Evaluation of Drop-Check Structures for Farm Irrigation Systems

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ABSTRACT

SMALL drop/check structures of various designs in the 28 to 115 L/s (1 to 4 cfs) flow range were installed in 1966 with their field performance evaluated in 1969. They were again evaluated in 1984 after 19 years of service. The parameters used to evaluate the structures included cost, structural integrity, stability, hydraulic performance and ditch erosion control capability. A numerical rating was given in each category. A precast concrete headwall with a rock-lined basin or plunge pool was the most economical and one of the most effective structures; however, special consideration must be given to provide sufficient headwall length and cutoff wall depth. Cast-in-place concrete structures were the most stable and generally the most costly with variable performances. Based on the study results and observations, conclusions and recommendations were made to improve the design of small drop structures.

INTRODUCTION

Gradient control and energy-dissipating structures are required in most farm ditches used in surface irrigation systems. Check and drop structures are used in unlined ditches for both water control and grade control to minimize channel erosion. Structures commonly used include cast-in-place concrete, precast concrete, and modular or prefabricated structures. Precast and modular structures often do not have sufficient headwall length or cutoff wall depth for good stability. They also tend to have stilling basins that are too narrow or too short, or both. They are commonly used because of economy and convenience compared to the more stable and costly cast-in-place structures. Information is needed from which to design small structures that are stable, economical, and which provide good erosion and water control, ease of installation, and farmer acceptance.

Design and installation criteria for these structures have not been fully standardized and are found in various references: American Society of Agricultural Engineers, 1980; Kraatz and Mahajan, 1975; Robinson, 1983; University of Idaho, 1958; and U.S. Department of Agriculture. The structures are commonly built from designs given by the U.S. Soil Conservation Service (SCS) or in agricultural Extension circulars and bulletins as noted in the previous references. Most SCS designs are for structures larger than those in the 115 to 140 L/s (4 to 5 cfs) flow range. Structure configurations and the basic dimensions commonly used vary considerably because of commercial availability, type of materials, user preferences, and different field conditions. A range of representative dimensions as defined in view A of Fig. 1 are included in Table 1.

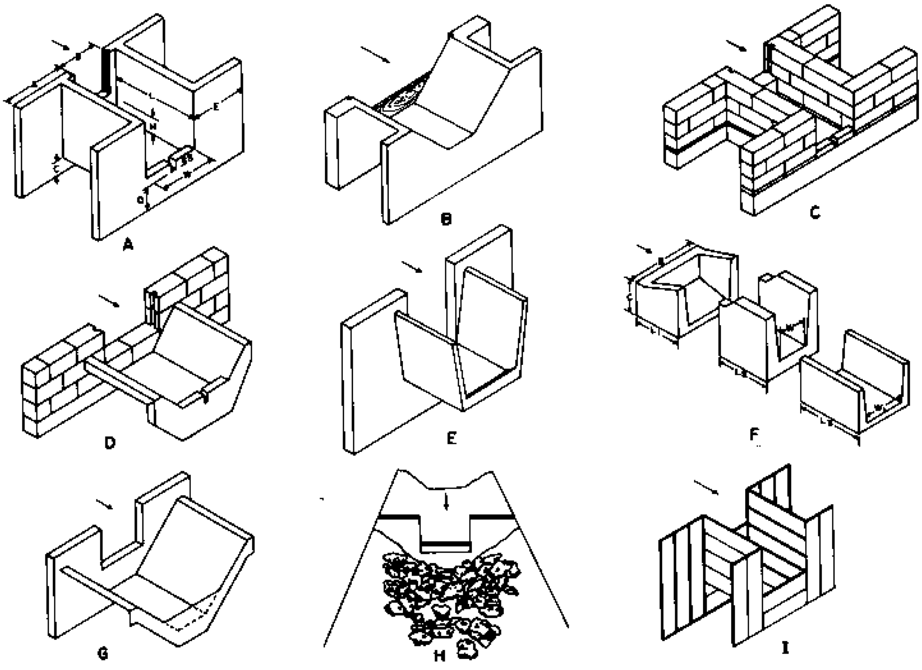

Fig. 1—Schematic drawings showing general configurations of the structures tested.

This article is reprinted from the TRANSACTIONS of the ASAE (Vol. 29, No. 2, pp. 505–511 & 516, 1986)
Published by the American Society of Agricultural Engineers, St. Joseph, Michigan

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Article was submitted for publication in October, 1985; reviewed and approved for publication by the Soil and Water Div. of ASAE in March, 1986. Presented as ASAE Paper No. 85-2634.

