



WATER, ENVIRONMENT AND MANAGEMENT

Spillway design for small dams

Euan R Nichol



INTRODUCTION

The Spillway or bywash is the weakest link in the small dam system, yet it usually receives insufficient attention during the design, construction and maintenance processes. Surveys (Ref 4,5) have indicated that spillway and overtopping failures (usually related) are the most common cause of failure in small embankment dams.

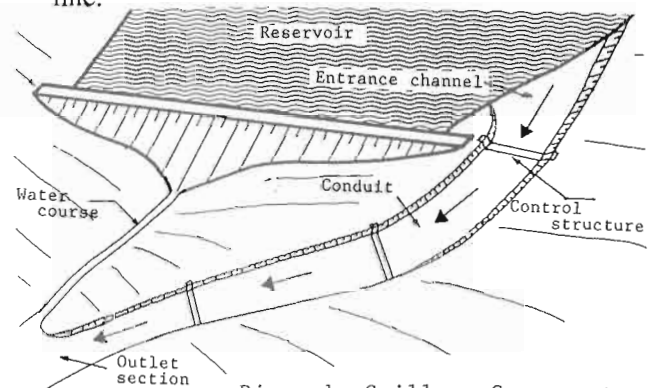
SPILLWAY FUNCTION

The spillway is the safety valve to the system as it provides the means by which flood flows in excess of the dam's capacity can be safely carried past the dam and returned to the water course. The design and construction process of the spillway requires a delicate balance between functional requirements and the economies necessary in small embankment dams.

COMPONENTS OF SPILLWAY

- A spillway system has four components:
- Entrance channel** - carries water to the forebay and spillway control structure.
 - Control structure** - admits water to the spillway and controls the discharge - overflow from the reservoir. Usually it is in the form of a sill which is a broad-crested weir and forms the control section.
 - Conduit** - carries the discharge from the control structure to the low level outlet, downstream of the dam. The conduit may be a pipe section in a drop inlet pipe spillway, a concrete channel section in concrete spillway, a rough hewn channel section in rock, a series of cascade drops from rock-filled gabions or a smooth, constant-graded section in a grassed spillway. All are designed to carry the maximum flow within allowable velocities which dictates the 'conduit' width or area.
 - Outlet structure** - dissipates energy of high velocity flows that are likely to occur with concrete chute spillways. (see design charts Ref. 8). Rock spillways and gabion drops dissipate energy all the way down the conduit and may not require a major dissipating structure at the outlet.

Grassed spillways are designed to limit conduit velocities and are usually transitioned (vertical curve) and widened at the outlet to further reduce flow velocities where they re-enter the drainage line.



Diag. 1. Spillway Components

DESIGN FACTORS

Factors affecting selection of spillway type and design include:

- Safety requirements consistent with the projects economics**
The hazard rating of the dam, that is the effect of dam failure on human life, service amenities and invested capital loss is a major design factor. A small earth dam providing secondary domestic and stock supplies and located such that there would be minimal hazard for loss of life and amenity would not need, nor could the designer justify a reinforced concrete spillway.
- Capital available**
The amount whether large or small appropriated for the spillway is a function of the hazard rating of the dam and needs-value of the water resource.
- Hydrological conditions**
 - Catchment size is a key parameter. The 'Art' is to try and match catchment yield to storage volume and thus minimise spillway stress.
 - Inflow flood hydrographs and frequency together with baseflow quantity and duration are all important design data.
 - Crest level of dam. This dictates the freeboard available and depth of spillway flow, which will determine spillway length.

- (4) Capacity of the reservoir at various levels provides information on the ability of the reservoir to absorb flood inflows, by routing them through the storage, reducing the outflow and hence the spillway size.

(d) Geological and site topographical conditions.

- (1) Steepness of terrain and return slopes and the stability of abutment slopes will affect the type of spillway adopted.
- (2) Amount of excavation, type of material and whether excavated material can be used in the bank are important factors.
- (3) Type of rock may allow a natural spillway with little erosion hazard, or provide material for gabion-based solution.

