

Paper presented for the
SYMPOSIUM
on
"Ways and means for disposal of surplus water in
storage reservoirs and other irrigation and
flood protective works"
at
The Annual Meeting of the Research Committee
of the
Central Board of Irrigation and Power
at
R o o r k e e
from 25th to 28th November 1957

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SYNOPSIS

In this paper new ways of classifying spillways have been suggested. The various types, merits and demerits of existing spillway devices have been discussed. The considerations governing the choice of a design of a spillway have been mentioned. A criteria for working out the economics of spillway design has been suggested. An efficient surplussing device has next been described and compared with other devices. In conclusion it has been suggested that the most efficient and at the same time economical arrangement will be a combination of crest gates, volute siphons and high head gates. The appendix gives a list of devices used in dams in various parts of the world.

WAYS AND MEANS FOR DISPOSAL OF SURPLUS WATER IN STORAGE
RESERVOIRS AND OTHER IRRIGATION AND FLOOD PROTECTIVE WORKS

By

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Introduction:

The safety of storage reservoir and other works depends to a considerable extent on the safety of the spillways which are built to dispose of the surplus.

Classification of spillways:

Their different types can be classified in several ways:

(1) Classified according to method of control:

(a) automatic such as open cuts, overflow dams and weirs, chutes, side channels, shaft and siphon spillways;

(b) semiautomatic such as overflow dams or weirs, chutes with crest gates. They are automatic when the gates are kept open, or otherwise they are under control. Ring gates have been installed to cover mouths of glory hole spillways making it also semiautomatic;

(c) controlled types such as various types of gates and valves.

(2) Classified according to method of passing the surplus:

(a) overflow dams - the flow is over the crest with a nappe adhering in most cases to the rear slope of the dam;

(b) side channel spillways - the flow is along a channel about parallel to the longitudinal axis of the dam;

(c) chute spillways - the flow along a steep channel about perpendicular to the longitudinal axis of the dam;

(d) saddle spillways - the flow is in a subsidiary valley away from the main river valley;

(e) shaft or glory hole spillways - flow is radial through an open pipe cut in the form of a funnel;

(f) siphon spillways - flow is circular or radial depending on whether a saddle or a volute siphon is used;

(g) crest gates - flow may be over or under the gates installed at the crest of the dam;

(h) high head gates - flow is through vents in the body of the dam.

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(3) Classified according to hydraulic characteristics:

Discharge:

(a) over a sharp or broad crested weir or a high coefficient weir. This is so in overflow dams;

(b) in an open channel as in side channel, saddle or chute spillway;

(c) through an orifice as in the shaft or glory hole spillway;

(d) through a siphon as in siphon spillway;

(e) through conduits as in vents through dams, or in diversion tunnels.

(4) Types, merits and demerits of existing spillway devices:**(a) Over flow dams without crest shutters:**

These are automatic in action and where hard rock is available and lands, and other utilities coming under submersion at levels below the F.R.L. of the reservoir are not expensive, this method of surplussing can be inexpensive. It has the advantage that flood gets moderated as it takes time to develop storage in rear of the dam for corresponding increase in the depth of overflow. The coefficient of discharge is high specially when designed as a high coefficient weir allowing for negative pressures at crest. Hydraulically it is very efficient.

(b) Side channel spillways:

Since the flow is almost parallel to the longitudinal axis of the dam this type can be economical if the valleys are very steep and the bed of the river and the channels consist of hard rock. Unless the channel is well lined there is always the danger of retrogression of levels taking place. These are also automatic in action unless provided with crest gates at the head of the channel. Since its discharge is through a channel, hydraulically it is not efficient as the flow is subjected to considerable frictional resistance of the boundaries, and turbulence, and also loss of head at the bend where the diversion from the dam to the river has to take place.

(c) Chute spillways used in the form of a ski jump has been successfully used in France. Where the height of dam is great, and the discharge to be passed is not very big, this type has been favorably considered for adoption. Since in the usual chute spillway type, velocities are great, the cost of protective works will necessarily have to be heavy. Though the first cost of constructing the spillway though smaller than in other types maintenance costs have to be heavy as velocities are great. The coefficient of discharge is poor

as the flow is similar to that over a broad crested weir or a channel. There is considerable air entrainment, which reduces the water content in the discharge.