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TABLE 1. BASIC DIMENSIONS FOR DROP/CHECK STRUCTURES IN CENTIMETERS (INCHES)

	View in Fig. 1	General structure dimensions as shown in Fig. 1							
		Headwall extension A	Crest length B	Upstream cutoff C	Toewall cutoff D	Basin length L	Basin width W	Wingwall E	Sill height S
Range of commonly recommended dimensions		45-100 (18-40)	30-75 (12-30)	10-40 (8-16)	10-40 (4-16)	60-120 (24-48)	40-75 (16-30)	30-100 (12-40)	0.15 (0-6)
Cast-in-place concrete									
2,3 (rect. w/o sill)	A	53 (21)	45 (18)	30 (12)	30 (12)	80 (32)	60 (24)	45 (18)	—
4,5 (rect. w/sill)	A	53 (21)	45 (18)	15 (6)	15 (6)	80 (32)	60 (24)	45 (18)	8 (3)
19,20 (trap. w/o sill)	B	40 (16)	60 (24)	20 (8)	20 (8)	105 (42)	30 (12)	40 (16)	—
21,22 (concrete block)	C	80 (32)	40 (16)	25 (10)	25 (10)	100 (40)	40 (16)	80 (32)	10 (4)
25,26 (block headwall w/ trap. basin	D	80 (32)	45 (18)	10 (4)	30 (12)	90 (36)	30 (12)	—	5 (2)
Precast concrete									
6 (w/sill)	E	43 (17)	45 (18)	18 (7)	—	50 (20)	45 (18)	—	8 (3)
7 (w/o sill)	E	45 (18)	38 (15)	20 (8)	15 (6)	48 (19)	38 (15)	—	—
8,9,10 (sm. cofferdam w/ end liner)	F	—	65 (26)	30 (12)	—	L1 48(19) L2 50(20) L3 75(30)	W 25(10) W1 48(19)	— —	— —
27,28,29 (lg. cofferdam w/end sidewalls	F	—	78 (31)	35 (14)	—	L1 55(22) L2 60(24)	35 (14)	—	—
Precast concrete headwall w/prefab. or gravel basins									
11,12 (fiberglass basins)	G	50 (20)	45 (18)	15 (6)	15 (6)	60 (24)	30 (12)	—	10 (4)
13,14 (galv. steel basin)	G	50 (20)	45 (18)	13 (5)	15 (6)	75 (30)	35 (14)	—	15 (6)
1,15,16 (gravel basin)	H	50 (20)	45 (18)	15 (6)	—	90 (36)	60 (24)	—	—
Prefabricated and modular									
23 (galvanized steel)	I	50 (20)	50 (20)	30 (12)	15 (6)	90 (36)	60 (24)	45 (18)	20 (8)
24 (aluminum w/wingwalls)	I	55 (22)	50 (20)	25 (10)	25 (10)	64 (26)	58 (23)	53 (21)	2 (0.75)
30 (alum., dealer design w/o wingwall or toewall)	I	55 (22)	38 (15)	25 (10)	—	50 (20)	55 (22)	—	—
31 (redwood)	A	60 (24)	45 (18)	—	—	90 (36)	45 (18)	60 (24)	15 (6)

A study was initiated in 1966 to evaluate and compare the field performance of various structures in the 28 to 115 L/s (1 to 4 cfs) flow range. The structures were evaluated during the four succeeding irrigation seasons (Humpherys and Robinson, 1971). They were again evaluated at the end of the 1984 irrigation season to note their condition and performance after 19 years of service. Results of the previous study are summarized and compared to those of the 1984 evaluation in this paper.

TESTING PROCEDURE

Thirty-one structures representing 16 designs were installed in a test ditch about 300 m (1,000 ft) long with a grade drop, H, of 15 cm (0.5 ft) at each structure. The streamflows varied in size; average measured rates during the first four seasons were between 28 and 60 L/s (1 to 2 cfs), with occasional flows of 85 to 115 L/s (3 to 4 cfs). Flow rates during the succeeding years were smaller. The ditch was poorly maintained throughout part of its length during the intervening years. Grass partially obstructed the flow and contributed to sediment deposition in the lower half of the channel while the upper section was grazed by cattle part of the time. Soils at the study site were loams and sandy loams with a slight hard pan at various depths over part of the area.

