DRY-WEATHER FORDS

By C. R. Yater, Engineer, Shelbyville, Indiana

Early in 1929 I was appointed engineer on the Murray Road, a free gravel road located in Van Buren Township, Shelby County. This road was about three-fourths of a mile in length and crossed a stream known as Big Brandywine. This stream flowed through a comparatively level district which permitted it, in flood periods, to overflow considerable territory.

The two viewers appointed on this project felt as I did, that the benefits to be derived from the building of the road would not equal the expense, and so reported. We had in mind the bridging of the stream, which would have called for heavy approach fills. The petitioners evidently did not care much for our decision, for at the next term of the commissioners' court they were there with a new petition, which was granted by the commissioners. During this time I had been interviewed by one of the interested petitioners, who incidentally had had considerable experience as a road contractor and who suggested the idea of constructing a dry-weather ford in place of a bridge over this stream. Upon making the second trip to view this road with the new set of viewers, I suggested this plan to them; and as the road was, in our opinion, a road that would not at any time have very heavy traffic, they decided in favor of granting the road and taking care of crossing the stream in the manner suggested.

This ford is not new in principle, as it is nothing more than a multiple culvert; yet we had never attempted any such construction in our county, nor did we have any such installation near to which we could refer.

Rough estimates revealed that it would have cost not less than $9,000 to bridge this stream and make the necessary approaches. We could more cheaply construct a ford using a series of corrugated iron pipes held in place with concrete spandrel walls on a concrete base. The estimated cost of this installation was $4,076.75. The contractor informed me that the actual cost ran around $2,500, which shows a saving of approximately $6,500 over a bridge construction.

The space between the pipes and between the spandrel walls was filled with a low grade of gravel tamped in place, over which was placed a concrete slab 7 inches thick reinforced with one-half inch bars 12 inches on center and with 40-pound wire mesh. The footings were made 30 inches wide and 21 inches deep. Immediately on top of the footings the corrugated iron pipes were laid. The pipes were 30 inches in diameter and 18 feet long.

As stated before, this construction was decided upon because it was the feeling that this road would carry but little traffic. How little we know about the future is revealed by the fact that the state highway department later routed State Road 9 over this strip of road. This may be a temporary routing, however; but should it become permanent, this stream crossing will have to be improved, as it was never intended to take care of regular year-round traffic.

After a year's trial under all types of weather conditions, this type of construction proved to be very satisfactory. When we were confronted with another problem of bridging Blue River on what is known as Alonzo Phares Road in Union Township, we did not hesitate to adopt a similar solution of the problem. This condition was not quite the same as had confronted us before, because we had a larger stream to take care of, a larger watershed, and a road assured of fairly heavy traffic. We were, however, handicapped in this case because of lack of money, the township being bonded already to nearly its limit.

DESIGN

The watershed consisted of about 8 square miles of medium-rolling farm land. With an assumed head of one foot on the pipe, the discharge through one 54-inch pipe would equal 110 cubic feet per second. A 4-inch rainfall per hour over one square mile would equal 269 cubic feet per second. The mean maximum rainfall for the State of Indiana as shown by the records is 2½ inches per hour. This condition occurs only once in 25 years and then only for a duration of 120 minutes. From these data we find that multiplying the 269 cubic feet per second by the area (8 square miles), we obtain 2,150 cubic feet per second. This figure is based on a 4-inch rainfall, and we are concerned only with a 2½-inch rainfall, equivalent to 63%. Sixty-three per cent of 2,150 cubic feet is 1,350 cubic feet, the amount of water to be taken care of. By dividing 1,350 cubic feet by 110 cubic feet, we find that a total of 12 pipes is required. Because the level lowland adjacent to this structure (Fig. 1) permitted the water in times of flood conditions to spread out over considerable territory, and because this stream has a fair run-off, we felt that 60% of the capacity computed would take care of this condition and as a result designed accordingly, using eight 54-inch pipes.

Having thus determined the number and size of the pipes to be used, we next had to determine the elevation for the top of the concrete slab that would give us the use of this ford for the greatest length of time during the year, yet keep the cost to a minimum. To do this I interviewed some of the older residents of the community to ascertain the high-water mark and the mean high-water mark. With this information at hand, I was able to establish the top of the road slab at such height that under normal conditions there would not be more than possibly five days out of the year that this ford could not be crossed. While the ford has been constructed for less than a year, the experience so far leads me to believe that these calculations are reasonably correct.

The next question involved was to work out a design which would make this structure stable under all conditions which it would have to meet. The soil condition, so far as we were

Fig. 1. The site before construction started.

able to determine, was sand and gravel with a possibility of some quicksand. I might state that this type of construction is advantageous if you do strike a quicksand deposit, as we did on this project; for it need cause you no worry, provided it is not too extensive. The spandrel wall is so designed that it also acts as a beam in the event that there should be a sluffing away of the soil on which it rests. Consequently, when we struck a pocket of quicksand on two different occasions during this construction, we maintained our established elevation for the bottom of the footing and proceeded with the construction, a practice that none of us would take any chances with in a structure such as a bridge or retaining wall.

Rough figures indicated that a wide footing on the spandrel walls would not be necessary. For example, taking the minimum bearing power of sand, namely, eight tons per square foot, it is obvious that we could not approach this weight, as the greatest dead load we could get was 2,312 pounds per square foot. This figure included the weight of the road slab, which it is evident, is supported on the fill. It was included in the dead load, however, to take care of the settlement in the fill should that occur. Assuming a uniformly distributed load of 200 pounds per square foot, with the further assumption that all of this load could be transmitted to the bearing soil through the spandrel wall, we would have a further load of 1,800 pounds as the live load, which added to the dead load gives a total load of 4,112 pounds per square foot, which is about one-fourth of the bearing power of the soil.

