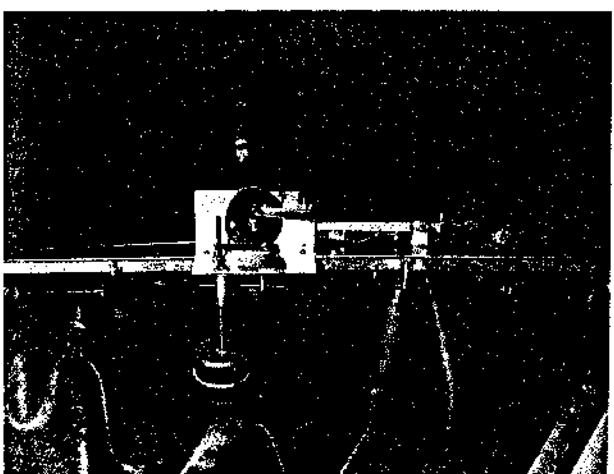


FIG. 2.—CLOSEUP VIEW OF TIMER WITH FLOAT-OPERATED ESCAPEMENT RELEASE AND ONE TYPE OF DRAWSTRING TRIPPING ASSEMBLY

The small float shown in Fig. 2 activates the timer escapement release when water fills the ditch immediately upstream from the check. The float may be constructed from plastic and also enclosed in a short section of pipe for protection.

The portable drawstring check is ideally suited for use in an automatic cutback furrow irrigation system (1)[2] (Fig. 3). When the check is used with this system, the number of acres one irrigator can manage may be increased up to ten or more times while keeping runoff to a minimum. However, it may be used in any system where it is desirable to release the water from one irrigation set to another. It may also be used with a companion structure to direct water from one ditch into another. The irrigator's labor may be utilized efficiently if enough checks are used so that they require moving only once or

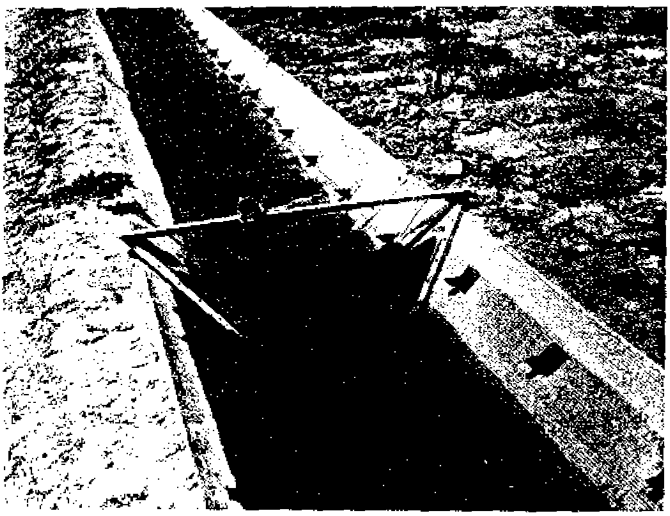


FIG. 3.—SEMI-AUTOMATIC PORTABLE CHECK BEING USED IN AUTOMATIC CUTBACK FURROW IRRIGATION SYSTEM

twice a day, depending upon the length of irrigation set. A check remaining in place or after being moved, may be reset in 1 min or less.

SEMIAUTOMATIC CHECK FOR UNLINED DITCHES

The drawstring portable check for lined ditches was modified in cooperation with an irrigation equipment manufacturer (The Swanson Company, Phoenix, Arizona) for use in an unlined ditch by adding cutoff walls. The basic structure is fitted with side wingwalls and a bottom cutoff as shown in Fig. 4 in place of the rubber seal around the edges. It is installed in the ditch at approximately 45°, the same as in a lined ditch, Fig. 5.

The first drawstring-type structures tested for unlined ditches were mounted on a vertical cutoff wall. These performed satisfactorily; however, they were usually more difficult to install than the check shown in Fig. 5. If the check were to be installed in a border dike, for example, or in the side of

[2] Numerals in parentheses refer to corresponding items in the Appendix II.—References.

a ditch, it might be desirable to mount it on a vertical headwall rather than at an angle as shown above. Design procedures for this variation and for a port-