(d) Saddle spillways: This has been successfully adopted where such subsidiary valleys are available in a project. As these form a unit separate from the main body of the dam, their maintenance costs are in addition to those for the dam itself. The saddle spillway itself may be of any type.

(e) Shaft or glory hole spillways: These have been successfully used in situations where diversion tunnels were first excavated for diverting the river flow during construction of the dam. The same have after construction been used as conduits for carrying the flow from the glory hole. In other situations it may not be economical as the discharge is very poor per foot of the circumferential length of the spillway. A lot of air gets entrained as the water drops into the shaft. The discharge gets reduced to the extent of volume of air entrained. The vortex movement of the flow also causes considerable losses due to friction resulting in a reduction of discharge. Hydraulically it is poor design.

(f) Siphon spillways: These are very economical and easy to construct and maintain them. The discharge per foot length of spillway as measured in a line perpendicular to the axis of the river is a maximum in this type. Its chief disadvantage is it does not come into operation till the water level is upto F.R.L. of the reservoir. Their flood moderating capacity is not as much as in many other types. The coefficient of discharge is quite high specially in the volute type.

(g) Crest gates: The types mostly in common use on dams are:

(i) Drum gates: These are useful where a large amount of debris and floating logs, ice etc., are to be passed over the crest without fully opening the gates. Lift gates require full opening to clear the surface of the water but drum gates need to be lowered just the amount sufficient for the purpose. The large shasta dam gates are 28 ft. by 110 ft. These require careful maintenance as housing for them is likely to be filled with dirt, making movement of gates difficult. Control in many of these gates is automatically effected through a device which admits or releases water from the chamber beneath the drum under the influence of water pressure on the upstreams of the gate.

Generally most crest gates are operated by externally applied power and require intelligent control. Travelling hoists are usually employed to lift such gates.

(ii) Taintor gates or section gates: These gates when submerged are hard to keep water tight both at the top and at the lower corners. Since

the gates are true sectors of a circle, the resultant water pressure passes through the pivot. Consequently they are capable of closing under free discharge by their own weight. The frictional resistance to motion is also small.

(iii) Wheeled gates, stoney gates, caterpillar gates, rolling gates are more widely used as high pressure gates rather than as crest gates. In crest gates, the discharge is similar to that over a weir.

(h) High head gates:

(i) Caterpillar gates: These work quite satisfactorily under heads as high as 200 ft. or more. The leakage in this type is very small and the force required to operate them is also small. When gates are opened partly they may be subjected to vibrations and cavitation. These may be minimised by providing suitable air vents and also lining a few feet upstream and downstream of the gate cill and sides with a stainless steel or other cavitation resisting shield.

(ii) Stoney gates: These also work satisfactorily and are fairly leak proof. After use of a few years, due to uneven wearing of rollers, gates start vibrating. Rollers need also frequent replacement due to uneven wearing after a few years of use specially if the gates are used mostly for part openings. The power required to raise them is very small.

(iii) Other types of high head gates are rarely used for flood disposal purposes and are therefore not mentioned here. The discharge through these types is similar to flow in conduits under high pressure. By proper design of the shape of the vent, high coefficients of discharge can be obtained.

(5) Considerations for fixing the type of spillway:

(i) Safety of dam: This should necessarily be the primary consideration. The method adopted for surplus disposal should be quick and certain in action at the required time, easy to manipulate and maintain. It is most desirable that there is arrangement for automatic spilling of some portion of the surplus so that in the event of all hoisting devices failing, there will still be time for repairing them or otherwise manipulating them manually.

(ii) Hydrological aspect: While considering the method of surplus disposal, the hydrology of design storms should be studied carefully. Overflow dams with or without crest gates have the advantage that considerable flood moderation takes place reducing the outflow from the dam. This reduces the cost of protective works below the dam and of the flood banks all along the river downstream. The number and size of gates or other openings should be determined such that the design storm is passed with the greatest safety to the dam, least damage to property below the reservoir and also ensures filling of the reservoir during its falling stages.

(iii) Geological aspect: A study of the geology of the area is necessary to determine the maximum scour that is likely to take place in the bed of the river due to operation of different intensities of floods. Certain types of spillways like those of the saddle, chute or glory hole types can only be considered (from the economic angle) in sites where rock is hard and the strata resistant against erosion.

