

SEMI-AUTOMATION OF IRRIGATED BASINS AND BORDERS:

II. DUAL-FUNCTION TURNOUT GATES

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ABSTRACT. Four types of dual-function gates were used to semiautomate basin and border irrigation systems. These gates open to admit water to a field and then close to terminate irrigation. They were released or tripped by timers, electric solenoids or a trip-cord gate release system. Gate descriptions and construction information are presented for (1) dual-panel combination gates, (2) butterfly gates, (3) linear actuator-operated jack gate, and (4) pipe turnouts in unlined ditches. The gates were field tested in different basin and border systems. An improved border system with combination gates reduced irrigation time from five half-days to two, compared to the previous system which used siphon tubes. On a manual basis, prior to completion of the control system, irrigation application efficiency was 68%. A battery-powered linear actuator was an effective means of semiautomating a jack gate. A drop-closed gate on the inlet and a flexible drop-tube on the outlet of a pipe turnout provided a low-cost means of semiautomating irrigation in unlined ditches. **Keywords.** Surface, Irrigation, Gates, Semiautomation, Ditch turnouts.

Semiautomation of surface irrigation can improve irrigation water management by increasing water application efficiencies, decreasing labor requirements, and providing greater operator convenience. It can help alleviate overirrigation and, thus, decrease deep percolation with its accompanying nutrient leaching, drainage, and other ecological problems. Soil movement from a field caused by excessive runoff can also be reduced. Irrigators often convert to sprinkler systems for greater convenience and to save labor. However, increasing energy costs and capital expenditures are major concerns, particularly in developing countries which traditionally use surface flooding methods. Semiautomated systems require manual input to either turn water into and out of the system at the beginning and end of irrigation or to reset or move system components from one position or location to another. Control devices can be moved from one gate to another to minimize costs. Gates and related equipment for automating or semiautomating basin and border irrigation are generally not available commercially. The gates described in this article were developed and tested to obtain design and performance information.

Basin and border semiautomated systems use two general types of gates, single- and dual-function. Single-function gates either open or close when tripped and are manually reset. Gates of this type were described previously (Humpherys, 1995a).

Dual-function gates described in this article perform two functions: (1) open to admit water to a field, and (2) close

to terminate irrigation. They are normally used in low-gradient head ditches with elevation differences too small for consecutive turnouts or groups of turnouts to be *stairstepped*. Fields that are most feasibly irrigated by surface flooding methods have very little side slope and, check gates in the supply ditch are usually spaced with more than one irrigation set in-between. The ditch remains full as irrigation proceeds from set-to-set between ditch checks. Dual-function gates are required to admit water to the field and to stop irrigation without a change in the water surface elevation or depth in the supply ditch. Dual-function gates made in different styles and configurations are described by various investigators (Bowman, 1969; Dedrick and Erie, 1978; Haise et al., 1980; Humpherys, 1986).

The purpose of this article is to describe several types of semiautomated dual-function gates tested in different surface irrigation systems and to present design and construction information from the tests.

GATE DESCRIPTIONS, INSTALLATION AND OPERATION

The first three types of gates were tested in concrete-lined supply ditches for border irrigation systems at Eskdale, Utah (fig. 1), and a level basin system near Delta, Utah.

COMBINATION GATE

This gate was developed and tested in conjunction with a trip-cord gate release system. It is a rectangular, dual-panel gate consisting of a drop-open gate and a drop-closed gate mounted on the same frame. In operation, the drop-open gate on the downstream side of the frame opens to begin irrigation and the drop-closed gate on the upstream side closes to terminate irrigation. The drop-closed gate is the same as that used as a single-function gate described previously (Humpherys, 1995a). Combination gates being tested in a border irrigation system are shown in figure 2.

