suited to different cases, and how best to design different types of LWCSs for various conditions.

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REFERENCES

1. Y.Y. Haimes and W.A. Hall. Multiobjectives in Water Resources Systems Analysis: The Surrogate Worth Trade-Off Method. Water Resources Research, Vol. 10, No. 4, 1974, pp. 615-624.
2. M.B. Sonnen and L.C. Davis. Wild Rivers--Methods for Evaluation. Water Resources Bulletin, Vol. 15, No. 2, April 1979, pp. 404-419.
3. L.B. Leopold. Quantitative Comparison of Some Aesthetic Factors Among Rivers. U.S. Geological Survey Circular 620, U.S. Government Printing Office, 1969.
4. M.T. Tseng, A.J. Knepp, and R.A. Schmalz. Evaluation of Flood Risk Factors in the Design of Highway Stream Crossings. FHWA, Rept. FHWA-RD-75-54, June 1975.
5. V.R. Schneider and K.V. Wilson. Hydraulic Design of Bridges with Risk Analysis. FHWA, Rept. FHWA-TS-80-226, March 1980.
6. M.L. Corry, J.S. Jones, and R.L. Thompson. The Design of Encroachments on Flood Plains Using Risk Analysis. FHWA, Hydraulic Engineering Circular 17, Oct. 1980.

Cost-Effective Low-Volume-Road Stream Crossings

MERVIN O. ERIKSSON

Because of their high relative cost and degree of importance in any transportation system, stream-crossing structures warrant careful site selection, structure type selection, and design. All too often a stream is spanned with a conventional structure merely because that is the way it has always been done, or a replacement structure is designed to the same standard as the previous structure without consideration of other options. The features to look for in selecting a stream-crossing site for low-volume roads are discussed and ideas are provided on improving communication among the road locators and designers, the bridge designers, and other necessary specialists. Some of many possible alternatives to conventional bridge-type crossings are offered, and ways are suggested to make a design and contracting system more cost effective through the use of standard drawings and contractor design options. Several examples are included of how low-water crossings can be used. These examples show some of the many possible variations that can be included in the design of low-water crossings. Costs are used to compare the low-water crossings and the design alternatives. Costs of the low-water crossings are based on actual bid prices, whereas costs of the design alternatives are based on the engineer's estimate.

Bridge construction and maintenance costs can be a substantial percentage of total road construction and maintenance costs. Careful site location, innovative structure type selection, and efficient design can significantly lower these costs without reducing the service, safety, load-carrying capacity, durability, or design lives of these structures. These structures can be designed and installed without damaging fisheries, wildlife, or aesthetics.

The Northern Region of the Forest Service of the U.S. Department of Agriculture (USDA) includes 15 national forests in northern Idaho and Montana. The region has jurisdiction over approximately 30 000 miles of road, which include more than 1300 existing bridges. The region annually constructs or reconstructs approximately 1600 miles of road and 30-50 stream-crossing structures. Approximately one-half of these structures replace existing structures and one-half are new construction. These crossing structures are usually on road systems that have low traffic volumes, low design speeds, and difficult alignments as well as fisheries constraints, limited access, and often difficult design parameters. These conditions offer many opportunities for imaginative design to produce the most cost-effective alternatives possible.

Ideas on crossing-site selection, structure type selection, types of design, and several examples of how low-water crossings can be cost-effectively used are discussed.

SITE SELECTION

Careful site selection provides the greatest potential for cost savings. Poor site selection can result in a longer, wider, or higher structure than is really needed or may result in a very costly curved bridge or complex and costly foundations. A poor location can cause difficult, dangerous alignments and a shortened structure life.