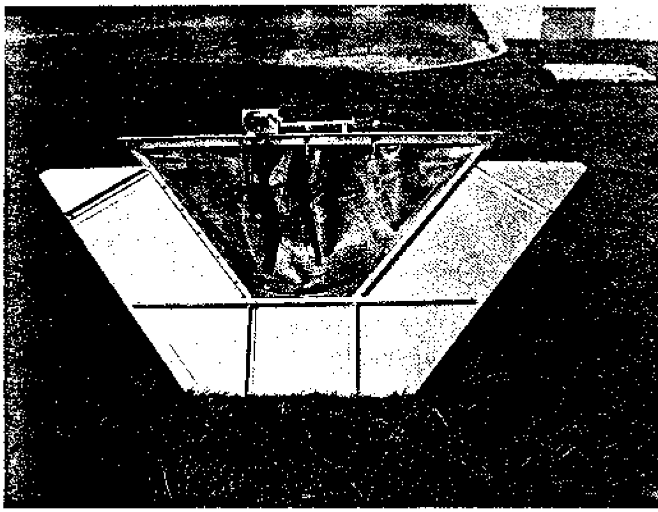


FIG. 4.—BASIC DRAWSTRING CHECK FITTED WITH SIDE WINGWALLS AND BOTTOM CUTOFF FOR USE IN UNLINED DITCH

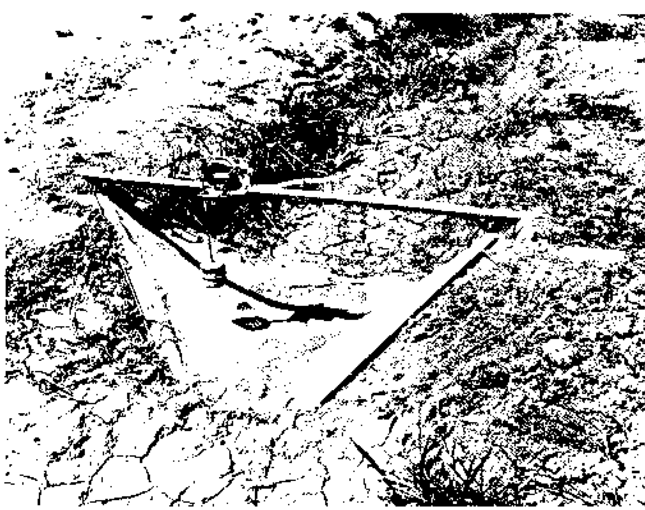


FIG. 5.—SEMIAUTOMATIC CHECK INSTALLED IN UNLINED DITCH

able unlined ditch check used in the same manner as the old canvas dam have been published (2).

The checks require protection when used in fields where cattle or other livestock are present because both the flexible dam and the timers may be damaged by livestock.

PRESSURE GATE

A trapezoidal check gate was developed using the principle of hydrostatic pressure distribution and the resultant center-of-pressure force for tripping. This gate, shown in Fig. 6, has a horizontal pivotal axis located above the ditch bottom a vertical distance of approximately 0.32 times the water depth at which the gate opens. It is fully automatic when fitted with a counterweight as shown. When the water level on the upstream side of the gate rises to a height such that the resultant force from the water pressure is above the pivotal axis, the gate opens automatically and remains open as long as the water flows over it. When water is turned from the ditch or an upstream gate closes,

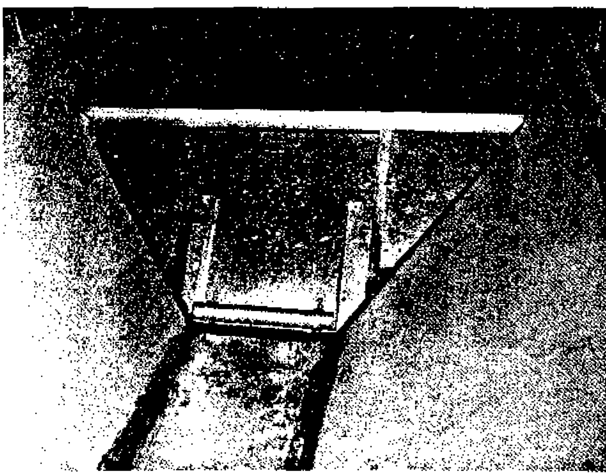


FIG. 6.—TRAPEZOIDAL PRESSURE GATE FOR USE IN LINED DITCHES

the gate automatically returns to its normally closed position. This check gate is ideally suited for use with companion structures where approximately 1-1/2 in. or more rise in the water surface is available for tripping the gate. If the normal water depth is near the gate tripping depth, the gate approaches a near-balanced position and leakage occurs.

The design procedure and basic dimensions for constructing pressure gate checks to fit most irrigation ditches are presented in the Appendix. Additional tests are being conducted to evaluate different methods of construction and gate sealing. The same basic check may be used in an unlined ditch as shown in Fig. 7 by replacing the rubber seals on the outside edges with a sheet metal cutoff similar to that shown in Fig. 4.