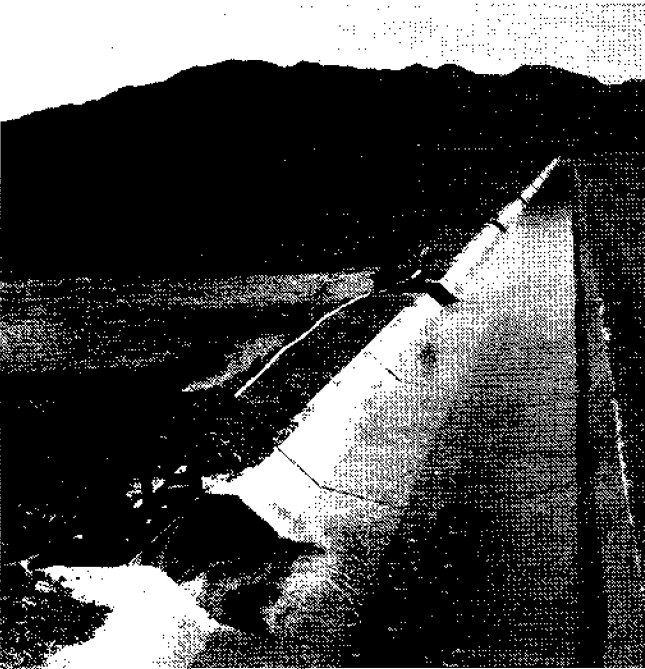
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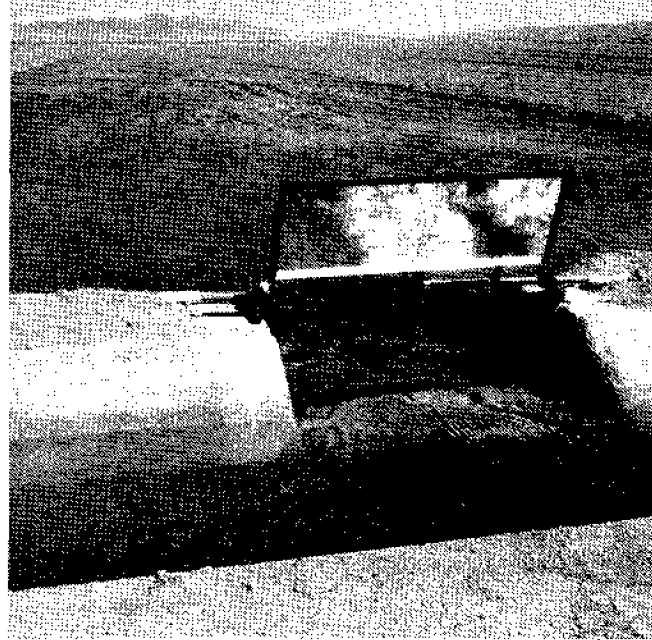


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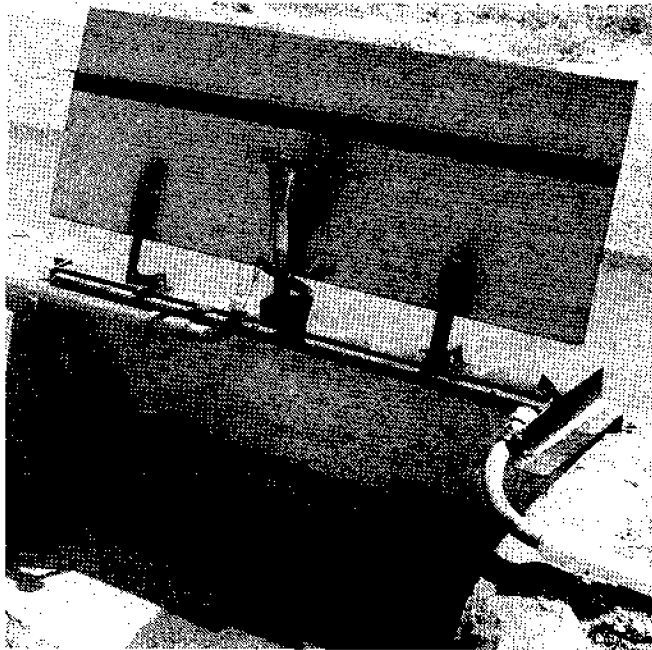
Figure 1—View of ditches at Eskdale, Utah, where dual-function gates were tested in border systems: (a) lateral no. 3 before irrigation, and (b) lateral no. 1 during irrigation.

Construction. Construction details for the drop-open gate component are shown in figure 3 for ditch turnout openings from about 30 to 50 cm (12 to 20 in.) deep and up to 108 cm (42 in.) wide. The gates tested were in this size range; larger gates need to be made with larger structural components.

The gate frame is made with 50 mm (2 in.) wide steel channel members on the sides and bottom, and a steel



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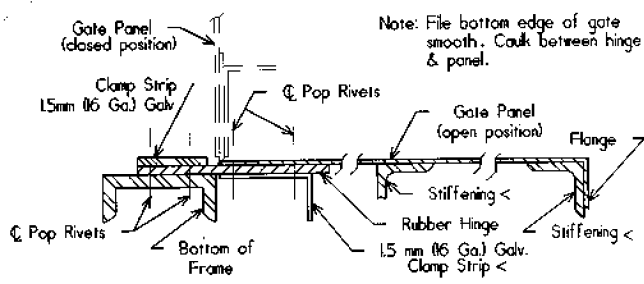


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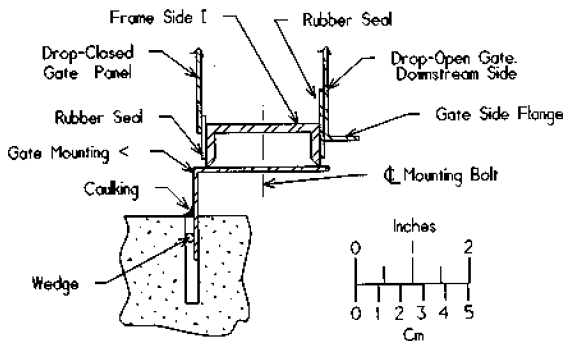
Figure 2—Dual-panel combination gate: (a) upstream view during irrigation, and (b) downstream view.

angle at the top. Steel angles bolted to the sides of the frame are used to install and adjust the gate in vertical slots in concrete ditch turnout openings.

