SOME MISTAKES IN THE DESIGN OF FLOOD CONTROL WORKS

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In the past a number of mistakes in the design of flood control systems have come to the writers attention. The mistakes are in most cases easily seen when they are pointed out, but most of them escaped the notice of very able engineers who were concerned with the preparation of the plans, and it is therefore reasonable to suppose that similar mistakes can be made in the future by other able men. In the hope of preventing some of these mistakes in the future, they are pointed out in the following paragraphs.

Errors in the Design of Levee Protection Systems

One of the most common mistakes in flood control plans results in the flanking of levees by the water from the main stream, due to inadequate tying in of the ends of the levees to the high land. In one case on a major stream a levee designed to protect a large area of low lying land was connected to high land at both ends. It was later discovered, however, that the local stream which drained the protected area entered the main stream many miles downstream from the end of the levee, and that in a major flood the water could back up this stream and cause extensive flooding within the flooded area. In another case a levee was built to protect a city and was adequately connected to high land at both ends. One end was connected to a gravel ridge, and some time after the levees were completed a pit to remove gravel for commercial purposes was started on this ridge. Had this fact not been learned by the flood protection authority, within a short time a considerable section of the gravel ridge would have been removed, causing a breach in the protection system, which would have been nearly as serious as a breach in the levee.

It is not always necessary to tie the levee into high land at the downstream end. On a steep stream it may be carried far enough downstream so that the maximum flood level at its downstream end is low enough that it will not back up into the area which it is planned to protect. This method has the advantage over the ordinary ring levee around the area, that pumping plants are not required to prevent runoff from local rainfall discharging into the protecting area and flooding it, as an outlet channel for this local drainage can be built leading down to the end of the levee and then discharging into the main stream. Advantage may sometimes be taken of the local stream for all or part of this channel. In the design of such an interior drainage channel, however, it is necessary to be sure that the backwater curve of the local storm runoff in this channel, starting at the lower end of the channel at the elevation of the flood water in the mainstream channel will not be high enough to overflow the banks of this interior drainage channel and cause damage. This may require that the main river levee be extended considerably farther downstream than would be necessary only to insure that the flood level at its downstream end was lower than any of the land within the levee. In one flood protection system for a town the levee was not continued far enough downstream and flooding damage resulted in the downstream end of the area protected by the levee.

Levee systems are often designed by building the levees to a certain height above the greatest previous flood of record. This is not always an adequate method since such systems can at times be quite complicated and the computation of the height required for them be very complex. Great care is necessary to insure that all of the possibilities of stream action are considered. One case where protection to a certain height above the highest recorded flood was inadequate can be illustrated with the help of the diagram in Figure 1. In the largest flood for which data was available a great flow came down the stream from A to G, where it divided, most of it flowing down the stream GH, to the sea, part flowing down the course GBC to the sea, and still another flowing down the course GBDF to the sea. The latter flow washed out the sluice gate and levee which controlled the flow down the channel DF. A small flow came down the channel ED and joined the part of the flow from A passing down DF to the sea. The sluice and levee near D was rebuilt with its grade based on making it higher than this flood. However, it was not recognized that it might be possible to have larger flows down the channel ED, which combined with a smaller flood down the stream AG, would cause a flow in the stretch DB in the opposite direction from that in the great flood, which might cause higher stages at the sluice than that observed in the highest flood of record. In complicated cases such as this one, all reasonably possible combinations of flows must be considered and the levees built at each point to a height sufficient to protect against the most severe conditions at that point. The highest flood of record is often an inadequate basis of design, unless very long records are available.

One unusual case of levee failure took place on a leveed stream due to the placing of a levee across a large slough leading out of stream, as shown on Figure 2. The point of land C between the river and slough was high and covered with a thick growth of brush. It will be seen that if no water flows from the slough back to the river over point C there will be no flow down the slough and consequently no slope. Hence the water level at point B, where the levee crosses the slough, will be as high as at A. Since the point C is high and brush covered, the resistance to flow over it is great and the discharge over it will be small. The flow down the slough will not be zero, but will be small, and therefore the water surface elevation at B will be only slightly less than at point A. In this case the levee was probably built without taking into account the very small slope required in the stretch AB, with the result that the crest of the levee at B was so low as to be below the flood level and was over topped. This indicates that in developing an adequate design of a levee system it is not enough to consider only the backwater curve for the main stream, but consideration must be given to the effect of the secondary channels including lakes in the overbank area.

