

HIGHWAY DRAINAGE

EUGENE M. WEST, Research Engineer
Kentucky Department of Highways

The Highway Research Laboratory is presently engaged in a rather extensive research project dealing with highway drainage. This project is directed towards improving the present methods of estimating the design discharge, the flow that must be accommodated, and the development of a more direct approach to design. I do not wish to report on the findings of this project at this time, but I would like to discuss briefly some of the necessary features of highway drainage that need be considered after the design discharge or culvert size has been estimated, in order to obtain anywhere near maximum performance from the structure.

The importance of drainage in highway construction can best be realized by considering it from two different standpoints: (1) the initial cost of construction of the drainage structure, and (2) the maintenance cost on these structures and on the backfill in the culvert area.

The Bureau of Public Roads recently published statistics showing that on an average for the country as a whole, about 25c out of every dollar spent on highways goes for culverts, bridges, and related structures. Approximately 60% of the total cost for drainage structures is for culverts and bridges with less than 20-ft. span. The higher percentage of the cost of drainage structures is in the culvert size. This is attributed to the fact that, although the unit cost is much lower, the tremendous number of them causes their aggregate cost to exceed that of bridges. These figures can easily be accepted as conservative for Kentucky then, since we have approximately 50,000 culverts in the state.

For the year 1950, slightly more than two billion dollars was spent on highway construction in the United States, of which approximately 300 million dollars was spent on drainage structures alone.

It has been estimated that between 15% and 25% of the maintenance dollar is spent on normal maintenance of culverts and bridges. This does not include the repair of damages caused by extreme floods, which in many instances require complete reconstruction of the roadway and structures.

In view of these figures, which would certainly apply to Kentucky, it might be well to question the extent to which we are utilizing the money we are spending on drainage structures.

The factors involved in the location and design of drainage structures are many and the conditions widely varying. Even by using the best known methods of approach we could not hope to obtain 100% efficiency from our structures, however, we could increase the overall efficiency considerably, by giving consideration to some of the more obvious factors that seriously affect the functioning of the structures.

There has been considerable research on the hydraulics of culverts in the past and a number of projects dealing with the flow of water thru culverts are being carried on at present. The majority of these efforts are directed toward increased efficiency by considering special shapes, critical slopes, and roughness; however, we can express some of the conditions with which we are more familiar in terms of the hydraulic behavior and energy distribution in a more general sense. These factors are: alignment, entrance conditions, outlet conditions, obstructions in the channel and scour.

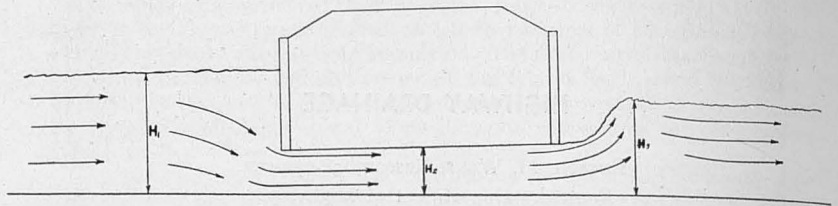


FIGURE 1

Let us consider a case where all of the important factors mentioned have been abused (See Fig. 1). Acknowledging the fact that the object in placing a culvert in a stream is to conduct the water under the roadway with a minimum of interference, we might express this in terms of the first law of physics: "Energy can not be created or destroyed"—it can only be transformed to some other form. Here, as in any energy problem, we are concerned with the transformation of the energy.

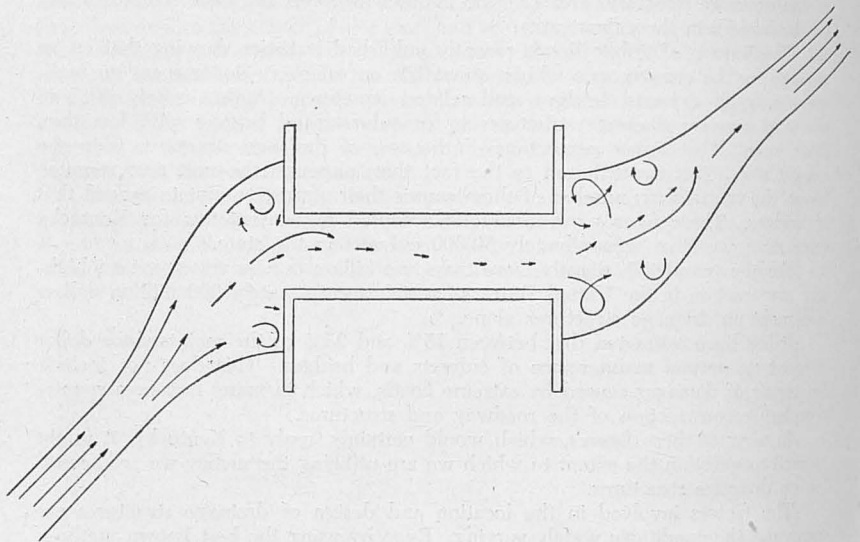


FIGURE 2

The flow approaching the structure has energy (H_1) in the form of potential head and in the form of velocity. At H_2 , due to the limitation on the possible head, there is an increased velocity. In other words, some of the potential head energy has been transferred to velocity energy. At the outlet end, the head is not limited to the size of the structure, allowing some of the velocity energy to be transferred back to potential head energy H_3 . The more nearly the total energy at H_3 approaches the energy at H_1 , the more efficiently the structure can operate.