The panel for the drop-open gate is constructed from 1.5 mm (16 gage) galvanized steel. It is hinged to the bottom of the frame with a nylon-reinforced, neoprene rubber hinge as shown in figure 3. Gates in relatively shallow or narrow turnouts do not require the additional stiffening angle located about one-third the gate height above the bottom of the gate on its back side. Rubber seals



Side Section View Through Gate & Frame Bottom



Plan Section View - Side of Gate

Figure 3—Section views of the drop-open gate component of a combination gate.

between the gate and frame are the same, or similar to, those used on drop-closed gates (extrusion no. 1169, Rubbercraft Corp. of California, Torrance, Calif. and extrusion no. ZX-10086, Minor Rubber Co., Bloomfield, N.J.), and are fastened with a high-quality weather strip adhesive (part no. 8, Master Chemical Corporation, Memphis, Tenn.).

The gates are released or tripped by either a trip-cord gate release system, as shown in figure 2b, by timers, or by both, as shown in figure 4. The gate latch and release mechanism for a trip-cord-released drop-open gate are shown in figure 5 and for an electric solenoid-released gate in figure 6. The trip arm and latch finger are mounted on an upright post attached to the gate frame (figs. 5 and 6) and extended to the rear. The upright post is also used to support timers when they are used. An extension arm attached to the side of the gate panel transfers motion to the nylon roller on the lever shown in figure 7 to operate a trip cord.

Operation. The trip-cord gate release system utilizes the motion and energy of either an opening or a closing gate to release or trip an adjacent gate by means of a buried trip cord connecting the two gates. Details and description of this release system are presented in another article (Humpherys, 1995b). The trip cord, attached to a lever on the drop-open activating gate, is pulled when the gate opens to trip an adjacent gate.

Timers are portably mounted so they can be moved from gate to gate. A male post attached to the timer backplate fits into a mating female receptacle (fig. 4). When combination gates are released by both a timer and trip cord, the drop-open gate is released first by a timer to begin irrigation and the drop-closed gate is released by trip cord

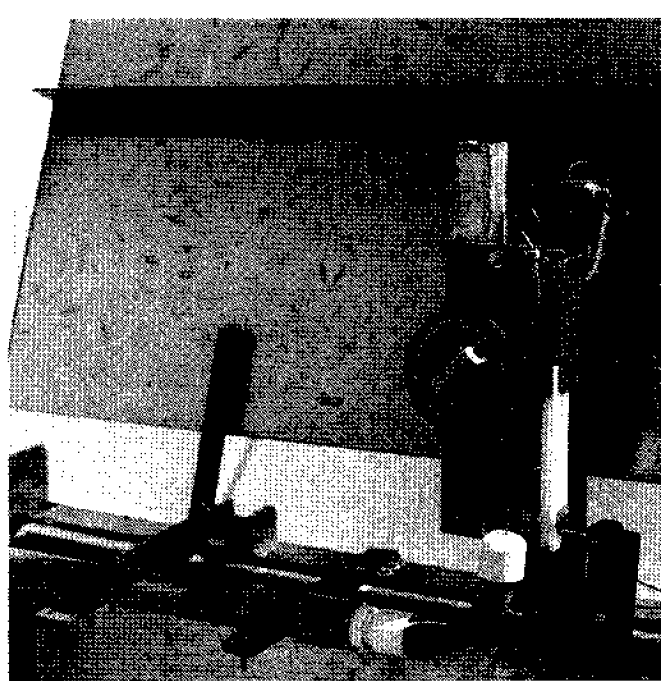


Figure 4—Photo of a trip-cord-released latch on the drop-closed gate component and a timer-released latch on the drop-open gate component of a combination gate. Note the mounting posts on the back of the timer for dual-position use and the female timer mount receptacle at the bottom of the timer into which a male post fits.

from the next adjacent gate to terminate irrigation (fig. 4). Both release mechanisms are mounted on the upright post. Timer mounting and release mechanisms are not shown in detail for the timers because they must be adapted to the specific timer used. The timers presently used are no longer available.