Errors in the Design of Channel Enlargement Projects

In the design of channel enlargement levee projects, it is not sufficient to compute what the enlarged channel alone would carry, but its connection with the channel downstream must also be considered. For example suppose in Figure 3, line AB represents the bottom of the river channel through a city in its original state and CD represents the flow line in this channel for the flood for which it is decided to design the channel enlargement. In several cases which have come to the writer's attention, it was decided to enlarge and deepen the channel to a uniform cross section and bottom grade with its bottom at, for example, the line EF, forming levees along the sides with the excavated material. From the channel cross section, roughness and bottom slope, the depth of flow required to carry the flood discharge, with a water surface GH parallel to the channel bottom, was computed. Levees along the channel were then designed to be a uniform height above this flow line, or on line IKJ.

The mistake in this method of design is that the flow line for the design flood downstream from the channel improvement (neglecting the storage effects mentioned later in this article) would not be lower than without the improvement. The flow line elevation at the downstream end of the enlarged channel with the improvement would be at point D and the flood water surface in the improved channel would follow a backwater curve, such as GKD. As this is above the levee top from K to D, the levees would undoubtedly be overtopped and probably extensive flooding of the lower end of the area supposedly protected by the levees would occur. Another error in this design is that at the lower end of the enlarged channel the bottom from L to F is below the level of the bottom further downstream and a pool or deeper section would be formed here at most river discharges. If the stream carries sediment, as nearly all do, some of it would tend to settle in this pool, gradually filling it up and thus decrease the discharge capacity of the channel. If channel improvements are made by channel deepening, the bottom at the downstream end should be sloped downward at the flatter slope than the natural slope of the stream, so that a pool will not be formed at low discharges. However, this smaller slope may cause some sediment deposit, and if the stream carries a heavy sediment load, serious deposits may occur.

This action may make channel deepening in a stream carrying heavy sediment load inadvisable.

Adverse Effects of River Straightening and the Reduction of Storage Space

Very crooked rivers are frequently straightened to increase their flood carrying capacity, by excavating channels across the neck of the bends, or in some cases by building a straight channel cutting off a few bends. In extreme cases a straight channel is excavated for considerable distance down the valley, connecting with the crooked channel only at a few points where the straight channel happens to intersect the crooked one. This procedure may lead to unexpected trouble, due to the decrease of valley storage capacity that straightening produces, and to the scour which may result in the straight channel if its slope becomes too steep.

In several cases crooked streams were straightened in the middle but not at the lower length of their course. The straightened channel was much steeper than the crooked stream; in fact, so much steeper that the flow in the straightened channel very badly scoured its banks and bed, and carried away large quantities of earth, trees and brush. When this material reached the unaltered section of the stream channel, this channel, because of its flatter slope, could not carry the additional sediment load resulting from the scour and bars were deposited in the channel, greatly reducing its capacity. On these bars the trees and brush scoured off of the banks further upstream collected, still further reducing the channel capacity and inducing additional sediment to deposit. The reduction of channel capacity thus produced, aggravated by the increased rate of flood flow caused by the cutoffs, as explained in the following paragraph, led to the complete abandonment of large areas of formerly productive farms in the lower ends of these valleys.

In one case an area along the lower end of a long, crooked river was protected from floods by cutting off many of the bends in this section. Later the cutting off of the bends was extended for a long distance up the stream. This reduced the overflow of the bottom land along the upper end of the river, thus reducing the space in which the water flowing into this section of the channel could be stored as the flood levels rose, and thus increasing the rate of flood discharge of the channel. The accumulative effect of the reduction of storage due to the cutting off of the bends along the length of the stream was so great that the rate of flood discharge at the lower end of the river was larger than the straightened channel would carry, and levees had to be built to protect the land which had formerly been adequately protected by the cutoffs.

In general, it may be said that any flood control construction, such as levees or cutoffs, which reduce the space in which the flood water of a stream can be stored as the flood rises will cause an increase in the rate of discharge of that stream. Where the reduction in storage space is great, the increase in discharge rate is likely also to be large. This fact must be considered in determining the effect of the construction of floodway channels. In the design of one floodway channel storage effects were neglected, but amounted to nearly 40% of the floodway capacity with the result that a major disaster would have resulted had the floodway been built as first designed and a flood of the size contemplated in the design occurred.