(e) Type of Dam

The type of dam tends to limit the location of the spillway. An earthen dam would have its spillway to one side and away from the dam, whereas a rockfill dam or concrete weir may incorporate the spillway as part of the main structure. A small earth weir structure (less than 3m high) may have a central spill section constructed of concrete or gabions but this requires careful detailing.

(f) Conditions downstream of dam.

The stability of bed and banks downstream of the dam will influence the spillway selection and method of energy control at the outlet section. An expensive concrete structure which may be required on less stable alluvial stream beds would not be needed if the streambed consisted of stable rock.

(g) Availability of Resources

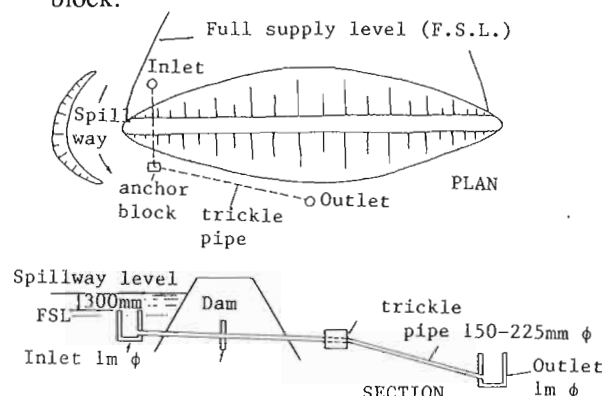
The degree to which material, water and labour is available and the appropriateness of the environmental conditions will have major influence in the selection of an 'appropriate' design in the right place.

TYPES OF SPILLWAYS

- (a) **Ogee or Overflow spillway** is a formed concrete structure shaped to match the underside of a free overfall. It is usually uneconomic for the order of flows in small dams.
- (b) **Free overfall** - straight drop spillway is a concrete or gabion drop structure, usually located in the centre of a low dam or weir (less than 5m high). Uneconomic solution in most cases but necessary with high flows from a large catchment.
- (c) **Drop Inlet spillways** - for narrow sites with no side spillway alternative. It is an expensive solution when it is the only spillway option, as the

pipe diameters must be large. It is useful where catchments yield long term base flows, for this spillway helps prevent waterlogging of the main grass spillways when the drop inlet is set 0.3m below the grassed spillway levels.

Factor of safety is low as the drop inlet may block.



Diag. 2. Drop Inlet Spillway

- (d) **Chute Spillway** - When formed from concrete, it is an expensive, but possibly the only option when slopes are steep and soils erodible. Check other water resource options. Design and construction details are vital for satisfactory solution.

When formed from soil, with a protective grass cover, it is a natural solution but requires a well established cover and enduring maintenance. Grass selection and supplementary irrigation are critical on this spillway which should desirably be constructed a year before the embankment. Concrete or wooden horizontal sills at the control section, any change of grade and the outlet section ensure an even spread of flow preventing localised high, potentially eroding velocities. The adoption of a drop inlet secondary spillway provides a factor of safety to the main spill system.

- (e) **Side channel spillway** - variation on the grass spillway. When return slopes are steep the conduit section conveys the discharge on a flat grade (near to contour) to a ridge where the flow is discharged over a long level sill around the ridge to the flatter slopes.

EARTHEN SPILLWAYS

As earthen spillways, either vegetated (grassed) or non vegetated, are the predominant systems used in small dams, the rest of this paper will cover more closely the design process and detailing of these. Earthen spillways are designed to discharge the peak flow calculated for the catchment. Where catchments are relatively small and base flows are of limited duration

earthen spillways are a feasible option. An additional low-flow trickle pipe spillway which adds a low-cost factor of safety to the system, should always be considered. An earthen spillway should always be located on excavated or natural ground and never on fill material. The spillway must be designed throughout to discharge the design peak flow at a non-erosive velocity to a safe release point, usually the return to the drainage line. This limitation restricts the use of this spillway system to sites where the soils and topography will allow discharge at erosion limiting velocities. Alternative spillway systems are usually uneconomic, though consideration could be given to the lowcost options presented later. If a suitable spillway site does not exist, the dam location should be abandoned and another site chosen. Too often a dam site is chosen with little regard to the potential spillway problems.