Determining the optimum crossing site requires balancing many variables; some affect design of the road and some affect design of the bridge. An ideal stream crossing from the perspective of the bridge designer may be described as follows:

1. It would cross the stream at an area with well-defined banks. The stream is generally narrower at these locations and the stable banks indicate a stable stream channel.
2. It would cross the stream away from curves in the stream. These areas are often unstable because the stream tends to move toward the outside of the curve. Also a stream usually is wider in a curve than in a tangent reach. A curve may require channel straightening if a pipe-type structure is installed or cause roadway fill retention problems if a bridge is installed.
3. It would cross the stream at an area with a uniform stream gradient. An increasing gradient increases erosion and scour potential. A decreasing gradient can cause streambed load and debris deposition.

4. It would cross the stream at an area of the channel that has relatively nonerodible streambed materials. Nonerodible streambed materials reduce scour potential and thereby allow some deviation from the above-listed constraints.

Road alignment also affects the type, size, and cost of a stream-crossing structure. If possible, again from the perspective of the bridge designer, an ideal stream crossing would have the following characteristics:

1. It would cross the stream at a 0-degree skew angle. Crossing the stream at right angles reduces the span length of a bridge or the length of a pipe.
2. It would cross the stream on a horizontal and vertical tangent. Crossing on a horizontal curve often means widening or curving a bridge, either of which is very costly. Installing a pipe on a curve increases the length of the pipe. Crossing on a vertical curve presents no problem with a pipe but can significantly increase bridge costs if the bridge deck must conform to the vertical curve.
3. It would cross the stream at the minimum elevation necessary to pass the design flood flow and any associated debris and ice. Raising the elevation of a bridge increases the abutment costs and in some cases lengthens the bridge. Raising the road elevation over a pipe increases the length of the pipe.

Obviously, ideal crossing locations are seldom found, and balancing all the above-listed variables along with road design variables is a complex process. Solving the problem in the most cost-effective way requires training of the personnel who make the site selection and cooperation and close coordination between the road locators and designers and the bridge engineer.

Stream-crossing sites are usually selected by a road locator who has substantial road design and construction experience but limited experience in bridge design and construction. Training sessions to teach these individuals the factors that affect bridge design and construction can be very beneficial.

Even more important is cooperation and coordination between locators and road and bridge designers from the very beginning of the project. At the time the locator has determined the approximate area of the stream crossing, particularly if the crossing is fairly complex, the road locator, road designer, bridge designer, and possibly the foundation engineer, hydraulics engineer, and land management specialists should review the potential crossing sites. The locator can then coordinate foundation, hydraulics, road and bridge design, and other special input before selecting the final crossing site.

The road designer and bridge engineer should continue to work closely together after the final crossing site has been selected. The major variables to be worked out at this point are horizontal and vertical alignments, road geometry, and required safety features.

The horizontal alignment should already be fairly well fixed; however, some variation may be possible. The road designer must be aware of any costs due to skewing the bridge or widening or curving the bridge if it is put in a curve. A sharp curve too close to the bridge may complicate installation of approach guardrails or necessitate longer wingwalls for a retaining-wall type of bridge.

The vertical alignment must remain flexible since different structures will have different minimum and possibly different maximum roadway elevations. The lowest possible roadway elevation will usually have the lowest cost. The additional costs involved in raising this elevation must be weighed against changes in road construction costs, safety, and alignment.

Occasionally the road designer has some flexibility in determining the roadway and shoulder widths. If it means eliminating a beam, a decrease of 1 or 2 ft in total bridge width may reduce the construction cost of a bridge by as much as 10 percent. The amount of curve widening or the critical design vehicle is sometimes variable on low-volume roads. The road designer should determine the amount of curve widening or the critical design vehicle only after knowing all costs involved.

Various questions concerning safety may need to be resolved. Many types of bridge rail are available. Also, bridge railings and approach guardrails are not always necessary. Features affecting safety should also be selected when their total cost is known (1).