(iv) Topographical aspect: A spillway in a steep gorge site is necessarily very short in length. High head gates and siphons may prove preferable to crest gates which require long lengths of spillway. A topography which admits of a saddle spillway close by may prove quite economical. A surplussing arrangement for a river in a deep gorge both up and downstream of reservoir will be different from that of flat valleys. Flood regulation will have to be done differently in each case.

(v) Method of energy dissipation: This depends to a very considerable extent on the type of the surplussing device. The two are mutually complementary to each other. A low height of dam, with tail water level at maximum flood discharge is hardly suited to energy dissipating devices like those of upturned buckets or by formation of hydraulic jumps. While high dams with low tail water levels would be well suited for design of stilling basins, or friction blocks and the like for energy dissipation.

(vi) River regimen: The effect of operation of surplussing devices on the regimen of the river downstream of the reservoir should be carefully considered. Since the velocity of inflow into the reservoir is checked, most of the silt is dropped into it. The discharge from a reservoir generally contains less silt than its carrying capacity for the velocity with which it passes downstream of the dam. The result of this is it is likely to scour both the bed and the banks of the river. It may also build up a new regimen to suit the new velocity of flow in the river which is different from that which existed before the dam was built. On the upstream side of the reservoir the process of silt deposition at the entrance to the reservoir may result in bar formations and consequent creation of spills over the banks in the upstream reaches. If the spillway device is such that it can create large bed velocities or bed movement in the reservoir, the formation of bars can be mitigated to a considerable extent. This requires large discharges to be passed at low bed levels of the reservoir. This will also help in maintaining the regimen of the river downstream also, as the silt charge in the discharge will be fairly heavy. From this point of view high head gates or siphons are preferable to crest gates.

(vii) Quickness and certainty of operation have to be ensured in every spillway device. In this respect automatic devices are better than those subjected to controlled devices.

(6) Economics of surplussing device: This should take into consideration the following:-

(a) First cost of construction of the length of the dam which houses the surplussing device, the gates, siphon, or any other device, hoisting devices, emergency gates, etc., protective works in rear and excavation of draft channel and any protective works necessary to the river downstream;

(b) Maintenance charges like cost of painting, oiling, replacement of parts, etc;

(c) Operation costs of salaries to skilled labour, supervisory staff, power charges etc., capitalised at the ruling rate of interest;

(d) Consideration should also be given to the fact whether they could be manufactured locally.

The cost per cusec of water spilled over the spillway should be a common measure of efficiency to compare the relative merits of the various surplussing devices.

(7) The efficient surplussing device: A study of the merits and demerits of the various types of spillway devices and those of the considerations which ought to weigh in taking a decision on the device to be adopted leads to the conclusion that in large reservoirs, it is not only risky but is also undesirable to have, only one device for surplussing the entire flood discharge. To ensure certainty and quickness of action it is imperative that a portion of the discharge is allowed to pass through automatic operation. The rest of it have to be passed through controlled devices which may be at the crest or near bed level of the river. The devices working at the crest have the advantage that they are easy to operate as water pressure against which they have to operate is comparatively small and the cost of gates themselves are cheaper than those installed at lower levels. But however their discharging capacity per foot length of spillway is smaller than high pressure gates. This results in long length of protective works etc. As they pass the discharge only at the F.R.L. of the reservoir, their capacity to remove silt is negligible. The overflow section of the dam is much costlier to build than the other sections in view of its heavier section and the cost involved in forming a hard and smooth surface for the overflow to pass in rear. The devices working near the bed level of the river have all the advantages which were mentioned as disadvantages in the case of devices working at the crest level. The only trouble with these devices is they are subjected to cavitation action. This has however been overcome with the provision now made of lining the vents for short distances upstream and downstream of gates with stainless steel or other cavitation resistant material and air venting.

Siphons do not suffer from any of these major disadvantages. Since they are comparatively of recent origin, their advantages have not yet received as much publicity as the other devices. About those, fear has been expressed about the following:

- (a) Choking up of siphonic flow due to entry of floating logs of wood or ice;
- (b) Priming depth being uncertain and high;
- (c) Depriming not taking place correctly at F.R.L;
- (d) Discharge being intermittant and pulsating;
- (e) Damages being, caused due to cavitation;
- (f) Vibrations being set up in the siphon and in the dam;
- (g) Difficulty of regulating reservoir levels;
- (h) Discharge being smaller per foot length of spillway than in other devices;
- (i) Costly protective works in rear of dam being required, and
- (j) Low coefficient of discharge.