Design Spillway Capacity

Earthen spillways should have the capacity to discharge the peak flow from a storm of a given return period (for small dams, usually one in 100 years) on a catchment at a velocity not exceeding 2.5m/s. The peak flow is obtained using the Rational Formula with local hydrologic (rainfall intensity) and topographical data. The spillway is designed as a broad crested weir with the width given by

$$W = \frac{Q}{1.55H^{1.5}}$$

where Q = flow (m³/s) W = basewidth of the spillway(m) H = depth of flow or surcharge over weir (m).

Minimum recommended width is 3.5m.

An approximate solution to the above equation is given in Table 1 for a surcharge height of 0.5m. The spillway outlet width is increased for a given slope to spread the flow such that velocities remain below 2.5m/s. Table 2 gives values of outlet width for given slopes, and various flow rates.

Other design rules to be met are:

1. The selected spillway width at the control section should not be greater than 35 times the design depth of flow. Where this ratio is exceeded the channel is likely to be damaged by meandering flows and accumulated debris. Where the required spillway width is large, spillways may be constructed at both ends of dam. One spillway is set 0.1m higher than the other to minimise potential base flow erosion effects.
2. Spillway side slopes should not be steeper than 2:1 unless excavation is through rock.
3. Spillways should always discharge on the flattest return slopes available such that the flow will diverge, or at least be parallel, but never converge. This requirement can often be met by constructing a flat-graded channel to carry the discharge to a level spill area around a ridge line.
4. Site the embankment and spillway such that the water does not erode the downstream toe of the embankment.
5. Unless there is very good reason, ensure that the spillway flow is returned to the drainage line from which it came. The flow may be inappropriate for other drainage lines and cause erosion.
6. Dam construction machinery must not touch the return slopes during the building process.
7. The spillway area and return slopes should be well grassed with a strong rooted running (stoloniferous) grass such as kikuyu, African star grass, couch and para grass. The area requires regular watering and careful grazing by small animals.
8. Where grass cover cannot be established and maintained, horizontal concrete sills that spread the flow should be placed at the control section, change of grade or at regular intervals across the return slope.

Table 1.

Recommended Minimum Spillway Inlet Widths	
Flood Flows (m ³ /s)	Inlet Width (m)
up to 3	5.5
4	7.5
5	9.0
6	11.0
7	12.5
8	14.5
9	16.5
10	18.5
11	20.0
12	22.0
13	23.5
14	25.5
15	27.5

Table 2. Minimum Outlet Widths of Spillways

Flow (m ³ /s)	Outlet width for various return slopes										
	24%	22%	20%	18%	16%	14%	12%	10%	8%	6%	>4%
up to 3	20	19	18	16	15	13	12	10	9	7	6
4	27	25	23	22	20	18	16	14	12	9	8
5	34	31	29	27	25	22	20	17	14	11	10
6	40	38	35	32	30	27	24	21	17	14	12
7	47	44	41	38	35	31	28	24	20	16	14
8	54	50	47	43	39	36	32	28	23	19	16
9	60	56	53	49	44	40	36	31	26	21	17
10	67	63	58	54	49	45	40	35	29	23	19
11	74	69	64	59	54	49	44	38	32	26	22
12	80	75	70	65	59	54	48	41	35	28	24
13	87	81	76	70	64	58	52	45	38	30	26
14	94	88	82	75	69	62	56	48	41	33	28
15	100	94	87	81	74	67	59	52	44	35	30

RESEARCH AND DEVELOPMENT IN LOW-COST SPILLWAY SYSTEMS.

