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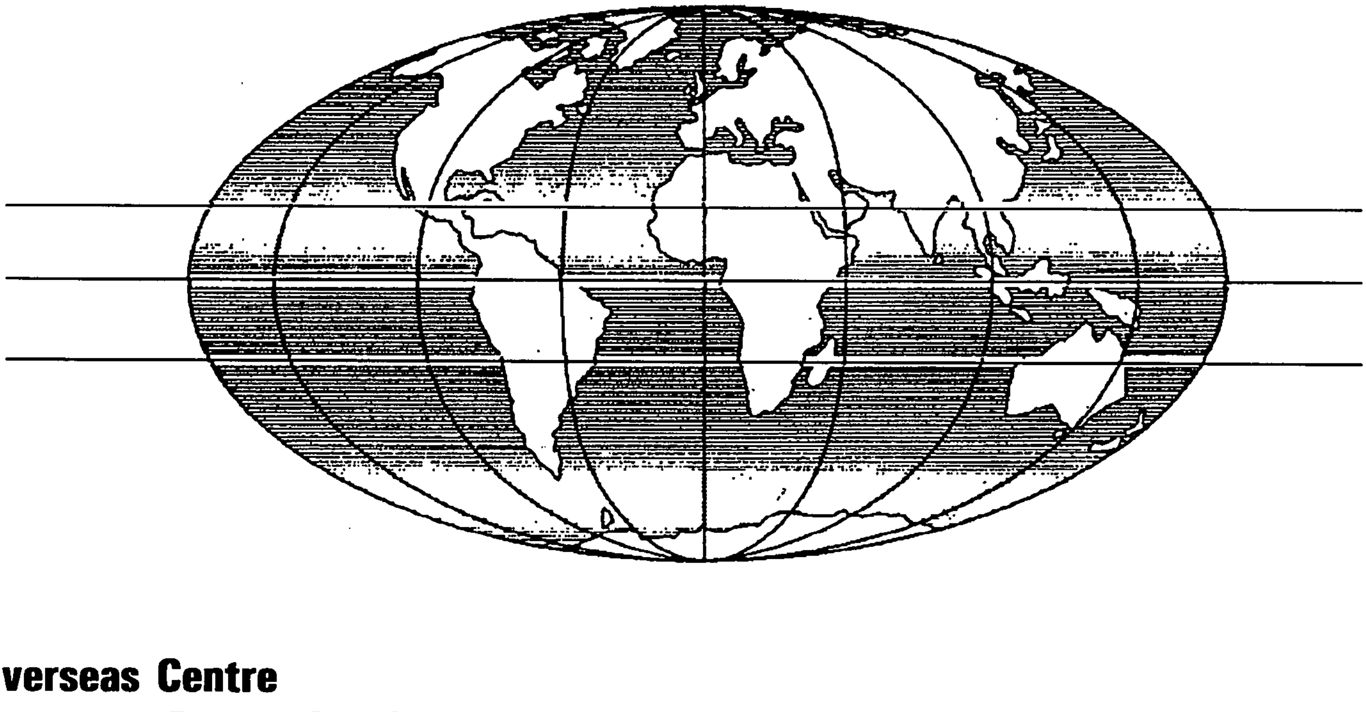

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Design of Irish bridges, fords and causeways in developing countries