STRUCTURE TYPE SELECTION

After site selection, the next greatest cost savings potential occurs in structure type selection. The following discussion lists a number of possible structures for various sizes of streams. Final structure type selection should be based on sound engineering judgment of environmental considerations, structural design, hydrology, hydraulics, foundation conditions, and total costs. This discussion assumes that fish passage is required, as is the case with most Forest Service stream crossings in the Northern Region.

For smaller stream crossings (stream channel less than 20 ft wide), bottomless pipe arches or buried pipe arches are possible alternatives to bridges. A buried pipe arch is simply a pipe arch with the invert covered by 1.5-3 ft of native streambed material (Figure 1).

If concrete is available and the construction area is limited, which does not allow easy diversion of the stream, the bottomless pipe arch is probably the more cost-effective of the two structure types. If the stream can be easily diverted during construction, the buried pipe arch will probably be more cost-effective. Backfilling inside the pipe arch can be difficult in smaller pipe-arch sizes. If the pipe arch is too small to allow operation of a rubber-tired loader inside it, this work will have to be done manually. Both structures provide natural stream bottoms for fish passage and are usually less costly to costruct and maintain then a similar span bridge. A pipe structure is particularly economical if the road grade is very high above the streambed or if the crossing is on a horizontal curve.

For medium-sized stream crossings (stream channels 20-40 ft wide), concrete precast, prestressed multibeam sections can provide an economical alternative to conventional treated timber or cast-in-place concrete superstructures (2).

Most bridges on low-volume roads are of simple configuration, which is made to order for precast work. The precast bridge can be constructed much faster than the cast-in-place type, and erection can proceed during cold weather.

The large percentage of streams in the Northern Region of the Forest Service are in the range of 20- to 40-ft spans. To reduce design and drafting time, a number of standard designs and drawings have been prepared. One set of standards details treated-timber retaining-wall abutments with clear heights (distance from the bottom of the stream to the bottom of the stringers) of 5, 7, 9, and 11 ft; another set of standard drawings details treated-timber beams and decking; and another set details concrete precast, prestressed multibeam superstructures (3) (Figure 2).

For larger stream crossings (stream channels greater than 40 ft wide), it is generally cost effective to design a spill-through type of bridge. This type of bridge differs from the retaining wall in that the abutment fills are laid back from the edge of the stream channel on a slope no steeper than 1.5 horizontal to 1 vertical. Laying back the abutment fills lengthens the bridge but substantially reduces abutment costs.

A contracting technique often used to keep costs down for these longer bridges is to allow a contractor design option. The type of structure considered to be the most cost effective is designed. The contractor is then allowed to submit an alternative design. Obviously, some limitations and guidelines on materials and design methods are included in the contract to ensure equal structure durability and performance. Including this option allows contractors to modify the structure and its design to best fit any special equipment or experience that they may have. This process also helps make the bridge engineer aware of any changes in the industry that can be used on future projects to reduce costs (4).

For projects that use precast concrete multibeam superstructures, substitution of different sections may be allowed. Many prestress plants have developed their own nonstandard sections, which may be easier for them to produce than the more standard sections. New sections are constantly being developed and the most cost-effective sections available should be used.

LOW-WATER CROSSINGS

A low-water crossing is an option that should be considered under specialized conditions and that can very substantially reduce costs (5). A low-water crossing is a possible alternative for any size of stream. A number of different types of low-water crossings are possible, including the following:

1. Ford: the road crosses the stream at a location where the stream banks are low and the road grade follows the cross section of the stream,
2. Vented ford: the vented ford is similar to a ford except that a more substantial roadbed is constructed and low water is passed through a pipe or box culvert,
3. Low-water bridge: a bridge that passes low flows and allows high flows to pass over the bridge structure is a low-water bridge, and
4. Low-water bridge with an overflow channel: this is a bridge, again, that passes low flows and allows high flows to pass around the bridge through an overflow channel.

Because of the relatively constant year-round flows in the Montana and Idaho area and topography that makes stream fords difficult, most low-water crossings constructed in the Northern Region of the Forest Service are bridge or vented-ford crossings.