More precise analysis of increasing amounts of hydrological data has revealed that spillways on many existing dams around the world are undersized for extreme events and the dams may therefore be at risk. By law, owners of large dams in Britain and Australia must make spillway improvements to meet newly determined flows based on the Probable Maximum Flood (PMF) determination. This situation has led to some innovative research by the Construction Industries Research and Information Association (CIRIA) in the UK into ways of providing low-cost emergency spillway systems and of upgrading existing systems. This led to research into reinforcing natural grass systems as an alternative to concrete. (Ref 2,3)

Using an old 11m high earth dam located in the English Midlands, CIRIA constructed ten channels, each with a base width of 1m, on the upstream 2.5 to 1 slope. Nine systems were tested, the tenth channel being the plain grass control. Four were geotextile systems that used 2- or 3- dimensional synthetic cloths laid beneath a grass surface to reinforce the plant roots. The five others were concrete block systems that provide a lattice through which grass can grow. Each channel was subject to up to 3 tests lasting more than 5 hours each, with velocities reaching a peak of 8 m/s at 1.3 m³/s flow rate. Tests were carried out at 2-week intervals to allow the grass time to recover.

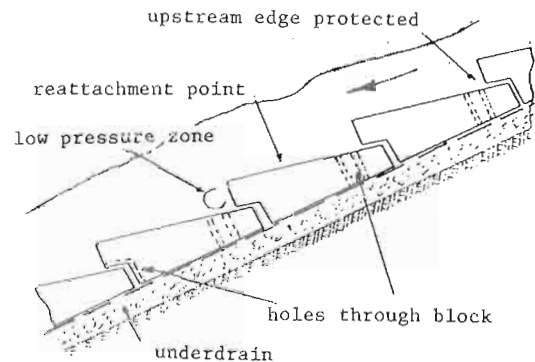
The plain grass control failed much as expected early in its second test at 5m/s. The concrete block systems showed that they all have high erosion thresholds but that a geotextile underlay is required to guarantee the high performance. There was no movement in these systems at the maximum velocity. The geotextiles performed beyond expectation with one 2-dimensional polyethylene cloth showing only limited grass loss at the end of three tests at 6m/s.

The economic advantage of the cloths which are one-third the cost of concrete block systems, is obvious. All of these systems have applications on small dam earthen spillways, but geotextile reinforcement of the grass surface seems to be particularly suitable.

WEDGE BLOCK SYSTEM

It was recognised during CIRIA's research work that there was a need for a low-cost reinforcement to unvegetated earth spillways as it appears to be impossible to maintain grass cover by any means on many, if not most, of the world's small earth dams.

Through the Salford University (UK) CIRIA undertook a laboratory research program, adopting Russian technology with American funding, to devise a simple low cost interlocking block system. (Ref 1) This research work has been successfully completed and, by mid-year 1992, CIRIA intends publishing a design guide in which this will appear. A British consulting engineer has a large concrete wedgeblock spillway under construction at the present time in Oman. A field trial of the system is planned in Australia next year.



Diag. 3. Wedge Block System

CONCLUSION

All of these developments should result in small earth dams providing a more durable, community-oriented water resource system. Mervyn Bramley former research director of CIRIA, put it this way - "Good design depends not simply on identifying the best material, but also on attention to the design of details, remembering that a spillway is only as strong as its weakest point".

REFERENCES

1. BAKER Ray, 1989. Precast concrete blocks for dam spillways, Water Power & Dam Construction. July.
2. BRAMLEY Mervyn, 1987. Reinforcement of steep grass waterways. Proc Nat. Conf. on Hydraulic Eng. ASCE. Williamsburg Virginia USA. Aug.
3. CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOCIATION. (CIRIA) 1989. Design of Reinforced grass waterways. Report 116 London.
4. DELAIN R.J. & VASEY G.H., 1961 A survey of farm dam supplies in Central Victoria. Melb. Uni. Aust.
5. MOHAMMED A. Samad et al., 1987 Statistical analysis of embankment dam failures. Proc. Nat Conf on Hydraulic Eng ASCE. Virginia USA Aug.
6. NELSON Ken. D, 1985 Design & Construction of small earth dams. Inkorta Pub. Melb Aust.
7. NICHOL Euan 1988. Rural water supplies W. Timor Indonesia. 14th WEDC Conf. Kuala Lumpur Malaysia.
8. UNITED STATES BUREAU OF RECLAMATION (USBR) 1977. Design of small dams.