Its efficiency may be compared to an open straight weir, equal in length to that occupied by the siphons to spill the same flood discharge. At Hirebhasgar, siphons have been designed for a discharging capacity of about 12000 cusecs. In the length of the dam occupied by the siphons, if an open weir had been constructed, the depth of overflow over the crest would have been 18 ft. to pass the same flood. The siphons have primed in less than 2 ft. The cost of payment of compensation for lands coming under submersion, the extra height to which the side flanks of the spillway had to be raised, the increase in thickness of the section of dam necessary to pass over this depth of overflow, and the increase in the number of villages that had to be shifted from the submerged areas would have all increased the first cost enormously. Like the open weir, the siphon is also automatic in action easy to construct and requires very little maintenance costs.

When compared to crest gates, these have the advantage that they suck water from levels far below the Full Reservoir Level. As the silt content in the water goes on increasing with depth substantially much more silt can be removed by siphons than by crest gates which merely skim the comparatively clearer water at the surface. It is also possible to remove silt from the bed of the reservoir to a small extent with the help of siphons. The high maintenance cost of crest gates which includes regular painting, oiling, frequent renewal of parts, power charges for hoisting and the high salaries of skilled operatives are all saved. The life of gates are generally put down as 30 years after which they start requiring heavy repairs and renewals. The water has to overflow on the rear face of the dam in case of crest gates. If the dams are built in stone masonry, joints require frequent cement painting

as they wear out quickly. The masonry stone surface gets eroded in a few years of flood discharge, requiring maintenance.

When the siphon is compared to an open circular weir of the same peripheral length with the same depth of discharge over it as the priming depth of a siphon, the discharge in a circular weir like the Glory Hole is only a fraction of the latter, the exact value depending on the operating head available for the siphonic discharge.

A few types of automatic gates have been designed but none of them work under as high operating heads as a siphon. Most of the gates, on account of long periods of disuse get rusty and may fail to act when they are most needed.

Maintenance and operating costs in case of high head gates are also much higher than in siphons. The parts require more frequent renewals. The high head gate has however the advantage that by opening them well in advance of the on coming of a flood, sufficient flood moderating capacity can be secured to reduce maximum peak flood discharge to safe limits. The outflow can be regulated so as not to cause any damage downstream of the reservoir.

About the siphons themselves, most of the apprehensions about their working are baseless. Since siphons draw their supply from water levels far below the surface there is no chance of ice blocks or floating logs getting in and choking them. There is a school of thought which seriously contends that air will get into the dome through the outlet if the discharge did not flow full bore and break the siphonic action or at least make the flow intermittent. Even siphons of 18 ft. in diameter through a little more than three fourths full have discharged continuously. Siphons either discharge continuously or not at all. Regarding priming depth, its depth can always be relied upon. Though in model experiments priming depth depends on rate of rise of reservoir level indicating a time factor in evacuating air, in the actual working the rate of rise of a reservoir is so slow that this does not affect priming depth. The priming depth can be as low as one twelfth the diameter of the throat. Depriming can be assured to take place at correct levels when designed with adequate capacity.

In high head siphons as in high head gates there will be cavitation in certain regions of flow. These are easily overcome in both these cases by the use of shields made of cavitation resistant material like stainless steels. When cavitation effects are overcome, vibrations which are primarily due to cavitation also get lessened considerably. By suitable designs, it is quite possible to overcome any small vibrations that may result due to inertia on account of change in discharge at the bend between the barrel and the outlet of the siphon.

The cost when calculated per cusec of surplus discharged, it will be found the cheapest will be that

of the siphon. The cost calculated at rates prevailing in 1946 in the manner already described worked out to Rs. 18/- per cusec in case of siphons and Rs.22/- in case of high head gates in Hirebhasgar dam. Now the cost of the gates will be very much more as cost of steel, labour and maintenance charges have all increased very much more than cement. The technique of designing siphons is now better known so that they can be designed cheaper than when they were done at Hirebhasgar.

Conclusion: It is apparent from the above discussion that it is desirable to have a surplussing device working at the crest level to allow debris and other floating material to pass through. Provision should be for passing only a very small portion of the total flood, as this type of device is uneconomical and plays no part in removing the silt content in flood flows. A major portion of the flood may be passed through siphons as they are automatic, quick and certain in action and are more economical. Provision is also necessary to have a few high head gates to bring down reservoir levels immediately before floods so as to moderate them. Such a combination of crest gates, volute siphons, and high head gates will be an ideal arrangement for most satisfactory disposal of surplusses.