Low-water crossing structures are generally designed to allow flooding during periods of high annual runoff. However, the design flow is something that should be evaluated in the design process. The standard of the road and its use, the magnitude of the streamflow and its variability, and the topographical characteristics of the crossing site are all factors that should be considered in determining the design flow of the low-water crossing structure.

In December 1980, heavy rainfall and rapid snow melt caused localized flooding in northern Idaho. The Lightning Creek Watershed in the Sandpoint District of the Kaniksu National Forest sustained substantial flooding. Two bridges were totally destroyed by high streamflow and heavy debris accumulation. Historical information indicates that major flooding occurs in this watershed on an average of once every 10 years. Review of hydrologic and historical data reveals that the flood that occurred in this drainage in December 1980 was at the most a 35-year recurrence-interval flood (6).

Much of the bridge damage that occurred was a result of debris accumulation. Approximately 1 million board feet of log debris was transported downstream by the flood. Much of this debris was full-sized trees 100 ft or more long with up to 30-in diameter.

Figure 1. Bottomless pipe arch (left) and buried pipe arch (right).

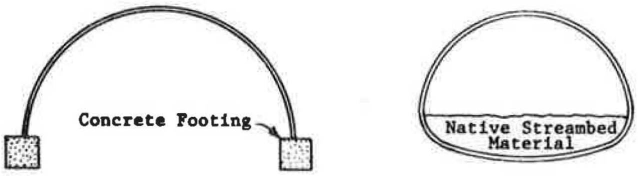
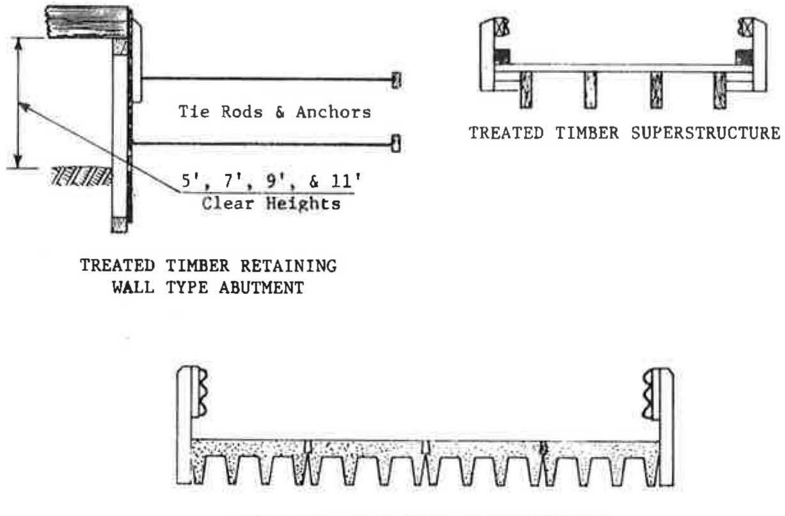


Figure 2. Standard designs for stream crossings.



TREATED TIMBER RETAINING WALL TYPE ABUTMENT

TREATED TIMBER SUPERSTRUCTURE

CONCRETE MULTI-BEAM SUPERSTRUCTURE

These bridges were destroyed by a 35-year recurrence flood. We estimate that a 20-year recurrence flood would also have destroyed these bridges. Therefore, replacing them with similar span structures would result in 20-year design life bridges.

Lightning Creek Bridge

The previous 60-ft span, single-lane treated-timber bridge with 12-ft, clear height retaining-wall abutments washed out when large log debris jammed across the span. This blockage backed up flow until the south abutment scoured out. The flood plain at this site is approximately 500 ft wide and a distinct overflow channel exists approximately 50 ft north of the main channel. The overflow channel had been blocked by the 10- to 12-ft roadfill. The calculated 100-year flood flow is 5020 ft^3/s. Passing this 100-year flood flow and associated debris would require a two-span bridge approximately 200 ft long. Our estimated cost for this structure was $195 000.