Schematic drawings of the various types of structures tested are shown in Fig. 1. Basic dimensions of the test structures, as defined in views A and F, are presented in Table 1, along with the respective range of commonly recommended values. The structures are grouped into four general categories: (a) cast-in-place concrete, (b) precast concrete, (c) precast concrete headwall with prefabricated or gravel stilling basins, and (d) prefabricated and modular structures. Structures 1, 2, 3, 6, 7, 11 to 16, and 19 to 20 all used wooden checkboards to create the grade drop, H. The wooden (No. 31) and concrete cast-in-place structures were all standard SCS designs (U.S. Dept. of Agriculture). The precast concrete and metal modular structures were commercially available and used in the area at the time of the initial study. Precast structures of the type shown in view F of Fig. 1 were an unconventional design produced locally. They consisted of a small stilling basin, referred to as a cofferdam by its producer, placed upstream from a rather narrow throat section. A short flume-type liner was placed next to the throat on the small structures (Nos. 8 to 10) while two individual precast sidewalls were placed downstream from the throat of the larger structures (Nos. 27 to 29).

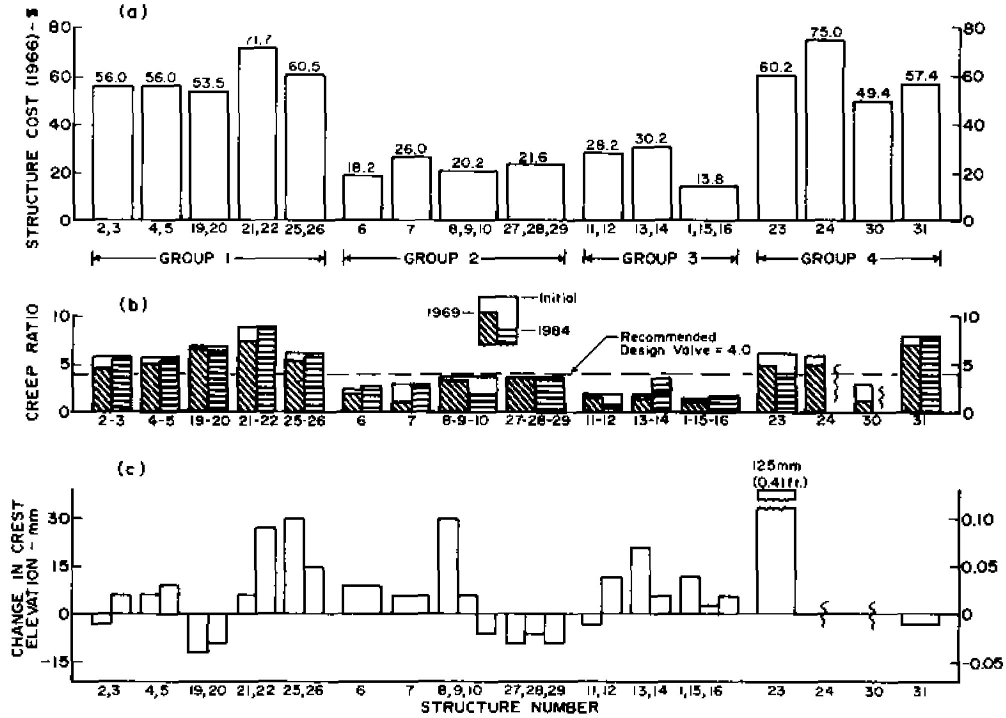

Fig. 2—(a) Structure costs, (b) changes in average creep ratios since 1969, and (c) elevation changes since 1969.

Four structures with precast concrete headwalls (View G, Fig. 1) had experimental stilling basins formed from fiberglass (Nos. 11, 12) and galvanized sheet metal (Nos. 13, 14). These materials were being used as ditch liners in the area.

The structures were operated both as checks and as drops at various times during the study. Parameters used to evaluate them included cost, structural durability, stability, hydraulic performance and ditch erosion control capability. Structural durability was determined from visual observations. Weighted-creep ratios were determined as a measure of structural stability along with elevations to detect structure movement. Hydraulic performance and erosion control effectiveness were determined from visual observations and measurements of flow velocity, channel width, scour depth, and soil erosion volume.

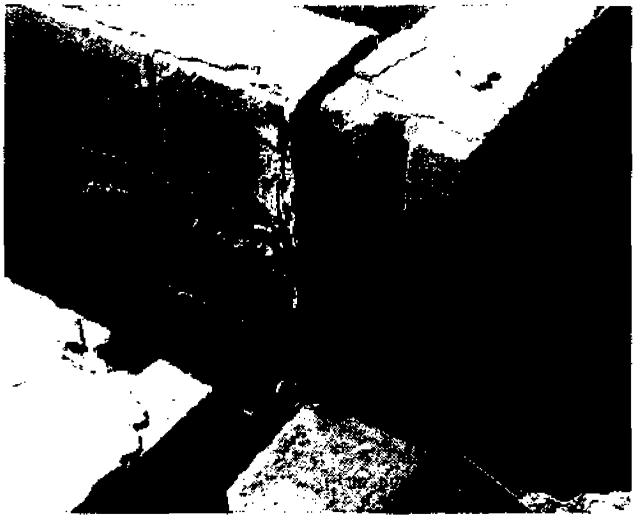

Fig. 3—Concrete block structure, No. 21, showing separation of sidewall from headwall.