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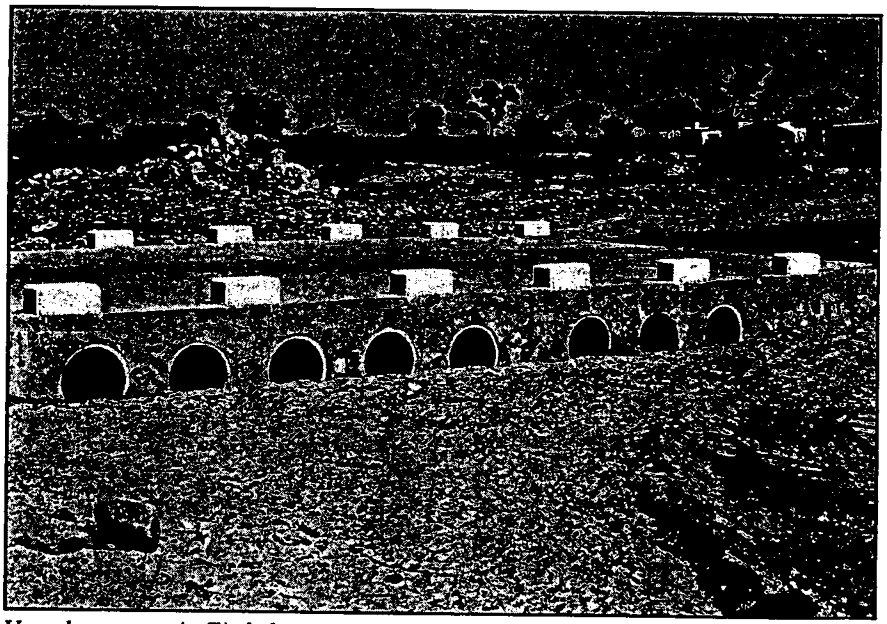
John Parry studied mechanical engineering at Reading College of Technology and became a chartered Engineer in 1972. Most of his career, apart from three years as engineer to a refugee team in North Africa, has been with the Transport Research Laboratory. Initially, he was a member of the team responsible for the design and evaluation of the mini roundabout and guardrail projects. In 1979 he joined the Overseas Unit at TRL where he has reported on the design and performance of modular timber bridges, and published manuals on bridge inspection, maintenance management and bridge design. More recently he has been responsible for the design and supervision of concrete pavement trials in several developing countries.



Vented causeway in Zimbabwe.

River crossings are vital to road networks and can absorb a significant proportion of the cost of both construction and maintenance. It is important therefore that these structures are appropriate to the category and volume of the traffic carried. In forestry regions of UK and rural areas in many countries, low level water crossings can provide practical, economical and simple alternatives to conventional bridges. This paper summarises the relative merits of water crossings for low volume roads from the simplest fords to the engineered bed-level causeways, vented causeways and submersible bridges.

There are two basic types of low level crossing:

- fords and bed-level causeways
- and vented causeways and submersible bridges.

The success or life of these structures depends very much on the hydraulic design. Fords and bed-level causeways, like conventional bridges, may be constructed so that they cause little interference with the design flood. Vented causeways and submersible bridges inevitably disrupt river flow and so are liable to sustain damage themselves or indirectly cause scour damage to the river bed or banks, which in turn may affect the road approaches to the crossing.

As fords and bed-level causeways are over-topped by any water flowing in the river channel, there is no advantage in raising the road surface above the stream bed. Vented causeways and submersible bridges usually present a dry carriageway for ordinary flows and are overtopped only during the design flood.

All four crossing types are suited to low traffic flows or where an all-weather bridge is available on a reasonably short detour. They should be designed so that for most of the year there will be a flow of water over the carriageway no more than 150mm deep.

Site selection

The best location for a low level crossing is similar to that for a conventional bridge, with the exception that a wide stretch of the river provides easier road approaches and slower, shallower water. The stream should be straight, with well defined banks and a uniform gradient and the bed material should be strong enough to support traffic. (The submersible bridge requires different considerations and is described briefly under that sub-heading.)

Table 1. Maximum rate of change per cent

Traffic speed	Descending	Ascending
45 mph (72 kph)	10	15
60 mph (96 kph)	8	12

Road approaches

Clearly, gentle slopes are required for both traction and safety. The maximum gradient for motor traffic should be 10%, and for animals 5%. Change of gradient should be gradual to prevent the underside of vehicles touching the road and to preserve long sight distances. A small change in horizontal alignment of the road at the crossing helps to draw the attention of drivers to a dip that may conceal an obstacle.

Suggested maximum rates of change of approach gradient are given in Table 1 (Bingham, 1979).

The equal cut and fill construction of the approach roads shown in Fig 1a requires less work than the cut and remove spoil of Fig 1b but the placing of the spoil in the river channel, shown hatched in Fig 1a, may cause scour problems during a flood. Fig 2 shows in plan how steep approaches may be relieved by a diagonal descent of the river bank for roads where speeds are naturally slow and the horizontal curve on the approach side is clearly visible.