FIGURE 3



FIGURE 4



FIGURE 5



FIGURE 6

In other words, when water flows through a culvert, the smoother the transition the smaller the amount of energy dissipated to the headwalls and embankment or lost during the transformation at the outlet, the more the structure can carry. The ill effects of poor alignment, improper wingwalls, and obstructions in the approach channel is apparent by the turbulence which is developed by the energy that would normally be transformed to velocity energy. This not only decreases the carrying capacity of the culvert, but it is also detrimental to the structure itself. This source of wasted energy is working on the wingwalls, abutment, and backfill.

At the outlet end of the structure there is another marked transformation of the total energy remaining after losses. Since the flow is no longer restricted to the size of the culvert, it must immediately take the shape of the channel again.



FIGURE 7

Here again, a serious effect can be caused by the abrupt transformation of the flow. The energy that is dissipated unnecessarily will be a force acting on the structure itself. This effect is noticeable in the turbulence set up at the outlet, around the wingwalls. A smooth transition from culvert flow back to channel flow can be aided by properly designed and placed wingwalls at the outlet.

When a structure is operating near capacity the flow leaving a culvert will invariably scour a hole, if the stream bed is erodable. In the transformation of the velocity energy in the culvert back to an increased potential head an abrupt change is experienced. This energy cannot be changed immediately and a turbulence is set up. This turbulence is necessary in order to dissipate the energy that is lost in transformation. This is known as the hydraulic jump. If nature has dug



FIGURE 8

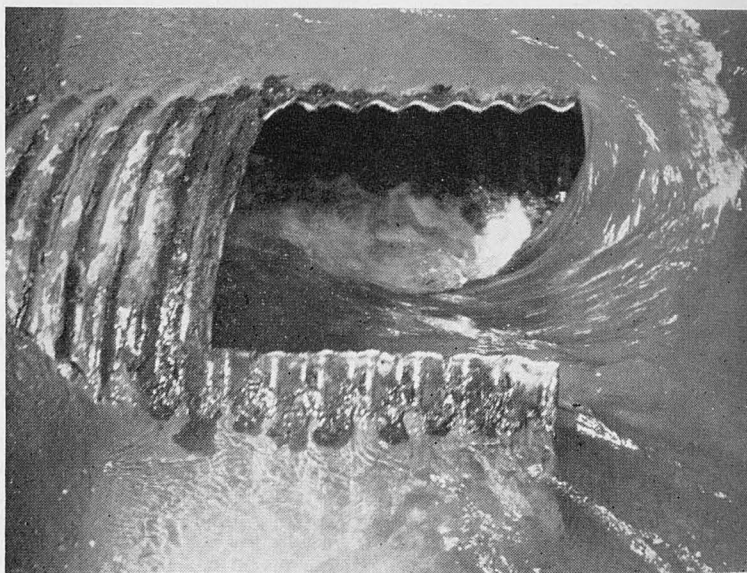


FIGURE 9

a pool through dissipation of this energy, this pool should not be filled with large stones, but should be rip-rapped at the bottom and around the edges to keep it from enlarging. Filling of this hole will tend to move the hydraulic jump down stream, but will add to the energy loss due to the increased roughness of the channel.

When conditions for transforming the flow from open channel flow to culvert flow and back to open channel flow are not smooth, serious conditions exist. This problem has to do with the silting of the structure. During the changing conditions a portion of the flow loses its velocity energy and becomes misplaced in the flow pattern. The silt-carrying capacity decreases to a point where the silt is deposited, usually at the wingwalls or in the cases of low velocities and low slope, at the outlet. In some cases where alignment is very poor, silting will take place within the barrels at the points where the eddy currents exist.

These are a few of the more obvious features affecting the flow of water through culverts. Many other features not discussed are also of outstanding significance and should be considered in all cases. The intent here has been to point out the fact that, for better drainage design and operation, it is necessary to go beyond the procedure of estimating the discharge to be accommodated. Even with the exact discharge known, which will rarely be the case, it is necessary to consider these features in the selection of the size. The flow to be accommodated might be estimated to within a very close tolerance yet the structure capacity could be grossly exceeded due to lack of consideration of these hydraulic principles that are known to exist.