The pressure gate may be used in a semiautomatic system having either lined or unlined ditches with drop gates which are described in the following section. It is shown being used in a lined ditch with a timer-controlled drop gate in Fig. 8. It is well adapted for use in a fully automatic border irrigation system with sinking float border turnout gates as reported elsewhere (3). The pressure gate can also serve as a safety structure to admit water into a

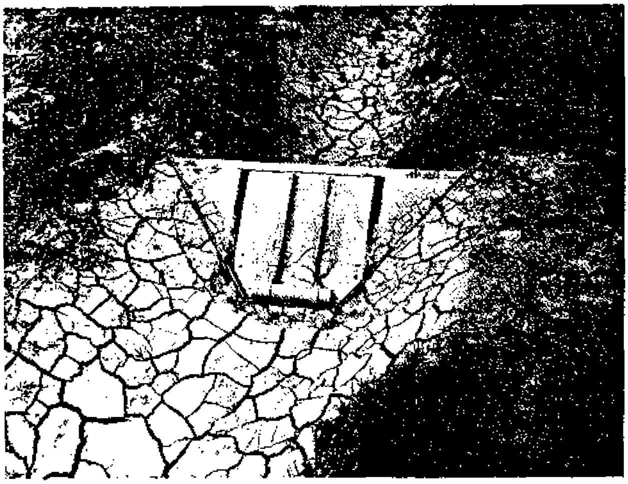


FIG. 7.—TRAPEZOIDAL PRESSURE GATE FOR UNLINED DITCH

FIG. 8.—PRESSURE GATE BEING USED IN LINED DITCH WITH TIMER-CONTROLLED DROP GATE IN FIELD TURNOUT

drainage channel or wasteway when the water level in a ditch, canal or reservoir exceeds a safe level. When used for this purpose, it is usually rectangular and is mounted on a vertical cutoff wall rather than constructed as previously shown. Used as a safety gate, it may be designed to completely drain a channel or it may be used to keep the maximum water surface within certain limits. A disadvantage of the gate is its susceptibility to clogging by weeds or other floating debris.

DROP GATE

The drop gate structure is hinged at the top, and in the open position is suspended over the top of the ditch as shown in Fig. 9. It may also be sus-

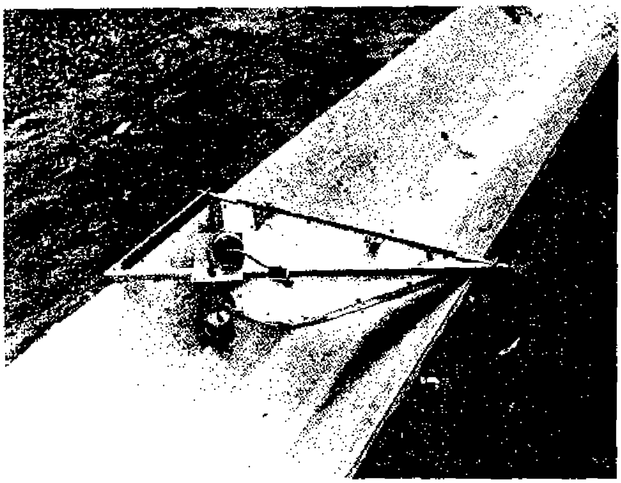


FIG. 9.—TRAPEZOIDAL DROP GATE FOR LINED DITCHES

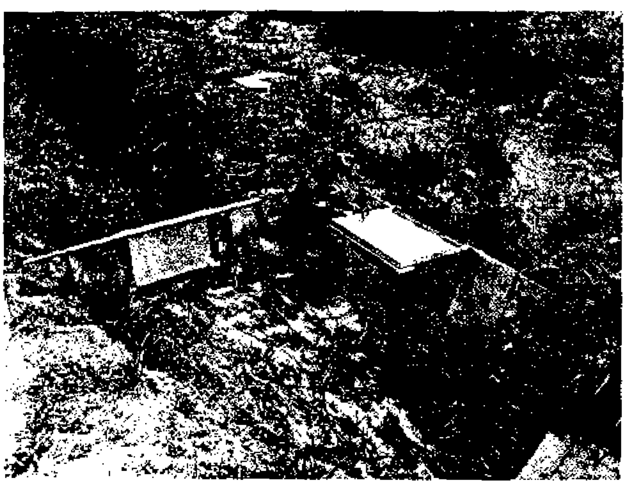


FIG. 10.—RECTANGULAR, TIMER-CONTROLLED DROP GATE (RIGHT) INSTALLED IN UNLINED DITCH WITH COMPANION RECTANGULAR PRESSURE GATE