To understand this situation, consider a hypothetical case where it is proposed to build a leveed floodway channel to carry the excess flow of a river in flood time, to prevent overflow, the leveed channel running parallel to the river. Suppose the river will carry a maximum flow of 3,000 cubic meters per second without damage, for which elevation of the water surface at the upper end of the floodway is 30 meters. Suppose however that a flood of 5,000 cubic meters per second can be expected to come down the river to the head of the channel, and protection against this flood by means of the leveed floodway is contemplated. It would seem at first glance that a floodway which would carry 2,000 cubic meters per second at an elevation of 30 meters at its upper end would have been ample. However, this is not the case. Had the 5,000 cubic meter per second flood occurred in the river without the floodway, it would have reached a higher elevation than 30 meters; for example suppose it would have reached to an elevation of 35 meters. To take the total flow down the river and the floodway without reaching an elevation higher than 30 meters would require that the floodway channel would have to carry not only the 2,000 cubic meters per second, but also the volume of water which would have been stored in the river channel and overbank area upstream from the floodway, between the flow line of the natural flood (which reach an elevation of 35 meters at the upper end of the floodway) and that produced with the floodway constructed (which reached an elevation of 30 meters at the same point).

The amount of additional discharge capacity required would depend not only on the storage space between these two flow lines but also on the rate at which this space would be filled up by the 5,000 cubic meter per second flood in the river without the floodway constructed. It should be noted also that the increased discharge that would require the increase in discharge capacity for the floodway will also increase the flood discharges in the river downstream from the floodway. This increased discharge downstream must be taken into account in designing the levee heights not only in the river downstream from the floodway but also in the floodway itself and along the main river in the stretch paralleing the floodway. The effect of the greater discharge in the river downstream from the floodway and consequently the higher water levels there is to reduce the slope in both the floodway and the river parallel to the floodway. Considerable information on the effect of storage reduction on the design of floodways is given by Linder.*

Mistakes Involving Reservoirs

A mistake which has frequently been made in estimating the effect of constructing a reservoir to reduce the flood on a river is to assume that all of the storage capacity of the reservoir is available for reducing the flood flow. The amount which is actually available is only the volume by which the storage available when the reservoir is constructed exceeds the volume within the reservoir which would be filled by the river during flood before the reservoir is constructed. In the case of reservoirs on large streams, the volume within a reservoir which is occupied by the river in its natural condition may be very large, and constitute an appreciable part of the total capacity of the reservoir proposed. In such cases it is important that this natural filling space be accurately determined.

A point which is sometimes overlooked in planning flood control schemes involving reservoirs with outlets which are built without gates to regulate their outflow, is that under certain conditions such reservoirs can increase the peak flow in the rivers downstream. For example, consider the effect of such an uncontrolled reservoir on a small tributary of a large river. The maximum discharge of the tributary may, under natural conditions, occur say three days after the rain storm producing a flood, and the maximum flow of the large river is likely to come later, say six days after the rainstorm. The reservoir may materially reduce the maximum flood flow on the tributary stream on which it is located, but it may produce a larger flow into the main stream six days after the storm, when the main stream reaches its crest, than would have flowed out of the tributary stream at that time if the reservoir had not been constructed. An increase in the height of the flood in the main stream would thus be caused. Flood control reservoirs with uncontrolled outlets produce their maximum outflows later than the maximum flow in the stream on which they are located, and the possibility that this could increase the size of the floods downstream should be investigated whenever such outlets are planned. The difficulty can usually be removed by using controlled outlets, but controlled outlets also have disadvantages.