This 100-year design life bridge had a higher cost than was justifiable for this site. The alternative of reconstructing to the original, 20-year design life bridge had an estimated cost of $76 000. However, the added costs of design and construction every 20 years along with the inconvenience and cost involved in having the road closed for the period needed to design and reconstruct the bridge make this alternative less attractive.

After consulting with specialists in structural design, hydrology, fisheries, geology, and resources, the flood study team determined that a low-water type crossing that used the existing overflow channel would best meet Forest Service goals of cost effectiveness and continuous operation of the road.

A bridge with approximately the same hydraulic capacity and at the same location as that of the previous bridge was designed. The bridge was lengthened to 85 ft and the abutment fills were laid back on a 1.5:1 slope to give a spill-through cross section (Figure 3). This bridge cost no more than the 60-ft retaining-wall bridge (Figure 3) and will have less chance of snagging the long log debris that it may have to pass. The bridge is designed to pass the 20-year flood flow and all associated debris.

The overflow channel begins at a curve in the stream 300 ft upstream from the crossing site. The stream-bank height is such that the stream will begin flowing over the bank and into the overflow channel when flow exceeds the 10-year flood flow. The gradient of the overflow channel is slightly steeper than that of the low-flow or regular channel. Therefore, most flow above the 10-year flood flow will move into the overflow channel and flow in the low-flow channel will not exceed the 20-year flood flow. The overflow channel will pass the full 100-year flood flow and associated debris in case the bridge should become blocked by debris.

The road across the overflow channel was lowered to 1.5 ft above the bottom of the channel and the fill was constructed of riprap with a gravel driving surface 1 ft thick. An hydraulic jump will occur just past the downstream side of the road, which would cause scouring. Therefore, a riprap apron 3 ft thick by 10 ft wide will be placed on the downstream edge of the fill (Figure 4).

The overflow channel has a bottom width of 120 ft and the riprap fill extends to a height of 5 ft up the vertical curves on either side of the overflow channel (Figure 5).

When water begins flowing through the overflow channel and over the road, the gravel surfacing will wash off. However, a pit-run gravel surfacing source is nearby and repair should not cause major traffic delays or costs.

To assist debris to move into the overflow channel, a debris deflector is to be constructed upstream at the point where the overflow channel leaves the regular channel. The debris deflector consists of four steel H-pilings driven on a line across the stream parallel to the overflow channel. The pilings are spaced 30 ft apart. The debris deflector will begin to function when debris hangs up on the pilings. This blockage will assist in moving both stream flow and floating debris into the overflow channel (Figure 6).

The bid cost of the new bridge at Lightning Creek is $73 900, the bid cost of the riprap and surfacing through the overflow channel is $11 700, and the bid cost of the deflector system is $4000. This results in a total cost of $89 600, which is substantially lower than the estimated cost of the bridge that would span the overflow and regular-flow channels. The bridge in combination with the overflow channel will pass flows in excess of the 100-year flood flow with only minor damage.

East Fork Creek Bridge

This stream, which is a tributary to Lightning Creek, also transported a large quantity of log debris in addition to a large gravel bedload. The previous 50-ft span, two-lane treated-timber bridge with 7-ft clear height retaining-wall abutments washed out when debris jammed across the bridge opening and caused one abutment to scour out. The stream then moved behind the abutment and scoured out several hundred feet of roadway. The flood plain is approximately 200 ft wide at this location.

The calculated 100-year flood flow is 2210 ft^3/s. Passing this 100-year flood flow and associated debris would require a bridge approximately 125 ft long with an estimated cost of $200 000. The alternative of reconstructing to the original 20-year design life bridge was estimated to cost $50 000.