DATA AND OBSERVATIONS

Cost

Cost is an important variable which influences an irrigator's choice of the structure that he will use. Structure costs in 1966 are shown graphically in Fig. 2a.

Structural Strength and Durability

Concrete cast-in-place structures 2 to 5 (view A, Fig. 1) were generally in excellent condition in 1984. Deterioration consisted of damage to the concrete crest of No. 5 and a crack in one wingwall. The crack developed early in the study and has widened with time. The concrete is not steel-reinforced. Trapezoidal structures 19 and 20 (view B, Fig. 1), which have cutoff walls but no headwall, show no signs of deterioration except on the wooden checkboards. Concrete block structures 20 and 21 (view C, Fig. 1) show significant damage from weathering. The concrete cap on top of the blocks is cracked and has started to spall (chip and crumble); some of the crest and end sill blocks are cracked and chipped; blocks at the base of the sidewalls are spalling and have cracked longitudinally such that the sidewalls are separating from the basin floor. Some of this deterioration occurred during the initial study period, but has since increased. The headwalls on both structures have separated from the sidewalls as shown in Fig. 3. Steel reinforcing was used in the blocks but was not used to tie the sidewalls to the headwall. Concrete blocks that cannot dry before freezing weather may have a shorter life than concrete in climatic zones with severe winters. The blocks are subject to greater freeze-thaw damage than is concrete. Trapezoidal structures 25 and 26 (view D, Fig. 1) have concrete block headwalls and cast-in-place stilling basins. Separation of the headwalls from the basins began during the initial study but has increased since. A longitudinal crack in No. 25 which developed early in the study from backfill settling has widened, Fig. 4. The concrete cap on the blocks is

Fig. 4—Concrete block headwall with cast-in-place trapezoidal stilling basin, No. 25. Large longitudinal crack formed early in the study when the sides settled.

cracking and starting to spall.

Precast structure No. 6 (view E, Fig. 1) is steel-reinforced and is in good condition. Precast structure No. 7 (similar to view E, Fig. 1) is not steel-reinforced and the concrete is beginning to crack such that spalling will follow in due time. Longitudinal cracks have developed at the base of the sidewalls. The concrete in precast cofferdam structures 8, 9, and 10 (view F, Fig. 1) is cracking and spalling in places while other parts of the structures appear sound. Since the concrete is not reinforced, the cantilevered walls are generally not strong enough to resist soil forces; they tend to crack at their base and lean inward. Because the individual component sections are not tied together, they can move independently and do not lend structural strength or support to each other. Most of the concrete in the larger structures, 27 to 29, is sound with some spalling on the cofferdams. The sidewalls of No. 29 have separated from the main structure and sloughed into the ditch.

Structures 11 to 16 (views G and H, Fig. 1) have relatively thin, precast concrete headwalls that were steam-cured and reinforced with steel. These are relatively light weight and durable with no evidence of deterioration. Structures 11 and 12 had fiberglass stilling basins. The basins had begun to separate from the headwall during the initial study period and some of the edges and corners had begun to crack and chip. During the intervening time period, the basins disappeared and the headwalls are now functioning alone. The fiberglass could possible have caught fire and burned when weeds on the ditch banks were burned. Structures 13 and 14 have sheet metal stilling basins formed from 22-gauge galvanized steel ditch liners. The basins are still intact; however, one of them is somewhat deformed and has a damaged end sill (14-gauge steel) while the other is in good condition.

Modular steel structure No. 23 (view I, Fig. 1) appears sound except where the galvanizing is wearing off with resultant rusting. Aluminum structures 24 and 30 are missing; however, observations made on similar structures that have been in service for comparable periods of time indicate that the aluminum alloy material is durable, resistant to weathering and is not adversely affected by these soils. The redwood lumber in structure 31 shows some checking but appears sound.

Structure Stability

A weighted creep or seepage path distance is used to evaluate a structure's ability to resist piping. The creep distance defined by Lane (1935) is the sum of the vertical distances plus one-third of the horizontal distances along the shortest seepage path at the interface between the structure and the soil from headwater to tailwater. The shortest seepage path for all of the test structures was horizontally around one end of the headwall and along the stilling basin sidewall. Lane's weighted-creep ratio is the weighted-creep distance divided by the seepage head. A minimum value of 4 is commonly used for design purposes for loam and sandy loam soils having a clay content of 15% or greater (U.S. Dept. of Agriculture, 1958).