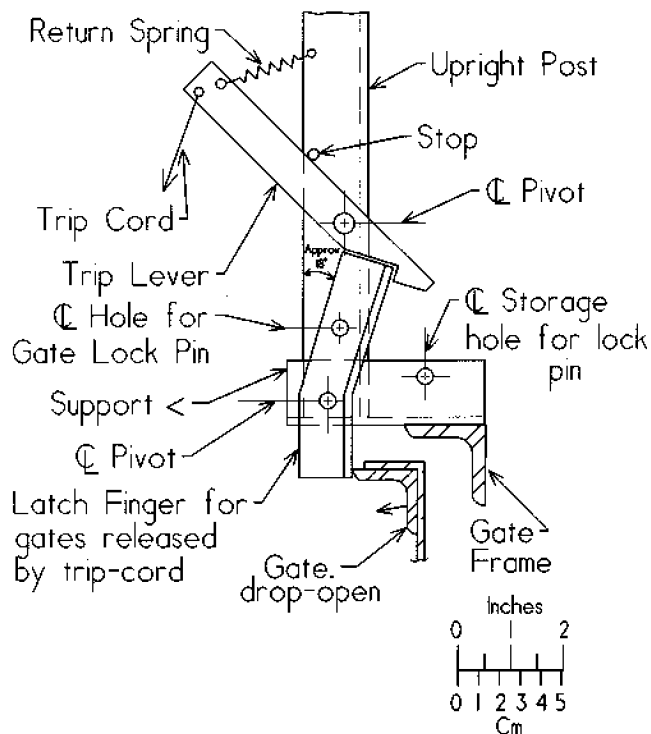


Figure 5—Diagram of a gate latch and release mechanism for a trip-cord-released drop-open gate.

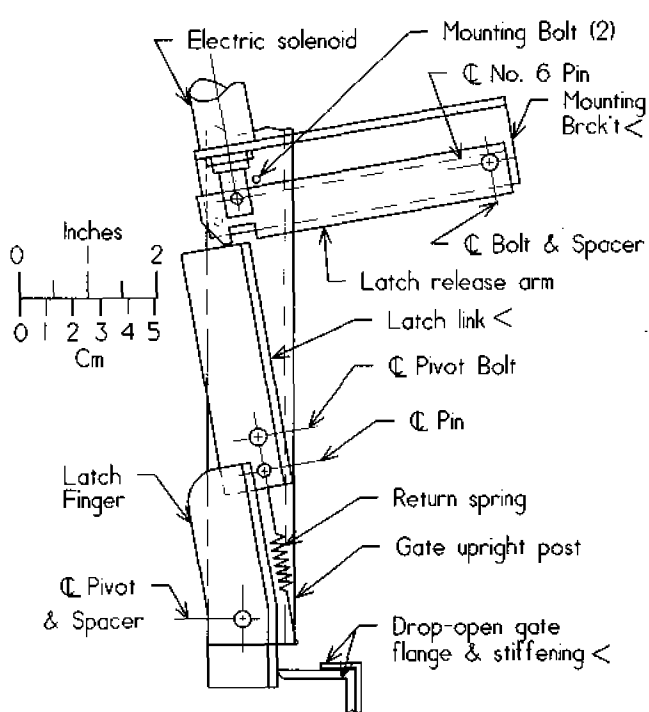


Figure 6—Diagram of a gate latch and linkage for an electric solenoid-released drop-open gate.

Installation and testing. Slots for mounting the gates in ditch turnout openings sometimes may not be exactly vertical. The mounting angles bolted to the sides of the gate may need to be adjusted to orient the gate vertically. The gate is sealed in the turnout by caulking (plan view, fig. 3). In some cases, a small wedge may be needed to hold the frame tightly in the gate slots to prevent gate movement, which could rupture the caulking seal.

Care is needed when constructing ditch turnouts that their inverts be level and without humps or irregularities which could interfere with good gate seating. Sidewall grooves for gate mounting need to be vertical. Rectangular concrete turnouts also need adequate support and cutoff-wall depth to prevent settling and cracking of the concrete lining near the turnout entrance.

Seventy-seven gates were installed during 1991 and 1992 in three border systems at Eskdale, Utah. They were installed in rectangular turnout openings in the side of

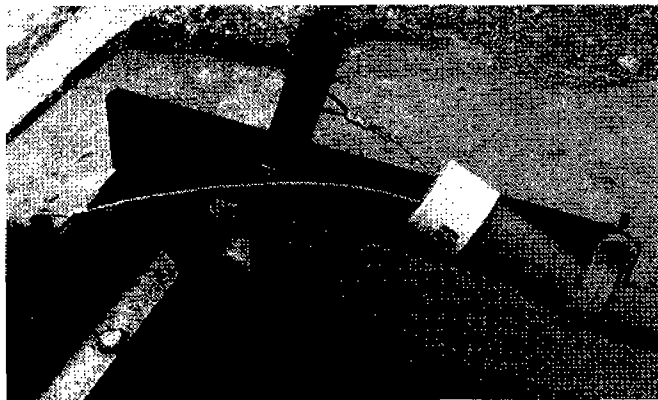


Figure 7—Lever mechanism for pulling a trip cord when the actuating drop-open gate opens.

concrete-lined supply ditches (fig. 1). Lateral no. 1 is 150 m (500 ft) long with zero slope. Fourteen gates were installed in this ditch at 12 m (40 ft) spacings. Since the ditch is relatively short and has zero slope, check gates were not required. Thirty-eight gates were similarly installed in lateral no. 2 which is a 460 m (1500 ft) long flat ditch with two 0.061 m (0.2 ft) elevation drops at 140 m (450 ft) intervals. A center-of-pressure check gate (Humpherys, 1991) was placed in the ditch at each drop. Twenty-five gates were installed in newly constructed turnouts in an older concrete-lined ditch, lateral no. 3. This ditch has a slope of 0.085% and requires check gates between every two borders with four turnouts between each check. Since there are two turnouts for each 24 m (80 ft) wide border, the gates are operated in pairs. The first gate is opened by a mechanical timer, which in turn opens its companion gate by trip cord. The gates, in general, are closed with the trip-cord system by the opening or closing action of the next gate or pair of gates in the operating sequence.