The cost of constructing the longer-span bridge to avoid frequent bridge replacements was obviously prohibitive. However, the option of having to replace the shorter-span bridge every 20 years with the resulting road closures and traffic delays was also undesirable. The solution reached by the flood study team was to construct another low-water type of crossing.

The flood plain at this site is not wide enough to allow construction of a bridge and a separate overflow channel. The stream channel is also very unstable and is constantly moving back and forth across the flood plain. The stream carries a large gravel bed load at times and has a high scour potential.

Because this stream is a very important kokanee salmon spawning stream, several additional constraints were placed on the design by the fisheries specialists. The maximum velocity during the average spring runoff (approximately 200 ft^3/s) cannot exceed 5 ft/s and the minimum waterflow depth during the average annual flow (approximately 52 ft^3/s) cannot be less than 1.0 ft.

To meet the above constraints, a three-barrel, reinforced-concrete box culvert centered in the 200-ft-wide channel was designed. The roadway surface is approximately 5 ft higher than the channel and is paved through the entire 200-ft width. The channel and culvert function as a weir with the culvert designed to pass the 5-year flood flow. Each of the culvert barrels, which have an 8-ft span and 24-ft length, has removable steel-grate tops to allow easy cleanout if the barrels become clogged with stream-

Figure 3. Retaining-wall structure (top) and spill-through cross section (bottom).

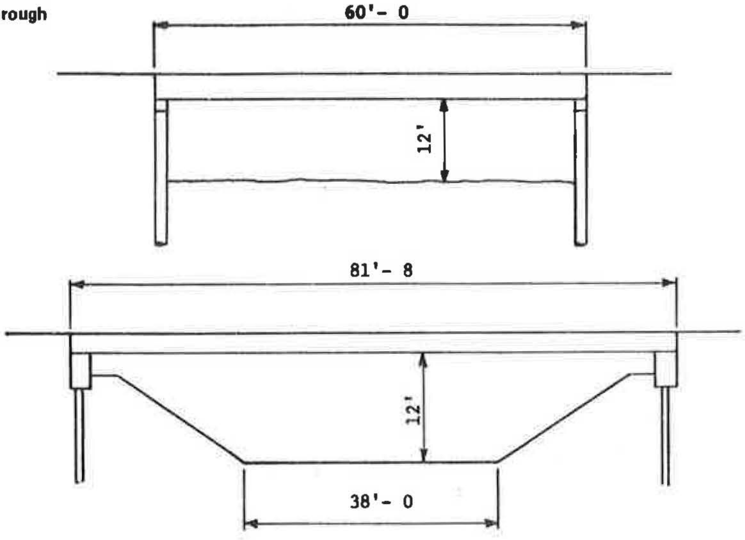


Figure 4. Road section at overflow channel.

Figure 5. Elevation view of overflow channel.

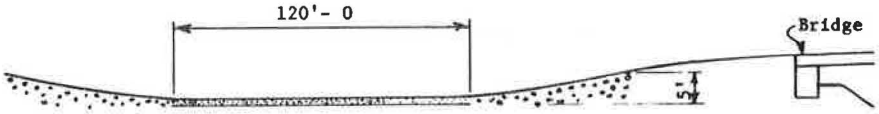
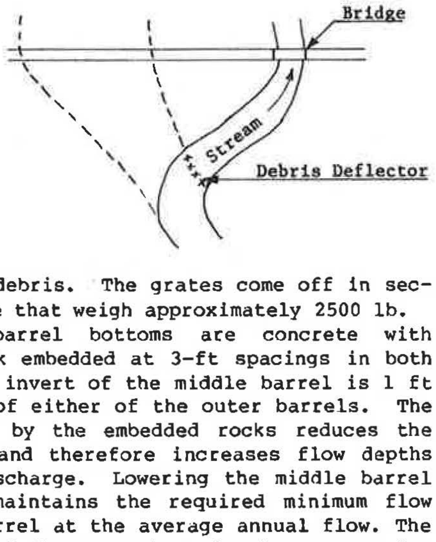


Figure 6. Plan view of debris deflector.



bed load and/or debris. The grates come off in sections 8 ft square that weigh approximately 2500 lb.