Creep ratios at the beginning of the study were the same for each structure of a pair (or trio) for a given design, and are shown graphically in Fig. 2b for a seepage head of 15 cm (6 in.). Changes in the average ratio for each pair, or structure design, from its initial value for the 1969 and 1984 evaluations are also shown in Fig. 2b. The ratios have not changed significantly since 1969, and in most cases, increased slightly because sedimentation replaced some of the soil that had eroded from around the structures earlier. As shown in Fig. 2b, all of the precast structures have low creep ratios of less than 4.0 and all but the cofferdam structures and structure No. 6 washed out at least once during the initial study period. The failures occurred early in the study by piping around the ends of the headwalls before the soil became fully consolidated and stabilized by vegetation. Much of the piping was caused by rodent holes. None of the headwalls have completely washed out since; however, water is flowing beneath the headwall of No. 12 which has lost its fiberglass stilling basin.

The cofferdam structures were installed with a slurry type backfill mixture of sand and fine gravel adjacent to the structure which discouraged rodent activity. However, the mixture was easily eroded by flowing water such as would occur if a structure were overtopped. The particle size distribution for this material, determined from a sample taken in 1984, is shown in Fig. 5. Since 1969, some sections of the cofferdam structures have settled and tilted such that cracks have developed between the precast sections. This has allowed water to erode the backfill material so that piping and further differential settling has occurred.

Aluminum modular structure No. 31 was almost washed out in 1969. Since it is now missing, it is presumed to have completely washed out. The panels forming the headwall were not driven deep enough and piping occurred beneath them. The stilling basin was also too short and soil behind the sidewalls eroded away. No explanation was found for the disappearance of aluminum structure no. 24. It was stable in 1969 and should have been resistant to being washed out.

Changes in crest elevations since 1969 were determined to detect structure movement and are shown graphically in Fig. 2c. Approximately one-third of the structures settled while the other two-thirds were higher. There was not a consistent correlation between structure type and elevation changes. Two of the precast structures

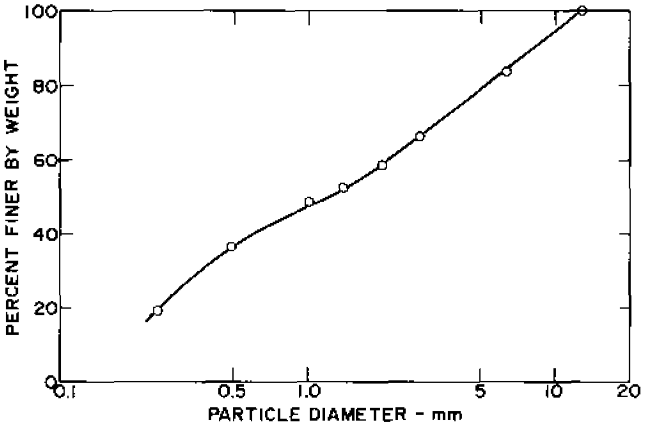

Fig. 5—Particle size distribution curve for puddled sand-gravel backfill mix used around cofferdam structures.

(Nos. 8 and 13) and two of the structures with concrete block headwalls (Nos. 22 and 25) were significantly higher, 21 to 30 mm (0.8 to 1.2 in.). Prefabricated, metal structure No. 23 was quite high and apparently had experienced considerable frost heave. This increased the grade drop through the structure and partially submerged the next upstream structure (No. 22) by increasing its tailwater depth. The elevation changes are not too surprising considering the cold and variable winter temperatures that the structures were subjected to in an area where frost heave is common.

Hydraulic Performance

Stilling Basins: The stilling basins in 1984 performed about the same as observed in the previous study. One of the most effective and economical basins was a rock-lined plunge pool beneath the drop, Fig. 6. Some structures were more effective than others because of the influence that their stilling basin design and geometry had on controlling the exit velocity. Structures with narrow basins contracted the flow and high erosion-producing exit velocities resulted, except where there was sufficient tailwater depth. Generally, channel scour depth was greater for those structures which had narrow basins and no end sill. End sills protected the channel bottom by directing high velocity flows away from the bottom of the channel. However, with low tailwater depths, the water cascaded over the sills and caused increased turbulence immediately downstream. This tended to cause lateral flow which impinged upon the sides of the ditch and resulted in undercutting and erosion of the banks. Short basin lengths aggravated the condition as shown in Fig. 7. This adverse effect can be minimized or overcome by placing the basin and end sill below grade so as to increase tailwater depths.