The gates were operated manually during 1991 and 1992 because the control system was not fully completed until after the second irrigation season. The fields were leveled just prior to the first irrigation in 1991. Irrigation the first year with the improved system, even without timer control, reduced the required irrigation time for the two fields from five half-days to two with an average field application efficiency of 68%. The gates performed well. The only problem encountered occurred at some turnouts in the older, sloped lateral no. 3 where the variable ditch slope resulted in unequal water depths and flows between the two turnouts of a pair flowing simultaneously into one border. This was solved by placing a low baffle plate between the drop-closed and drop-open panels of the gate in the downstream turnout to provide more uniform flows between the two turnouts.

Fabrication costs per gate on a piecemeal basis in a small shop were approximately \$150 excluding the cost of the timers.

BUTTERFLY GATE

The butterfly gate (shown in fig. 8) is a sheet metal panel which rotates with a horizontal pivot shaft mounted on top of a frame. The gate panel is made from 1.5 mm (16 gage) galvanized steel with 25 mm (1 in.) stiffening flanges on three sides and a steel stiffening angle extending from top-to-bottom in the center of the gate (as shown in figs. 8 and 9). The panel is bolted at its center to a horizontal pivot shaft on top of the gate frame. The shaft is made from 13 mm (1/2 in.) nominal diameter galvanized pipe whose ends extend through oblong holes in steel supported angles welded to the top of the frame's side mounting angles. The oblong shaft holes are needed to allow the panel to self-align from one closed position to the other. Rubber seals, cemented to three sides of the gate panel and the downstream sides of the frame, are the same as those used on drop-closed gates (Humpherys 1995a).

The gate frame is similar to that for a drop-closed gate and is made from 25 mm (1 in.) steel channel (fig. 9). The steel channel which forms the bottom of the frame is raised about 19 mm (3/4 in.) from the bottom of the turnout opening with a wood spacer to provide clearance for the gate clamp rod and lever arm. The clamp rod has a bar, or



Figure 8-Butterfly-type dual-function gate.

steel angle stiffener, welded to it (fig. 10). A lever arm welded to one end of the clamp rod is held in its closed position by the first trip latch (as shown in fig. 11).

The gate panel is positioned vertically on the downstream side of the gate frame in its original position. When the first latch finger (shown in fig. 11) is lifted by a trip cord, solenoid or timer, the lever arm falls to its gate-open position, assisted by the force of the opening gate on the clamp rod. The gate is pushed to its open, horizontal position (fig. 8) by water on its upstream side to begin irrigation. It is restrained in this position by the second latch (fig. 11). The end of the gate panel on one side is weighted (figs. 8 and 9) to provide a closing moment so that when the second latch is released, the panel rotates another 90° to its second closed position on the opposite (upstream) side of the frame to end irrigation. Thus, it acts similar to a drop-closed gate. The gate rotates from its

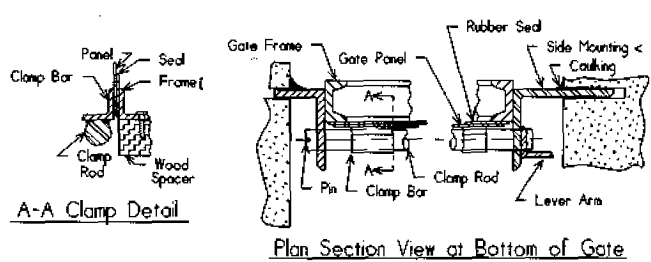


Figure 10-Diagram showing the butterfly gate clamp and mounting details.

closed-to-open-to-closed positions through 180° as the two latches are sequentially released. The gate is reset manually by rotating it backwards to its original closed position. Functionally, there is little difference between the butterfly and combination gates. While the butterfly gate may be simpler to construct, a pull force for activating a trip cord is easier to obtain from a combination gate.

Experimental butterfly gates were installed in three turnout openings of a level basin near Delta, Utah, in 1987 and 1988 (fig. 8). They are simple to operate and satisfactorily controlled flow through the turnout. Several modifications were made during the testing period. Subsequently, the only problem was obtaining sufficient trip-cord travel to release the next gate. The trip cord and linkages must be finely adjusted to minimize slack in the system. Not enough gates were made to estimate fabrication costs on a production basis; however, the cost should be similar to that for combination gates.