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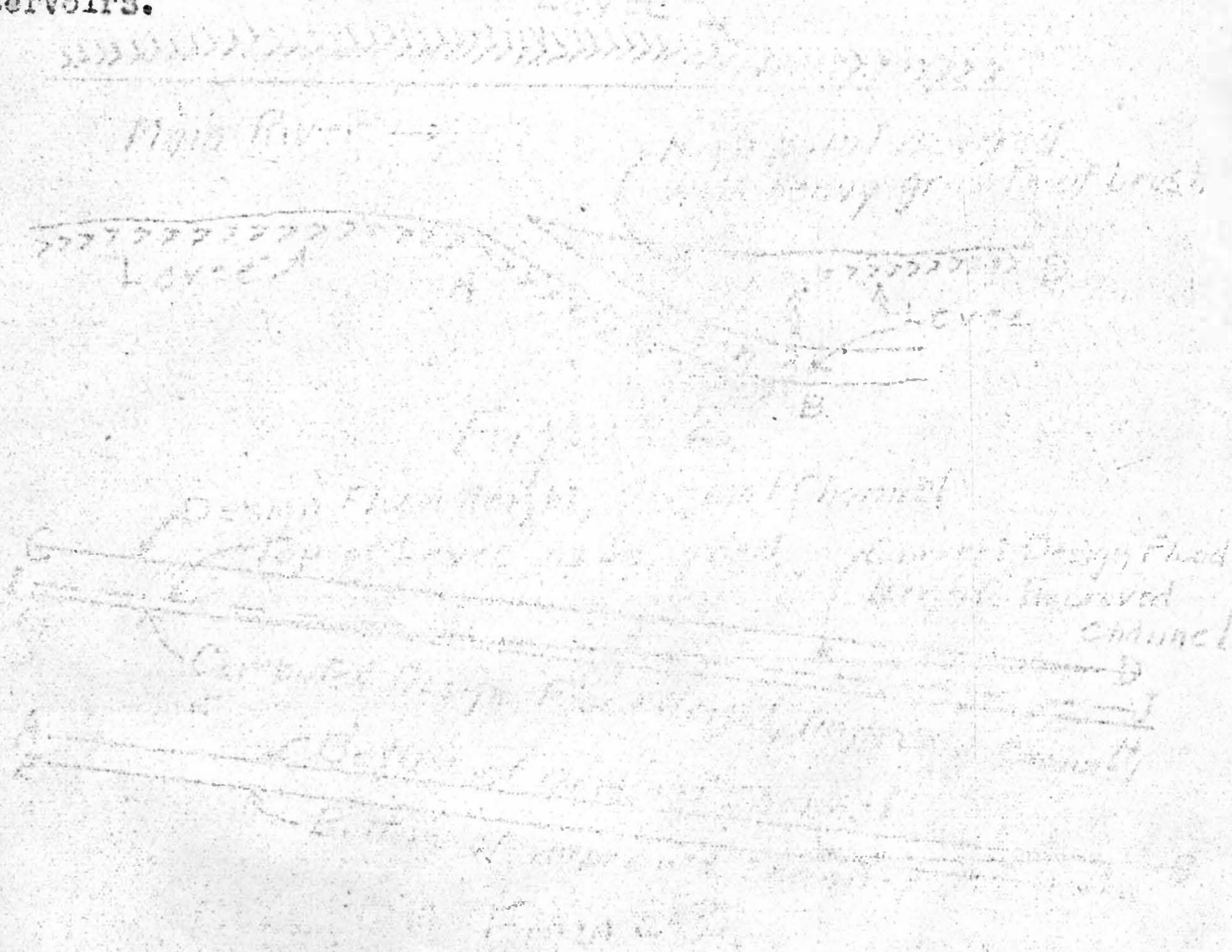
* Diversions from Alluvial Streams, C. P. Linder, American Society of Civil Engineers, Separate No. 112, January 1952.

As a result of the construction of reservoirs for flood control on streams carrying a very heavy sediment load unexpected detrimental effects may arise because sediment is likely to be deposited, not only in the reservoir but also upstream from it. When the heavily sediment laden water coming down the stream reaches the level at which water is being stored in the reservoir, it will drop a large part of its sediment load, causing the river bed at this point to fill up somewhat. This will decrease the slope in the river upstream and cause deposits and a rise of the river level there also. Some of this deposit may wash out later, but if the river banks and bed are of easily erodible material the deposits probably will increase with time and may cause a material raising of the stream bed for a long distance upstream from the reservoir. This same effect occurs above storage and water power reservoirs, usually even to a greater extent than in flood control reservoirs.