Fig. 6—Precast concrete headwall with a gravel-lined stilling basin or plunge pool, No. 15. Cattle tromping has reduced the size of the basin and moved gravel toward its center.

Fig. 7—Channel downstream from precast structure No. 6 illustrating bank undercutting and erosion caused by end sill-induced turbulence at low tailwater depths.

The influence of tailwater depth was demonstrated with structures 19 and 20. Because of their trapezoidal shape and long crests, Fig. 8, flow depths over the crest of structure No. 20 were relatively shallow. This resulted in shallow flow depths on the apron of structure No. 19 immediately upstream. On the other hand, structure No. 21 (Fig. 3) immediately downstream from No. 20 has a

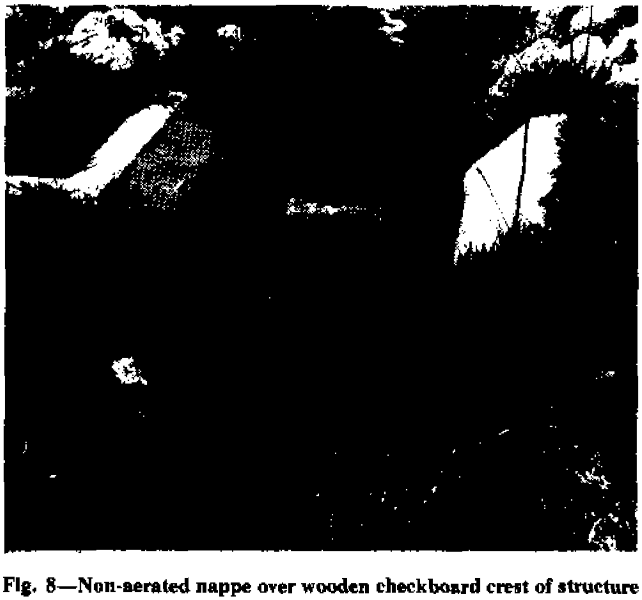

Fig. 8—Non-aerated nappe over wooden checkboard crest of structure No. 19. This structure does not have an end sill.

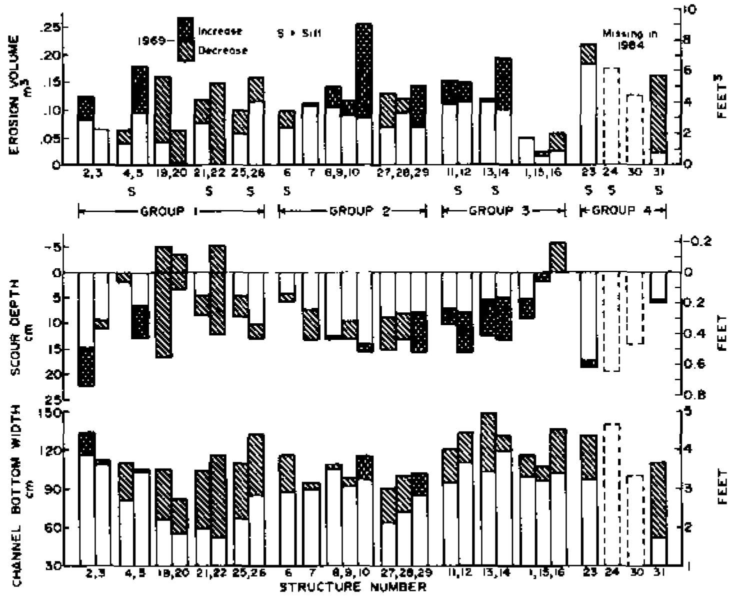

Fig. 9—Changes in (a) downstream erosion volume, (b) scour depth, and (c) channel width in 1984 compared to 1969 values for the drop/check structures tested.

short crest length which resulted in greater flow depths on the apron of structure No. 20. The superior performance of structure No. 20 with its greater tailwater depths, compared to No. 19 with shallow depths, can be seen in the erosion volumes and scour depths shown in Fig. 9a and 9b for the 1969 evaluation, before sedimentation occurred. This effect was also observed with structures 2 and 5 in 1984. A narrow piece of the checkboard in structure No. 3 was all that remained in place while the checkboard for structure No. 6 was completely missing. This lowered the upstream water surface elevations and reduced tailwater depths at structures 2 and 5. It also caused the sill of No. 5 to act as a drop. As noted in Fig. 9, both the erosion volume and scour depths increased for structures 2 and 5, which had shallow tailwater depths. This also partially explains the erosion volume and scour depth increase for structure No. 10 since the checkboard in No. 11 was also missing.