LINEAR ACTUATOR-OPERATED GATE

Manually operated jack gates are commonly used both as field turnout gates and as check gates in basin systems where relatively large ditches and stream sizes are used. Operation of these gates can be automated by using a linear actuator to raise and lower the gate panel. A linear actuator was installed on a check gate in a head ditch (fig. 12). The actuator (Burr Engineering and Development Corporation, Battle Creek, Mich.) is powered by a 12-V auto battery and has a 61 cm (24 in.) stroke. Internal limit switches turn the actuator off at each end of its stroke. It has a load capacity range from 450 kg (1000 lb) to 800 kg (1750 lb) at

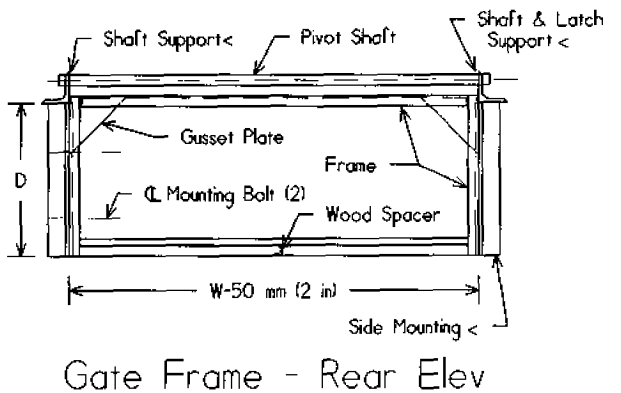


Figure 9-Diagram showing the frame and panel for a butterfly gate (D = depth of turnout opening, W = width of opening) (see also figs. 10 and 11).

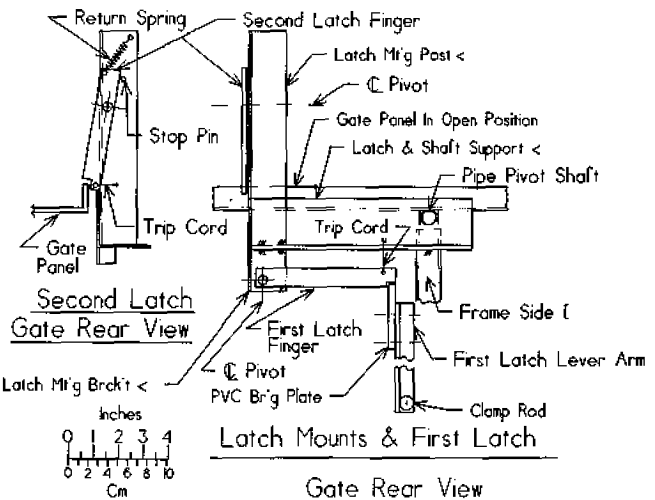


Figure 11-Diagram of trip latches for butterfly gate.

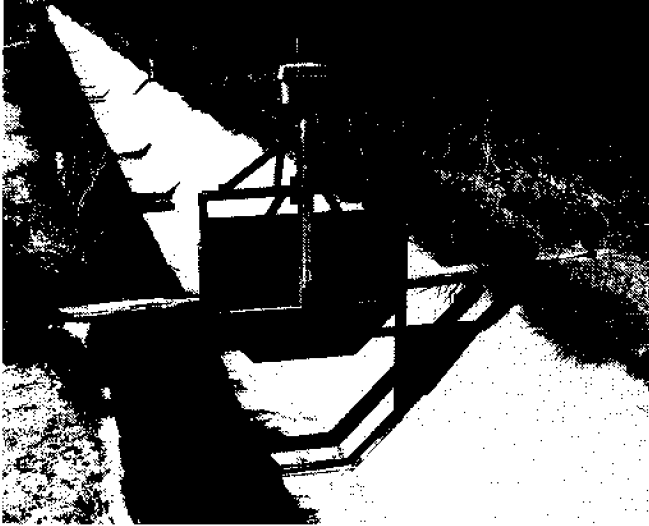


Figure 12—Linear-actuator-operated jack gate in the head ditch which serves level basins.

corresponding load currents ranging from 15 to 22 amp. Corresponding travel speeds vary from 8 to 6 mm/s (0.32 to 0.25 in./s). The actuator has more than adequate lift capacity since the maximum lift required to raise most jack gates is about 250 kg (450 lb) as reported by Dedrick and Erie (1978) and Dedrick (1989).

The actuator is available with several different styles of mounting brackets. We used an outer tube bracket clamped to the upper end of the actuator column and bolted to a sturdy mount on the gate frame. The clevis-end on the moveable, tubular, inner element fit in between, and was connected by a bolt to two steel angles attached to the gate panel.

The actuator control unit, mounted on the gate frame, includes a 3PDT relay to control the gate with a water sensor or timer and a DPDT toggle switch for manual operation. The two irrigated basins immediately upstream from the check gate have drop-closed gates at the turnouts controlled by water sensors (Humpherys and Fisher, 1995). When water in the second basin reached the sensor, a control signal was transmitted by buried wire to the actuator control unit where it activated the control relay to open the check gate. The check gate was lowered to its closed position before the next irrigation by manually operating the toggle switch. Although not used with the gate tested, a low-cost solar battery charger can be used to maintain the battery charge if the gate is to be used frequently.