pended in a near-vertical position such that when it is released it falls by its own weight and stops the flow of water in the ditch or through the turnout where it is placed. This gate has been used with alarm clocks more commonly than any other type of structure for automatically diverting water from one ditch to another, or from a head ditch into the field. It may be mounted and tripped in a variety of ways so that none may be classed as typical. For use in lined ditches, it may be constructed as shown in Fig. 9 using dimensions shown in Table 2 in the Appendix. It may also be designed for use with conventional turnouts from the side of a lined ditch. Gates for unlined ditches may be constructed: (1) Similar to that shown in Fig. 10 and mounted on near-vertical headwalls; (2) trapezoidal in shape and installed in a sloping position in the same manner as the pressure and drawstring checkgates described above; (3) mounted on a frame which in turn fits into the checkboard guides or slots of conventional irrigation structures; or (4) mounted on the inlet end of a pipe turnout.

A simple and relatively economical automatic irrigation system results when the drop gate is used with the pressure gate. When used together, the drop gate is placed in the turnout to the field and the pressure checkgate is placed in the head ditch. (See Fig. 10.) The drop gate is tripped by a mechanical timer, a float, or an electric solenoid. When released, the flow of water into the field stops; the water level in the ditch rises; the pressure gate automatically opens; and water flows to the next pair of gates where the operation is repeated. Thus irrigation proceeds down the ditch, irrigating each portion of the field in sequence. The gates may also be operated in the same manner to automatically divert water from one supply ditch to another.

When the gate positions are reversed from that previously described irrigation proceeds from the lower end of the ditch towards the upper end. A disadvantage of this method is that the ditch is left partially full of water at the completion of an irrigation. Also, in areas where flooding occasionally occurs, the head ditch cannot pass flood waters.

METAL APRON GATE

A timer-controlled metal apron gate installed in an unlined ditch is shown in Fig. 11. The basic structure consists of a sheet metal gate hinged at the bottom and mounted on a cutoff wall. This structure is used in the same manner as the drawstring check. When the gate latch is released by the timer, the gate opens and forms an apron in the bottom of the ditch below the headwall. This gate, as well as the drop gate, may be constructed with an overflow to bypass part of the stream.

WATER LEVEL CONTROL CHECKS

Proportioning may be needed in some systems where water is diverted into two or more ditches simultaneously. This may be accomplished by using water level control checks as shown in Fig. 12. When used in pairs, one check has an orifice opening while the other has an overflow weir-type opening. The check with the orifice opening is placed in the ditch requiring the greatest precision in water control. Commercial checks may also be obtained in various designs to accomplish the same purpose. Automatic control structures are placed behind the water level control checks and operate independently.

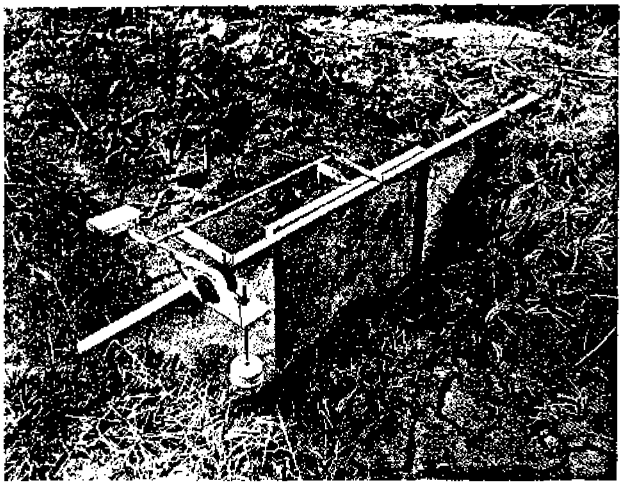
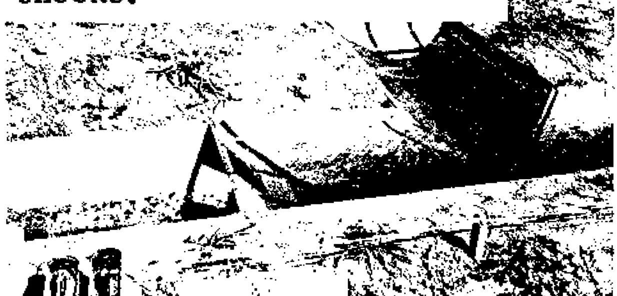


FIG. 11.—METAL APRON GATE FOR UNLINED DITCH

The lower photograph, Figure 12, is entitled: Drawstring check being used at a flow diversion where water is proportioned with water level control checks.