Low, 5 to 10 cm (2 to 4 in.) high end sills caused less turbulence and were more effective than higher sills for these small structures. Sills could perhaps be eliminated where minimum tailwater depths of 15 to 30 cm (6 to 12 in.) can be maintained for drop heights up to 30 cm (12 in.). To maintain minimum tailwater water depths without sills, the apron must be installed 10 to 15 cm (4 to 6 in.) below grade (University of Idaho, 1958). Low sills, which were the most effective, also need to be installed with their top below grade to provide minimum tailwater depths.

With adequate tailwater depth, a trapezoidal basin without a headwall provided good stilling (Fig. 8). The non-aerated nappe (water flow over a crest) caused the flow to cling to the crest wall such that turbulence and energy dissipation occurred in the upstream portion of the basin; this resulted in a longer effective basin length. With these small structures, a non-aerated nappe does not create the low pressures normally associated with non-aerated nappes of larger structures and streamflows. Adequate tailwater depth is especially important for trapezoidal basins because of their narrow bottom-width. Non-aerated nappes also contributed to the good hydraulic performance of block structures 21 and 22.

The relatively poor performance of prefabricated steel structure No. 23 was attributed partly to the high 20 cm (8 in.) end sill which was required by the modular panel dimensions. This caused excessive turbulence and lateral currents which resulted in considerable erosion and channel widening. Downstream erosion was also increased because frost action raised the structure such that the end sill acted as a second drop. The lack of tailwater depth by the disappearance of downstream structure No. 24 also adversely affected its performance.

The wall attachment or coanda effect was observed under certain conditions with structures 8 to 10 which had narrow basins without sills and relatively high exit velocities. When this occurred, high flow velocities developed near one of the sidewalls. This is undesirable because water left the structure on one side and tended to accelerate bank undercutting and erosion on that side more than if the velocities were uniform across the channel.

Scour and Erosion

Channel cross-section measurements were made between 30 cm (6 in.) and 150 cm (30 in.) downstream from the structures. The erosion volume in 1969 and volume changes since 1969 (the volume of soil eroded from or added to the measured channel section) are shown graphically in Fig. 9a. Average scour depths and channel widths in 1969 and subsequent changes to 1984 are shown in Fig. 9b and 9c. Because of smaller average stream sizes and poor channel maintenance, sedimentation occurred in the lower ditch section between structures 19 and 31. Thus, the erosion volume and channel widths below these structures were generally less than in 1969. Erosion downstream from structure No. 29 increased because of high exit velocities which were aggravated by the sidewalls which sloughed into the ditch and contracted the flow. Scour depths generally decreased in the downstream section and were variable in the upstream section. It was difficult to relate structure performance to the 1984 channel cross section

TABLE 2. RATINGS OF DROP CHECK STRUCTURES*

Structure no.	Structural adequacy	Stability	Hydraulic performance		Erosion control	Practical aspects	Performance rank†,‡	Cost rank†
			Drop	Check				
2,3	9	9	7	8	6	6	4	7
4,5	9	9	8	9	7	6	2	6
19,20	9	9	7	9	7	7	1	8
21,22	5	8	8	9	7	5	6	2
25,26	6	9	8	9	6	6	5	3
6	8	5	5	7	6	7	7	15
7	6	5	4	7	5	6	13	12
8,9,10	5	4	5	7	5	5	14	14
27,28,29	7	6	5	8	5	6	9	13
11,12	3	3	6	7	5	4	15	11
13,14	6	5	7	8	5	5	10	10
1,15,16	8	5	8	9	9	8	3	16
23	7	6	5	7	3	6	12	4
24	8	7	5	7	3	5	11	1
30	5	2	3	6	3	5	16	9
31	6	8	7	7	4	6	8	5

*Rating scale: 1-Unsatisfactory, 2-Very poor, 4-Poor, 6-Fair, 8-Good, 10-Excellent.
†Based on a scale of 1 (highest) to 16 (lowest).
‡Does not include cost.

measurements because of outside influences such as livestock tramping and overgrown vegetation.

Two scour patterns were observed during the initial study. Channel widening below the structure was generally associated with end sills while scouring of the channel bottom was associated with structures without end sills. These patterns were not so strongly identified from the 1984 channel measurements because the smaller average stream sizes of recent years did not produce the strong end sill turbulence and high exit velocities that the former larger stream sizes did.

STRUCTURE RATINGS

Following the initial study, the structures were given a numerical rating on each evaluation parameter and an overall rating. Based on the 1984 evaluation, the former ratings were updated and readjusted and are shown in Table 2. The structures were ranked for performance in 1984 based on the numerical average of the individual ratings. Cost was not included in the average ratings but cost rank is shown separately.