PIPE TURNOUTS

Pipe turnouts commonly used in both lined and unlined ditches are equipped with a slide gate on the inlet end. These can be semiautomated as low-cost dual-function gates by replacing the slide gate with a drop-closed gate and attaching a flexible drop-tube on the outlet end. The first structures tested used prefabricated concrete pipe headgates with a headwall in an unlined ditch. The original slide gate was replaced by a drop-closed gate mounted on a bracket that fit over the top of the headwall as shown schematically in figure 13. The drop-tube, made from hypalon, nylon-reinforced butyl or PVC, or similar material, and clamped onto the outlet end of the pipe is

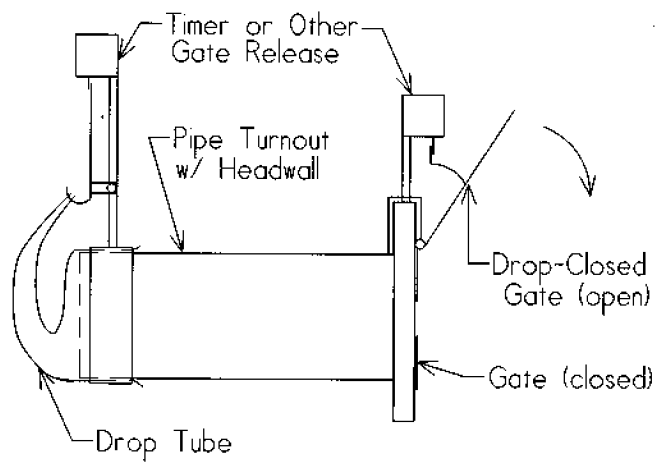


Figure 13—Schematic diagram of a semiautomated pipe turnout for an unlined ditch with a drop-tube outlet.

supported in its raised (closed) position by a bracket and trip release mechanism. Two grommets in the end of 150 to 200 mm (6 to 8 in.) in diameter tubes were used to hang the tube on a trip release hook. Tubes 250 to 300 mm (10 to 12 in.) in diameter, which are the largest feasible sizes, use clamp bars on the bottom side of the tube (fig. 14).

Two timers are used on each turnout, one for the inlet gate and one for the outlet tube. The timers are portably mounted and can be moved from one set to another. The total cost is minimized by using only the number of timers needed for one day's set and moving them once each day. The drop-tube timer mount and trip release shown in figure 15 has a lock pin for holding the tube in its suspended position when the timer is used at another location.

Eight 250 mm (10 in.) diameter semiautomated turnouts were tested in a border irrigated alfalfa field near Rigby, Idaho. The head ditch had a flat slope so check structures were not required and irrigation was sequenced downstream. Because of the inherent error in setting the timers, the set time from turnout to turnout overlapped to assure that one turnout would always be open. Overall, the structures performed well. Vegetative growth near the inlet gates sometimes lodged under the gates and caused them to leak slightly; however, this could be prevented by

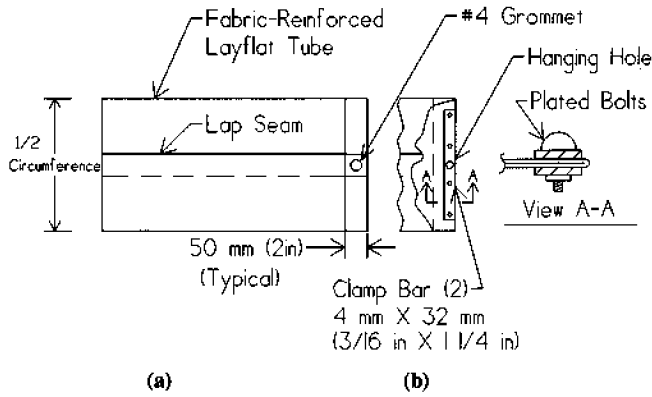


Figure 14—Drop tube for a pipe turnout: (a) top side of the tube in its lay-flat position, and (b) cutaway view showing the clamp bars with which to hang the largest size tubes.

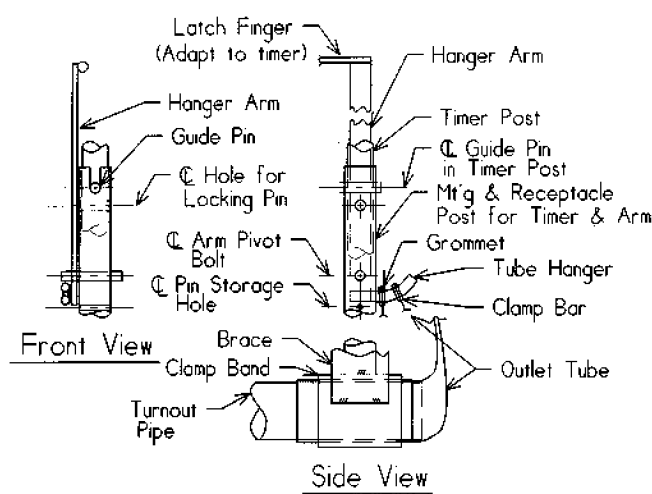


Figure 15—Schematic diagram of a drop-tube timer mount and trip release.

controlling weed growth in unlined ditches. Generally, the leakage was less than previously with the original slide gates. Two operational problems were encountered: (1) estimating the time required to complete irrigation of a border, and (2) timer reliability. The time was difficult to predict because a strip of gravelly soil extended laterally across the length-of-run part way down the field. This was compounded by different stages of crop vegetative growth. An automated system with feedback control is needed for these conditions. The mechanical timers, which are no longer available, occasionally malfunctioned. Adequate timers are still a constraint for most semiautomated systems.