The culvert-barrel bottoms are concrete with 12- to 15-in rock embedded at 3-ft spacings in both directions. The invert of the middle barrel is 1 ft lower than that of either of the outer barrels. The roughness caused by the embedded rocks reduces the stream velocity and therefore increases flow depths for any given discharge. Lowering the middle barrel of the culvert maintains the required minimum flow depth in this barrel at the average annual flow. The shallower depth of the outer barrels also causes low flow velocities in the outer barrels during high flows due to the reduced hydraulic radius.

The design flow depth at the average annual flow is actually 1.4 ft and the velocity does not exceed 5 ft/s in the outer barrels until the flow is almost double the required design runoff of 200 ft^3/s.

The roadway portion of the weir is 6-in-thick reinforced-concrete pavement and the fill slopes are lined with gabion baskets 1 ft thick. The baskets extend to 4 ft below the toe of the fill slope on the upstream side of the road and extend out as a gabion blanket 10 ft on the downstream side. The weir has a flat bottom width of 30 ft at the low-water structure and extends to a height of 5 ft up the vertical curves on either side (Figure 7).

Due to the instability of the stream channel, a portion of the channel bank upstream is stabilized with gabions that tie into the gabions in the weir.

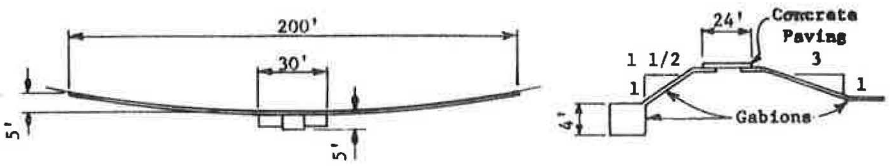
The bid cost of the low-water structure at East Fork Creek is \$51 000, the bid cost of the concrete paving is \$11 500, and the bid cost of the gabion baskets for the weir is \$15 000. This results in a total cost of \$77 500, which is substantially lower than the estimated cost of the bridge needed to pass the 100-year flood flow. The only traffic interruptions that should occur with this structure are the two to three days every five years (plus or minus) when the water overflows the culvert and during the times that the culverts are being cleaned.

SUMMARY AND CONCLUSIONS

Because of the relatively high cost of stream-crossing structures, special care should go into their design to produce the most cost-effective structure possible. Extra effort put into training location personnel and cooperation between the road designer and the bridge designer will always pay off. Structure type selection should be done with an open mind after all possible alternatives have been evaluated. Different contracting methods are available that not only can help keep costs down, but also keep the designer abreast of new developments in the construction industry.

Low-water crossings are just one type of crossing that should be considered. There are many possible variations of the low-water crossing concept. Careful thought and analysis are necessary to design the most cost-effective structure that best meets the design constraints.

Figure 7. Elevation view of weir (left) and road cross section at weir (right).



REFERENCES

1. L.D. Bruesch. Forest Service Timber Bridge Specifications. Journal of the Structural Division of ASCE, Vol. 108, Dec. 1982, pp. 2737-2746.
2. R. Tokerud. Precast Prestressed Concrete Bridges for Low Volume Roads. PCI Journal, Vol. 24, No. 4, July-August 1979, pp. 42-56.
3. Bridge Design Manual. Forest Service, Northern Region, U.S. Department of Agriculture, 1982.
4. E. Gower. Many Factors Determine Bridge and Building Economics. Logging and Sawmill Journal, April 1982, pp. 22-25.
5. C. Goghlan and N. Davis. Low Water Crossings. TRB, Transportation Research Record 709, 1979, pp. 98-103.
6. L. Leibbrand. Big Lightning Flood Study. Forest Service, Northern Region, Kaniksu National Forest, U.S. Department of Agriculture, Dec. 1980.