SYSTEMS OPERATION

Certain operational problems are more important and require greater emphasis with automatic structures than with conventional systems. For instance, greater attention must be given to rodent control to avoid ditch washouts. Gopher mounds in furrows or corrugations in the field cause unequal water distribution. An irrigator would normally remove these while irrigating if he were in the field. Ditches must also be kept clean and weed free to prevent overtopping when an irrigator is not present and to maintain constant water levels in the ditch. Constant water levels are necessary from one irrigation to the next to obtain uniform water distribution from previously adjusted controls. Automatic structures that are controlled by the depth of water, such as the pressure gate, are affected by unpredicted variations in the water level caused by weedy or partially clogged ditches. The overgrown weeds themselves may interfere with the structure's normal operation. Where weeds are a problem, it may be necessary to install a weed-screening device.

Tillage practices may have to be altered to some extent with automatic irrigation systems. For example, unequal tractor wheel or other farm machinery traffic in row crops changes the intake rate from one furrow to another. Greater attention must be given to distributing this traffic as evenly as possible in all furrows to minimize intake rate variations. This becomes important if the operation is performed when the soil is wet. With an automatic furrow irrigation system, it is difficult to compensate for these variations.

COSTS

The per acre cost for automatic irrigation structures will vary with the method of irrigation, soil, topography, cropping practice, water supply and other factors. Because the structures described herein were made for experimental testing, their costs would not be indicative of commercial production. Quantity buying, streamlined assembly procedures, and profit and sales costs are factors that will influence costs when produced commercially. The structures are relatively simple to construct, and may be made in most farm

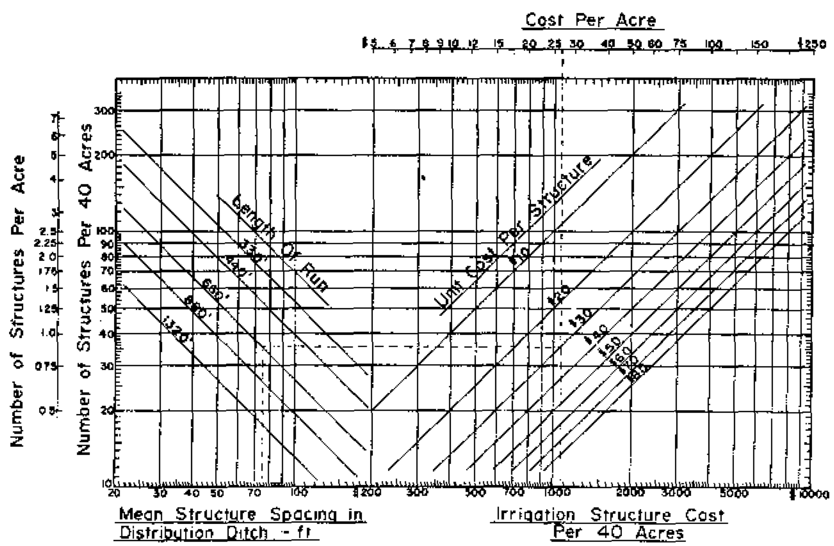


FIG. 13.—IRRIGATION STRUCTURE COST FOR DIFFERENT STRUCTURE SPACINGS, UNIT COSTS AND LENGTHS OF RUN

shops at a materials cost varying from approximately \$5.00 to \$20.00 each. Some items, however, such as the special timer, are easier and cheaper to obtain in large quantities.

The per acre cost and cost for a square 40-acre field for different structure spacings, length of irrigation runs, and unit structure costs may be estimated from Fig. 13. These values represent the cost of one structure installed at each turnout of irrigation set. If portable structures are used, which serve more than one set, or if more than one structure is used, i.e. used in pairs, the cost per unit of area will be respectfully reduced or increased proportionately.

SUMMARY

Mechanical, automatic irrigation structures are being developed to improve surface irrigation methods and systems. These are being tested for use in various types of irrigation systems and include both timer-controlled and automatic water-pressure-controlled structures. A specially designed mechanical timer is being tested for controlling automatic irrigation checks and gates.

Generalized design information is presented for a semiautomatic timer-controlled check for both lined and unlined ditches. This structure is ideally suited for use in an automatic cutback furrow system. Runoff water is kept to a minimum and irrigating labor is practically eliminated when the check is used in this system.