Eighteen 375 mm (15 in.) diameter turnouts were tested in an unlined ditch near Fairfield, Montana. Sheet metal headwalls were fastened to the inlet end of PVC pipe. The headwalls were sealed with caulking, but, expansion and contraction of the PVC pipe sometimes broke the seal. Concrete or metal pipe may be more satisfactory than PVC for these turnouts. This was the largest size tested and is larger than optimum for this type of structure. The smaller-diameter semiautomated turnouts were more satisfactory and performed well except for unreliability of the mechanical timers. Electronic timers would avoid this problem.

SUMMARY AND CONCLUSIONS

Four types of semiautomated dual-function gates were tested. Gate descriptions, construction, and field operation are described for: (1) dual-panel combination gates, a drop-closed and a drop-open gate mounted on the same frame, (2) butterfly gates, a gate panel mounted on a horizontal pivot shaft which rotates 180° from a closed-to-open-to-closed position as two trip latches are sequentially released, (3) linear actuator-operated jack gate, a conventional, manually operated, jack gate equipped with an electrical linear actuator to raise and lower the gate panel, and (4) pipe turnouts in unlined ditches, a pipe turnout with a drop-closed gate on the inlet and a flexible drop-tube on the outlet. The gates were tested in surface flooded basin and border systems. The following are conclusions noted from the tests.

Performance was satisfactory for most gates.

Care is needed when constructing concrete turnout openings for combination and butterfly-type gates to assure that their invert is level and smooth, side slots for mounting the gates are vertical, and foundation support is adequate to prevent settling or piping which can cause cracking of the ditch lining near the turnout entrance.

The gates were generally watertight with little leakage except when trash occasionally caught beneath closing gate panels or when the combination and butterfly gates became slightly warped because the gate mounting slots were not vertical. Unless the irrigation water supply is free from trash and debris, trash screens should be used in all automated systems.

Irrigation time for two fields was reduced from five half-days with siphon tubes to two with an average field application efficiency of 68% when manually operated combination and drop-closed gates were used. The gates were operated manually prior to completion of the control system.

Low baffle plates placed between the drop-closed and drop-open panels of a combination gate corrected a differential flow problem between a pair of turnouts in a sloped supply ditch.

There was little functional difference between the combination and butterfly gates. A pull force for actuating a trip cord is easier to obtain from the combination gate, but the butterfly gate is simpler to construct except where it is used with a trip cord.

Fabrication cost per gate in a small shop for dual-panel combination gates made in 1991 and 1992 was about \$50 for materials and 11 h of labor. Timer cost is not included. Costs for the butterfly gate are not available since only a small number of gates were made as experimental prototypes and modifications were made during their development. However, their cost is estimated to be similar or less than for dual-panel combination gates of comparable size.

A 12-V battery-powered linear actuator was easy to install on an existing jack gate; the modified gate and actuator worked well. A linear actuator provides a feasible means for automating or semiautomating a jack gate. The 1989 cost of the actuator was \$120 plus a set up charge of \$150 per order for quantities of less than 50 units. Materials cost for the control unit was approximately \$40 with about 2 h assembly labor.

The addition of a drop-closed gate on the inlet and a flexible drop-tube on the outlet of a pipe turnout provided a low-cost means of semiautomating these turnouts. Of the two sizes tested, 250 mm (10 in.) and 375 mm (15 in.), the smallest size was the most satisfactory. Expansion and contraction of PVC pipe used in the larger turnouts made sealing around the headwall difficult. Sizes up to 300 mm (12 in.) should be considered the most feasible size range for this type of outlet.

Timer reliability was sometimes a problem with the mechanical timers that were used. Electronic timers would be satisfactory, but they have not been available in the United States for this application. A 24-h timer that was satisfactory for controlling electric solenoid-actuated gate trips is described by Humpherys (1995b) while an electronic timer just recently became available (Irrigation Systems Company of Western Colorado, Fruita, Colo.).

Maintenance required included checking the gate seals and latch or release system at the beginning of each irrigation season, lubricating hinge and pivot points, checking the gate caulking and paint, and removing the timers prior to winter for service as needed. The gates should be painted before installation with a good quality paint suitable for intermittent submersion in water.

The need for feedback control was observed in some field tests. This is particularly needed in fields with variable soil infiltration characteristics and water supply rates. Different stages of crop growth also have different retarding effects on the rate of advance, which makes predicting the time required to complete irrigation difficult. Feedback can be provided by using water advance sensors (Humpherys and Fisher, 1995).

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