The earlier ratings were adjusted up or down according to a structure's physical condition in 1984 and its ability to perform its designed function. Most structures which use the precast headwall were upgraded because their structural integrity and stability over the long term were good, after the ditch banks became consolidated and stabilized. The concrete block structures were downgraded because of further block deterioration and relative movement between headwalls and sidewalls. The cofferdam structures, which are no longer available, were downgraded to reflect structural weaknesses and the instability of Nos. 8 to 10, 29.

The cast-in-place structures generally had the highest overall performance ratings. The precast headwall structures with gravel-lined stilling basins, 1, 15, 16, also have high ratings which could have been higher if the headwall had been longer with a deeper cutoff. Most other precast and prefabricated structures would also receive a higher rating if they had longer, wider stilling basins and longer headwalls to insure against piping.

The ratings for erosion control were adjusted for relative performance between structures. Practical aspect ratings are somewhat arbitrary and are based on the amount of maintenance required, obstruction to ditch-cleaning equipment, utility of operation and farmer acceptance based on convenience and ease of installation.

In applying the ratings to a particular field situation, one category may be more important than another and may be the dominant criterion. Hydraulic performance will usually be very important. However, in some cases, structure cost or convenience aspects may be the deciding factors; or soil conditions may require that more consideration be given to the stability rating. Structures that combine the most desirable features of several structures could have a higher rating than any shown.

CONCLUSIONS AND RECOMMENDATIONS

Based on observations and field data, some general conclusions and recommendations can be made:

1. Cast-in-place concrete structures were the most stable and were still sound after 19 years of service, even though they were not reinforced. Small structures such as these may not require reinforcing if placed on a firm, well-drained foundation with quality concrete and workmanship. However, reinforcing is always good insurance and is recommended; the additional cost is nominal compared to the overall cost.
2. Concrete block structures showed greater deterioration than cast-in-place concrete. They should be more durable in areas having a more moderate winter climate than that under which they were tested.
3. Precast concrete structures generally did not provide adequate stilling basins for energy dissipation because of their small size. They tended to wash out because headwall lengths and cutoff wall depths (creep distance) were generally not adequate to protect them from piping during the first two years after installation. Separate headwall extensions are recommended in sandy and sandy loam soils. Extensions can be metal, precast concrete slabs or redwood. A cutoff wall extension is also recommended unless a concrete base is poured beneath the headwall. Precast structures, however, cost less and were easier to install.
4. Most washout failures resulted from piping caused by rodent holes. This type failure can possibly be minimized by using a dense, puddled, clay-sand-fine gravel backfill mix to discourage rodent activity adjacent to the structure.
5. Precast concrete headwalls formed in thin sections that were reinforced and steam cured were still in sound condition in 1984.

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6. With low tailwater depths, end sills generally caused turbulence which undercut and eroded the ditch banks immediately downstream. Sill heights from 5 to 10 cm were the most effective and are recommended. The top of these low sills should be installed below grade to provide 15 to 30 cm water depth on the apron for drop heights up to 30 cm and design flows in the 110 to 140 L/s range. End sill turbulence for higher sills can be contained within the basin by installing the sill a short distance upstream from the end of the basin; however, this may require a longer basin length.

7. With adequate tailwater depth, both wide rectangular and trapezoidal basins without end sills performed well. However, the stilling basins must be installed with the invert 10 to 15 cm below bottom grade to increase tailwater depth.

8. Wide stilling basins performed better than narrow basins. They provided a larger flow area with lower exit velocities; conversely, narrow basins contracted and accelerated the flow, resulting in high velocities.

9. Non-aerated nappes contributed to good stilling within the structure and are recommended. They also reduce stilling basin length requirements. The adverse effects commonly associated with non-aerated nappes on larger structures are not a problem with these relatively small structures and streamflows.

10. Basin length per se was not studied, however, lengths of less than about 75 cm (30 in.) appeared short. Short basins, however, should be satisfactory with low sills, non-aerated nappes, and sufficient tailwater depth.

11. With adequate headwall length and cutoff depth, plain headwall structures with a gravel-lined basin or plunge pool were the most economical and one of the most effective structures tested. These may need some maintenance to reshape the basin and redistribute the rock if livestock have access to them.

In summary, the most effective small drop/check structure for unlined ditches in the 110 to 140 L/s range would appear to be one with a non-aerated nappe, a relatively wide rectangular or trapezoidal stilling basin with or without an end sill but installed below bottom grade to provide a minimum tailwater depth of about 15 to 30 cm, depending upon drop height and flow, or a headwall structure with a gravel-lined basin and the same minimum tailwater depth. Adequate headwall length and cutoff wall depth are required for all structures consistent with the soil in which they are installed.

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