A pressure gate which opens and closes automatically when the water depth in the supply ditch approaches certain limits is also described. Other structures include a drop gate, metal apron gate and water level control checks. Certain operational problems such as rodent and weed control, and certain tillage practices, require greater emphasis with automatic irrigation than with conventional systems.

ACKNOWLEDGMENTS

This paper is a contribution from the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture; Idaho Agricultural Experiment Station cooperating. Company names are included for the benefit of the reader and do not imply endorsement of preferential treatment of the products listed by the U.S. Department of Agriculture.

APPENDIX I.—SUPPLEMENTAL DESIGN INFORMATION

Semi-Automatic Drawstring Check.—The design procedure for the drawstring-type checks has been modified from that presented earlier (2) by designing for a given water depth rather than for a certain size ditch. Generalized design and construction details are shown in Figs. 14, 15 and 16 in which the symbols used are defined in Appendix III.—Notation.

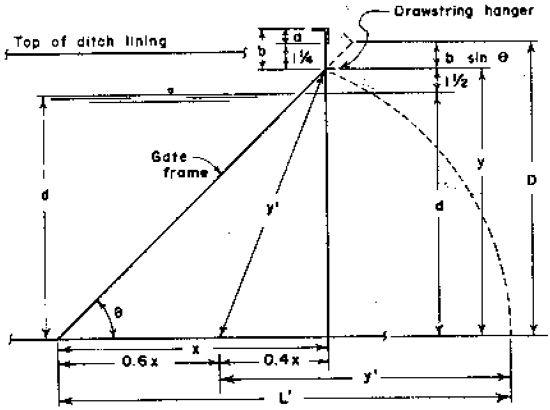


FIG. 14.—GENERALIZED DESIGN AND DEFINITION SKETCH OF BASIC DRAWSTRING SEMIAUTOMATIC IRRIGATION CHECK

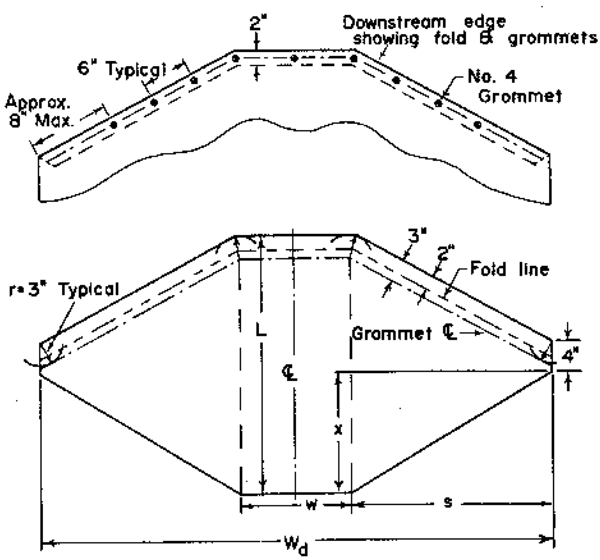


FIG. 15.—FLEXIBLE DAM DETAIL FOR DRAWSTRING CHECK

Basic dimensions for automatic checks for water depths from 12 in. to 20 in. are presented in Table 1. These fit in the ditch with an angle θ between the frame and ditch invert of 45°. Structures tested in the field were stable in concrete ditches when θ = 50°; however, because they tended to slide easily in smooth, steel-lined ditches at this angle, it is recommended that θ = 45° be standard for all checks.

Some concrete-lined ditches are constructed with a radius at the corners of the invert. Structures for this type of ditch would also be made with a corresponding radius at the lower corners. When used in an unlined ditch, the supporting frame is constructed with an angle, rather than a rectangular flat member (Fig. 16).

Automatic checks constructed with a nylon-reinforced butyl rubber flexible dam have been in service for 3 yr without any noticeable deterioration. Flex-