Even where the road is a single track, it is usual to make the crossing and the approaches of two-lane width to allow traffic to pass a broken down vehicle or one which fails to mount the gradient.

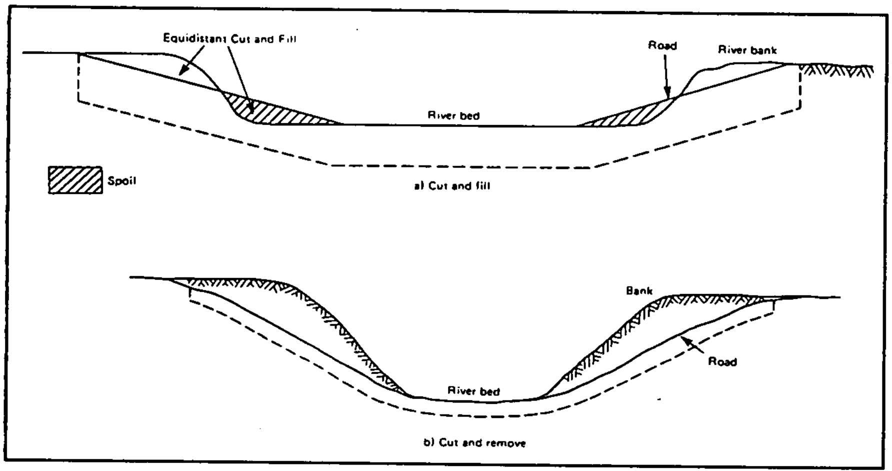


Fig 1. Vertical alignment of road approaches.

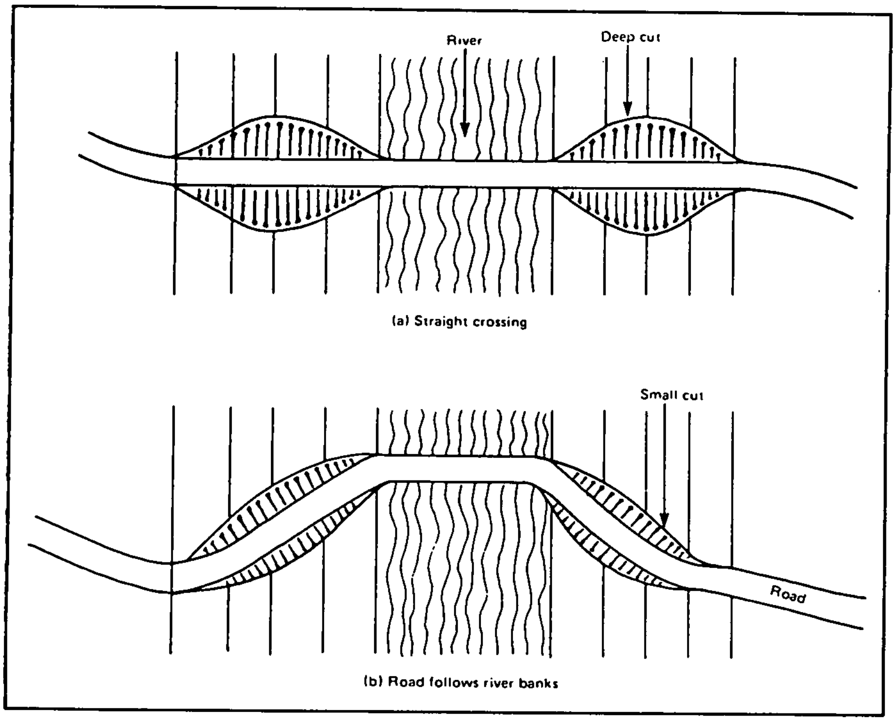


Fig 2. Plans of low level crossings and approaches.

Fords

Fords are unpaved and only suitable for the lowest of traffic flows. These are the simplest form of river crossing where the stream is wide, shallow and slow, the approaches gentle, and the surface firm. Improvements to the approaches are chiefly concerned in lessening the gradient. The running surface can be strengthened and made more even with stones which are brought in and buried just below the surface. Alternatively, if stones are carried in the flow, these may be trapped by barriers made of boulders, gabions or piles.