The table appended herewith gives a general idea of the various devices that have been used for surplussing.

No.	Name of Dam	Type	No. of Dam	Maximum flood discharge	Type of spillway
<u>I N D I A</u>					
1	Krishnarajasagara Dam	Gravity	146 ft.	280,000 cusecs	Automatic gates High head gates
2	Mettur Dam	"	231 ft	456,000 cusecs	Saddle escape 810 ft. long and 16 Nos.crest gates 60 ft.by 20 ft. each
3	Khadakwasla	"	130 ft.	81,270 cusecs	Automatic crest gates
4	Thokerwadi	"	195 ft	4,010 cusecs	Open cut 557 ft.in length
5	Lloyd Dam	"	194 ft	51,505 cusecs	45 automatic and 36 rolling gates.
6	Marconahalli	Composite Earth and Gravity	87 ft	60,000 cusecs	Volute and saddle siphons
7	Hirebhasgar	-do-			Volute siphons and high pressure gates.
8	Hirakud	Composite dam	200 ft	1.5 m. cfs.	Thirty four crest gates 51'X 20' high and Sixty four deep set gates 12' x 20.33'.
9	Bhakra-Nangal	Straight Gravity	726 ft.	369,000	24 river outlets 93000 cfs. 2 drum gates 110' x 28' 123,000 cfs. Tunnel spillways with 2x 50' x 50' radial gates 153,000 cfs.
10	Rihand	Gravity	296 ft.	440,000 cfs	4 taintor gates 40' x 28' high.

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Sl. No.	Name of Dam	Type	Discharge	Type of spillway	Ht. of dam
<u>UNITED STATES OF AMERICA</u>					
1	Hungary Horse Dam	Variable thickness concrete arch dam	50,000 cusecs	Morning glory type with a ring gate.	564 ft.
2	Grand Coulee Dam	Straight gravity type-concrete	10,00,000 cusecs	11 openings with steel drum gates each 28 ft. high 135 ft. long	550 ft.
3	Hoover Dam	Concrete arch gravity		Four steel drum gates each 100 ft. long 16 ft. high	726 ft.
4	Shasta dam	Gravity and earth and rockfill at left and.		Drum gates each 110 ft. x 28 ft.	502 ft
5	Arrow rock	Gravity	40,000 cusecs	Gated side channel type	349 ft.
6	Angostura	Gravity and earth sec.	2,47,000 cusecs	Radial gates each 50 ft. by 30 ft.	135 ft.
7	Bartlett	Arch buttress	1,75,000 cusecs	Stoney gates fixed roller type	286 ft.
8	Stony Gorge dam	Ambursen type (slab and buttress construction)	30,000 cusecs	Steel caterpillar type gates each 30 ft. x 30 ft.	125 ft. above stream bed.
9	Anderson Ranch	Earth	20,000 cusecs	Concrete lined open channel	456 ft.
10.	Medicine creek	Earth	9,78,000 cusecs	Chute spillway	115ft. above river bed.

No.	Name of Dam	Type	Ht. from lowest level of foundations.	Max. flood discharge	Type of spillway
<u>F R A N C E</u>					
1.	Chastang	Gravity arch	279 ft.	140,000 cusecs	Two ski-jumps over the two power station roofs.
2.	Tigues	Arch	590 ft.	very little	Two sluice way tunnels each of 7 ¼ ft. in dia.
3.	Bort	Gravity arch	394 ft.	42,000 cusecs	Ski-jumps over power station roof.
<u>S W I T Z E R L A N D</u>					
1.	Spitallamm dam (oberhasli scheme)	Arch Gravity dam	114meters	very little	siphon R e m a r k s Built to catch mostly water from melting glacier.
<u>U. K</u>					
1.	Tummel-Gray Scheme Churia dam	Gravity	70 ft.		Two Drum gates 60 ft. x 16 ft.
2.	Galloway Scheme Loch Doon	Gravity	61 ft.	4,675	3 siphons each 5 ½ ft. dia
3.	Tongland	Arch and Gravity	72 ft. above river bed.	30,000	Overflow dam 325 ft. long and two high head gates 25 ft. by 31 ft.