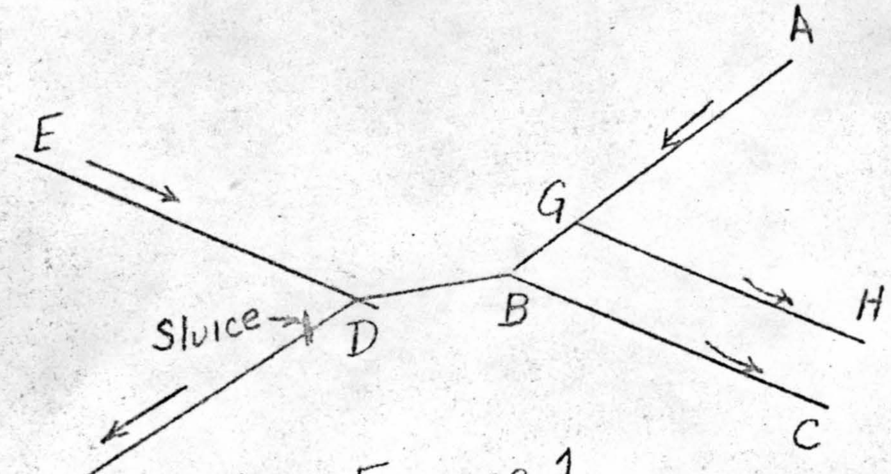


Figure 1

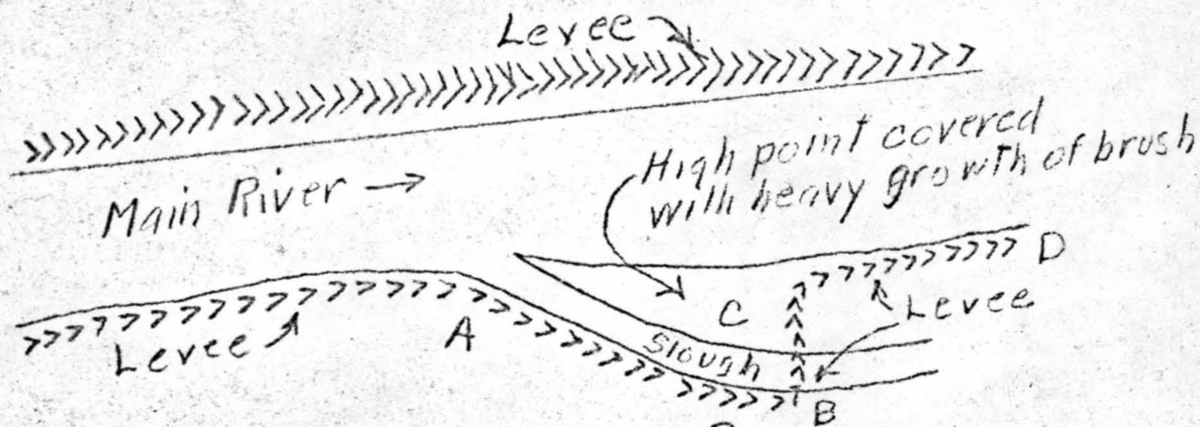


Figure 2.

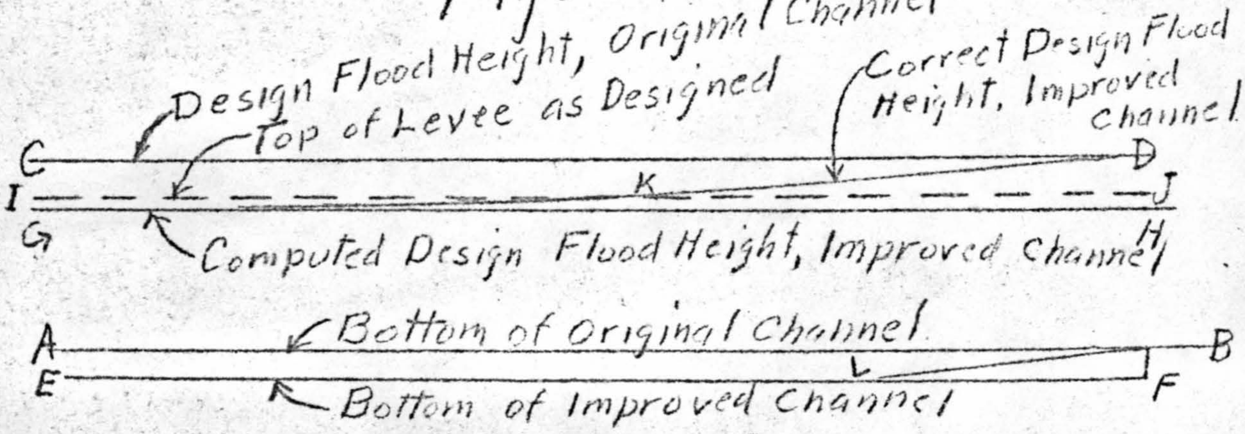


Figure 3