Ten-Year Performance Report on Asphalt-Stabilized Sand Road with Instrumentation

EUGENE L. SKOK, JR., TEJ S. MATHUR, NORMAN G. WENCK, AND NEIL RAMSEY

In 1972, a test road that consisted of 12 sections of sand stabilized with bituminous materials was built in the Chippewa National Forest near Cass Lake, Minnesota. The local outwash sand is a very clean and one-sized material. One-half of the sections were stabilized with a 200-300 penetration asphalt cement and the other half with a medium-curing (MC) 800 cutback. Thicknesses were determined by using criteria based on strains calculated with the elastic-layered system. The permanent deformation criteria were shown to be critical for the predicted timber and recreational traffic. Thicknesses of 3.5, 5.0, and 8.0 in were constructed with each stabilizing material. These thicknesses represented design lives of 5, 8, and 15 years for the predicted traffic, respectively. Mixing of the materials was done in an asphalt batch plant and lay down with a standard paver for uniformity and control. Compaction was based on laboratory densities. Strain-measuring devices composed of induction coils were placed in the sections to monitor static (long-term) and dynamic deformations in the pavement layers. These have been compared with calculated values. It was found that the strains in the asphalt-cement-stabilized sections were close to the calculated values, but that the strains in the MC-stabilized sections were higher, probably because of incomplete curing. Pavement condition has been evaluated by using present serviceability index, rut depth, cracking, and deflections. After 10 years of service, the sections have all performed well under the applied traffic with no maintenance overlay, surface treatment, or seal coat. Design comparisons are made to evaluate how this performance information can be used to improve current design methods.

The Forest Service, U.S. Department of Agriculture, in cooperation with the University of Minnesota, has sponsored the design, construction, and evaluation of a test road in the Chippewa National Forest. The test road was designed and constructed on a timber access and recreational road called the Third River, which is located northeast of Cass Lake, Minnesota, north of US-2 off of Cass County Road 10. It crosses the Mississippi River between Cass and Winnibigoshish Lakes. The Third River Road is divided into three major segments--designated A, B, and C. Segment A includes the first twelve 1000-ft test sections constructed in 1972. Six of these have asphalt-cement-stabilized sand and six have medium curing (MC) cutback-stabilized sand of various thicknesses as pavement structures. The six 2000-ft segment C test sections were constructed in 1975 and are composed of the same outwash sand stabilized with asphalt emulsion. Segment B is a short portion of the road near the Mississippi River constructed in 1970 with an emulsion-treated sand base and a conventional asphalt concrete (AC) surface. The sections have been evaluated based on their structural condition, ride, and strength. The strength has been evaluated by using a number of techniques: strain sensors in the pavement, Benkelman beam deflection device, and road rater.

Because there is not much information available for designing stabilized-sand pavements, a number of different design procedures and values were adapted from standard pavement design procedures. In order to verify the designs, the test road was instrumented to monitor strains and deformations that occur within the pavement to relate these parameters to the actual performance of the sections.

The criteria used for evaluating the performance of the test sections include (a) present serviceability rating of the section over a period of time, (b) rut depth measured at the surface, (c) cracking, and (d) surface condition. Static deformations have also been measured electronically to compare them with the measured rut depths. Dynamic deformations under moving axle loads have also been determined, and an attempt is made to relate these to the performance of the sections. The design and performance evaluation must take into consideration the effects of traffic and the environment on the road. Traffic has been analyzed in terms of equivalent 18 000-lb single-axle loads. The traffic on the sections has been a mixture of loaded and unloaded timber trucks, recreational vehicles, and cars.

By any measure of performance, the sections stabilized with asphalt cement and MC cutback are in good condition and have performed better than anticipated over the 10-year period. There was no surface treatment put on the sections as planned after construction, and there has not been any major