The stresses that would be set up in the spandrel walls would be similar to those produced in a retaining wall, particularly during the process of filling between the pipes and in the event that a flood condition should be encountered during construction. The thickness was thus determined by using Baker's rule covering stability for retaining walls, which provides that for back-filling level with the top of the wall, the thickness at the bottom should be one-fourth of its height. Because of the fact that these walls are tied together at the top as well as by the culvert pipe, we felt perfectly safe in cutting the figured dimension from 21 to 18 inches, with a batter of about one inch per foot, or to be exact, six inches in seven feet. In order that the concrete should take care of beam action if such action resulted as explained above, and also further to strengthen and tie the entire concrete part together, two longitudinal bars 9 inches on center were placed on the footing, or rather that part of the spandrel wall which was below the flow line of the pipe. The design called for the filling between walls and pipe to be made with low-grade gravel. This fill was to be slushed and tamped into place and to cover the top of the pipe two inches in order to form a cushion for the concrete slab which forms the roadway. This slab was designed 8 inches thick, reinforced with one-half inch bars spaced longitudinally 12 inches on center, and transverse bars of the same size, 12 inches on center. All bars were straight except the three which came between the pipe; these were bent at right angles, one leg being made three feet long and inserted into the spandrel walls as soon as the concrete was poured in order to tie the spandrel wall and road slab together. This could be improved on, from a construction standpoint, by making the bent bars three feet on one leg and 50 diameters on the other, the transverse bars all being straight, and all installed just before the slab is poured. This eliminates the bars being in the way of the workmen during the filling process and other work previous to the pouring of the slab.

The approaches to the ford proper were made by constructing a wall on each side of the concrete to support it (Figure 2). These tapered from the depth of the spandrel wall on either end of the ford proper to a depth of two feet below the top of the slab on the extreme ends. This was particularly designed to prevent washing in times of flood conditions. The slab not over the ford proper was reinforced with 40-pound wire mesh.

Fig. 2. Construction progress. Pump dewatering cofferdam for approach wall.

Fig. 3. Ordinary flood conditions. Note guide posts.

The ford proper was 63 feet long and the overall length, including approaches, was 250 feet. The width at the ford proper was 18 feet, and the width of the slabs for the approaches was 14 feet. Twenty feet for the ford and 18 feet for the approaches would have been a better design had money been available. A 2-inch crown was placed in the road slab. The concrete was a 1:2:4 mix of washed sand and gravel for all concrete except the slab, which specified a $1:1\frac{1}{2}:3$ mix, in order to get a denser concrete. This would eliminate a certain amount of water absorption and prevent disintegration by frost action.

Guide posts of $2\frac{1}{2}$-inch black pipe were placed on each side, painted white to serve as a guide when the water is over the ford (Figure 3). There should also be markers placed at every foot in elevation on either end to inform the stranger just how much water is over the top of the roadway.

CONSTRUCTION

The first step in the construction of this ford was the building of a cofferdam large enough to permit construction of half the structure. This cofferdam was constructed of native one-inch lumber held in place by wales. The forms were built about 18 inches apart and the space was filled with loam and clay tamped in place. The construction area was dewatered by the use of a four-inch pump propelled by a Ford engine. The trenches were excavated to the depth shown and the concrete was run in up to the bottom of the pipes. The pipes were then placed and the forms built for the spandrel walls. After the reinforcing steel was placed, the concrete was poured. After the forms were stripped, the exposed face of all concrete was honed to a smooth and uniform surface, and the back-fill was made. When the first section was thus completed, the cofferdam was removed and rebuilt on the other half of the stream and the process repeated, the water being forced through the section already completed. Expansion joints of one-inch precast asphalt were used at both ends of the ford proper. Construction joints were formed by a V-shaped bulkhead.

In order to relieve as much as possible strain on the structure during flood periods, and to help such debris as might be floated down the stream to pass through the pipe, buttresses were constructed on the upstream side between the pipes (Figure 4). These were formed very much like a wheel guard you have noticed at garage doors. On the site of the ford was considerable rip-rap in the form of large boulders which were specified to be distributed on the downstream side of the structure to prevent undue washing.

The engineer's estimate on this construction was $4,600, which we figured was a saving of $5,400 over the cost of a bridge. These figures, as to saving, are very conservative, I

Fig. 4. Pipes in place. Note buttresses between pipes to aid in passing debris.

think. The actual cost of construction was much under the estimate, judging from the bids received. I have no actual cost data. I have always felt that this was a private matter with a contractor and made no attempt to get this information.

Do not get the impression that we are recommending this type of construction for general use. I do, however, think that there are many places for its use, especially in level territory where the water, during flood periods, spreads out over large areas where, in order to accommodate all-year traffic, long and high fills would have to be built for approaches. A further determining factor is that most of the county roads now being built are light-traffic roads, connecting in most cases heavier-traffic roads. Even though for 5 or 10 days during the year traffic desiring to use the road would be forced to detour, the saving in original cost of 50% justifies this type of construction. At least, it has met with universal approval wherever we have used it in our country.

DESIGN AND CONSTRUCTION OF CONCRETE CULVERTS

By J. W. Botset, Marshall County Surveyor

In designing a culvert, one of the first things to determine is just what kind of structure is needed for the particular situation. It seldom happens that the same design of structure will fit two locations. For instance, the stream may cross at an angle with the center line of the roadway, necessitating a skewed culvert, or special wing walls or retaining