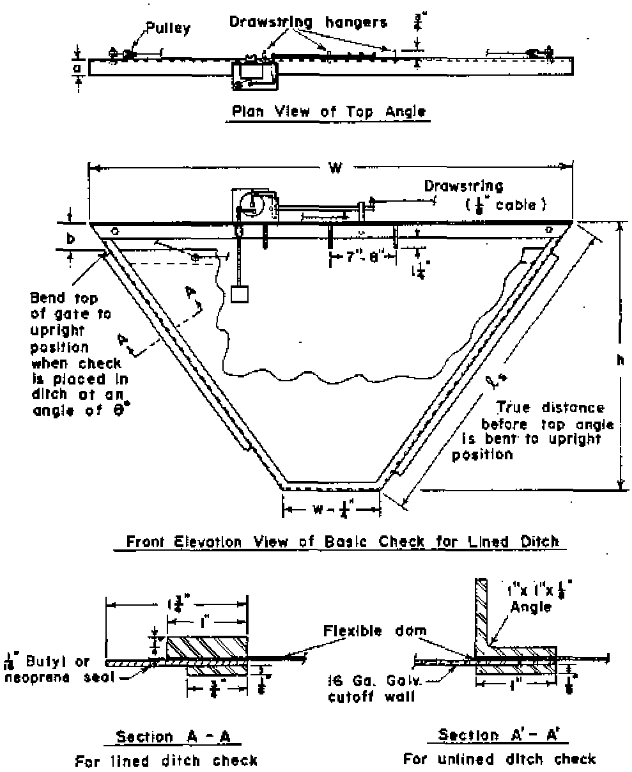


FIG. 16.—DESCRIPTIVE DRAWING OF BASIC SEMIAUTOMATIC DRAWSTRING IRRIGATION CHECK

ible dams made from lighter neoprene-impregnated nylon had to be replaced at the end of the second season because many small pinholes developed. The portable checks were first tested without a separate rubber seal along the edges. The flexible dam material was extended beyond the frame of the check to form this seal. This was satisfactory when the checks were used in a smooth surfaced ditch constructed true to shape with plane surfaces. However, it is recommended that a rubber seal be used along the sides. Even if the extra rubber seal is not used on the sides of the check it should be used on the bot-

TABLE 1.—DESIGN VALUES FOR AUTOMATIC DRAWSTRING CHECKS FOR VARIOUS WATER DEPTHS[a]

Design water depth d (1)	Basic Structure Dimensions, in inches[b]							
	a (2)	x (3)	s (4)	L (5)	W_d (6)	W (7)	h (8)	l_s (9)
12	1-$\frac{1}{4}$	13-$\frac{1}{2}$	19-$\frac{1}{8}$	26-$\frac{5}{8}$	50-$\frac{1}{4}$	42-$\frac{1}{2}$	21-$\frac{5}{8}$	26-$\frac{7}{16}$
14	1-$\frac{1}{4}$	15-$\frac{1}{2}$	21-$\frac{7}{8}$	30	55-$\frac{3}{4}$	46-$\frac{1}{2}$	24-$\frac{3}{8}$	29-$\frac{7}{8}$
16	1-$\frac{1}{2}$	17-$\frac{1}{2}$	24-$\frac{3}{4}$	33-$\frac{3}{8}$	61-$\frac{5}{8}$	50-$\frac{7}{8}$	27-$\frac{9}{16}$	33-$\frac{3}{4}$
18	1-$\frac{1}{2}$	19-$\frac{1}{2}$	27-$\frac{5}{8}$	36-$\frac{3}{4}$	67-$\frac{1}{4}$	54-$\frac{7}{8}$	30-$\frac{3}{8}$	37-$\frac{3}{16}$
20	2	21-$\frac{1}{2}$	30-$\frac{3}{8}$	40	72-$\frac{3}{4}$	59-$\frac{5}{8}$	33-$\frac{5}{8}$	41-$\frac{1}{4}$

[a] Bottom width, w, of ditch = 12 in.; ditch side slope, ϕ, = 45°; and angle of structure in ditch, θ, = 45°.
[b] See Figs. 14, 15, and 16 for symbols.

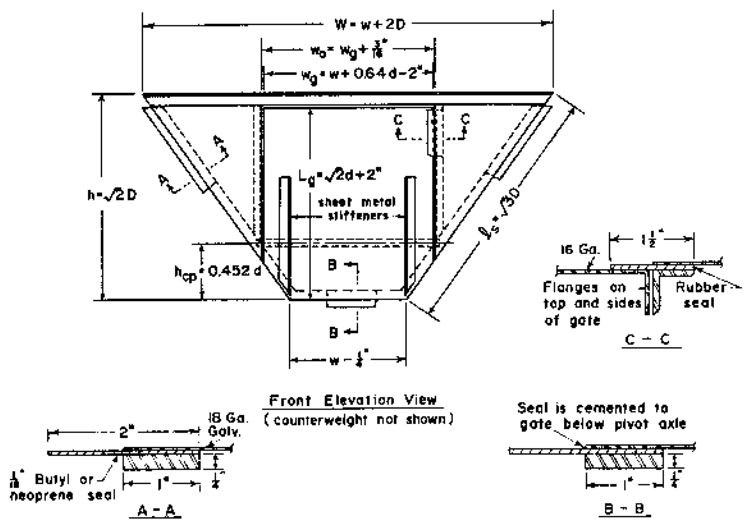


FIG. 17.—GENERALIZED DESIGN AND DEFINITION SKETCH OF TRAPEZOIDAL PRESSURE GATE FOR LINED DITCHES

tom, because the flexible dam material wears rapidly at the lower corners when extended beyond the frame.

Pressure Gate.—Fig. 17 shows a generalized design for the pressure gate. Basic dimensions for constructing the gate for water tripping depths from 12 in. to 18 in. are shown in Table 2. The gate may be designed to open at depths not shown in the table by placing the pivotal axis above the bottom of the ditch or opening a vertical distance of approximately 0.32 times the water tripping depth. The gate may be counterbalanced by a solid metal bar at its lower edge as shown in Figs. 6 and 7 or by a constant force return spring. The counterbalance force should exceed the weight required to balance the gate to provide a positive return. For unlined ditches, the frame is

TABLE 2.—BASIC DIMENSIONS OF AUTOMATIC IRRIGATION CHECKS AND GATES FOR TRAPEZOIDAL LINED DITCHES FOR DIFFERENT WATER DEPTHS[a]

Design water depth d (1)	Basic Structure Dimensions, in inches[b]								
	D (2)	a (3)	W (4)	h (5)	l_s (6)	h_{cp} (7)	w_g (8)	w_b (9)	L_g (10)
12	14-$\frac{1}{2}$	1-$\frac{1}{4}$	41	20-$\frac{1}{2}$	25-$\frac{1}{8}$	5-$\frac{7}{16}$	17-$\frac{11}{16}$	17-$\frac{7}{8}$	19
14	16-$\frac{1}{2}$	1-$\frac{1}{4}$	45	23-$\frac{1}{4}$	28-$\frac{5}{8}$	6-$\frac{5}{16}$	18-$\frac{15}{16}$	19-$\frac{1}{8}$	21-$\frac{3}{4}$
16	18-$\frac{1}{2}$	1-$\frac{1}{4}$	49	26-$\frac{1}{8}$	32	7-$\frac{1}{4}$	20-$\frac{1}{4}$	20-$\frac{7}{16}$	24-$\frac{5}{8}$
18	20-$\frac{3}{4}$	1-$\frac{1}{2}$	53-$\frac{1}{2}$	29-$\frac{3}{8}$	36	8-$\frac{1}{8}$	21-$\frac{1}{2}$	21-$\frac{11}{16}$	27-$\frac{1}{2}$

[a] Bottom width, w, of ditch = 12 in.; ditch slope, ϕ, = 45°, and angle of structure in ditch, θ, = 45°.

[b] See schematic sketches for symbol notations.

constructed with an angle instead of the rectangular flat member shown in Fig. 17.

APPENDIX II.—REFERENCES

1. Garton, James E., "Designing an Automatic Cut-back Furrow Irrigation System," *Oklahoma State University Experiment Station Bulletin B-651*, Oct., 1966.
2. Humpherys, Allan S., "Control Structures for Automatic Surface Irrigation Systems," *Transactions*, American Society of Agricultural Engineers, Vol. 10, No. 1, 1967, pp. 21, 22, 23, and 27.
3. Humpherys, Allan S., "Automatic Mechanical Irrigation Gates," *International Commission on Irrigation and Drainage. Seventh Congress on Irrigation and Drainage*, Question 24, Report 17, Mexico City, Apr., 1969, pp. 24.251-24.261.

APPENDIX III.—NOTATION

The following symbols are used in this paper:

w = bottom width of ditch channel, in inches;
d = design water depth, in inches;
ϕ = ditch side slope, usually = 45°;
θ = angle at which the check is placed in the ditch, 45° recommended;
$y = d + 1\text{-}1/2$ in.;
$x = y/\tan\,\theta$;
$y' = [(0.4\,x)^2 + y^2]^{1/2}$;
$L' = 0.6\,x + y'$;
$L = L' + 4$ in.;
$s = y/\sin\,\phi$;
$W_d = 2s + w$;
a = width of top angle, in inches;
$b = a + 1\text{-}1/4$ in.;
$D = y + b\,\sin\,\theta$;
$W = w + 2D/\tan\,\phi$;
$h = D/\sin\,\theta$ = slope distance of upstream side of check; and
$l_s = h/\cos\,[\tan^{-1}(D/\tan\,\phi/h)]$.