Boulders

Large stones placed across the river bed at the downstream side of the crossing are reputed to filter the flow of water and retain gravel and sand, which eventually form a more level and even surface for vehicles. However, if the stones are too large or form too high a wall, scour will result. If they are not heavy enough, they will be washed away at the first flood. Fig 3a shows a typical cross section.

Gabions

A more expensive but durable improvement may be made by replacing the boulders with gabions to trap river gravel or retain imported material, as shown in Fig 3b.

The standard gabion is a rectangular basket made of hexagonal steel wire mesh. It is strengthened by edges of heavier wire and by mesh diaphragms which divide it into 1m long compartments. It is usually supplied as a flat pack and assembled on site and is normally filled in-situ with quarried stone or rounded shingle of sufficient size that the stones cannot pass through the mesh. The

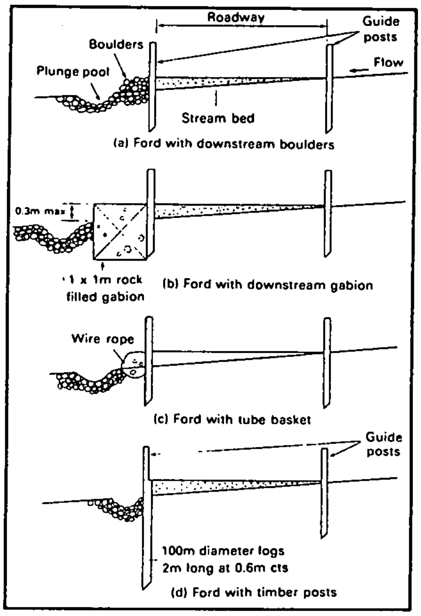


Fig 3. Types of ford.

[illegible]bion structure is more stable and durable if the stones are packed carefully by hand, almost as if building a wall. Internal tie wires at about 0.5m intervals help to retain the shape. At a ford, gabions are securely wired together in position to form a continuous revetment.

The gabion baskets (typically 2 or 3m long x 1m wide and 0.5 or 1m high) are wired together and dropped into a prepared trench. The central gabion is first filled and, using that as an anchor, the line of gabions is pulled taut and straightened by a chain attached to a truck or winch. This tension is maintained while the remaining baskets are filled. When filling is complete, final adjustments are made to the top course of rock and the baskets are closed.

It is important that gabions protrude only 150-300mm above the natural bed level of the river, depending on the nature [illegible] the bed material, otherwise they will [illegible]t as a weir and cause heavy scour downstream of the crossing.

As an alternative to conventional gabions, tube baskets can be made from a roll of fencing mesh filled with stone or shingle. During filling, the edges are raised and then bent over at the top to form a tube and tied; finally a wire rope is attached as shown in Fig 3c and securely anchored at each end. As with gabions, tube baskets need to be installed in a previously excavated trench approximately half the depth of the basket, ie 0.2 to 0.3m. After installation, sand and gravel transported by the stream is trapped behind the baskets and provides a firmer fairly level surface suitable for vehicles.

Piles

Where gabions are unobtainable, timber piles, driven into the river bed are suitable [illegible] a cut-off wall, as shown in Fig 3d. To be effective, timber piles need to be about 2m long and placed at no more than 0.6m centres. If the river is fast flowing, a continuous line of piles may be needed. As with the gabions and wire baskets, the top of the piles should be no more than 0.3m above bed level.

Provision of a curtain cut-off wall made of gabions or piles may be necessary on the upstream as well as the downstream side if the road bed is erodible. Note that all four types of ford may require rip rap scour protection on the downstream side, as shown in the Figures.

Bed level causeways

Where the type of traffic or the distance to an alternative crossing justifies the expense, a pavement may be laid on the river bed. A paved ford is also called a bed-level causeway, drift, paved dip or Irish bridge. Three common designs are [illegible]wn in Fig 4. To protect the pavement [illegible]m scour damage, curtain walls or aprons are usually required on both the upstream and the downstream side and

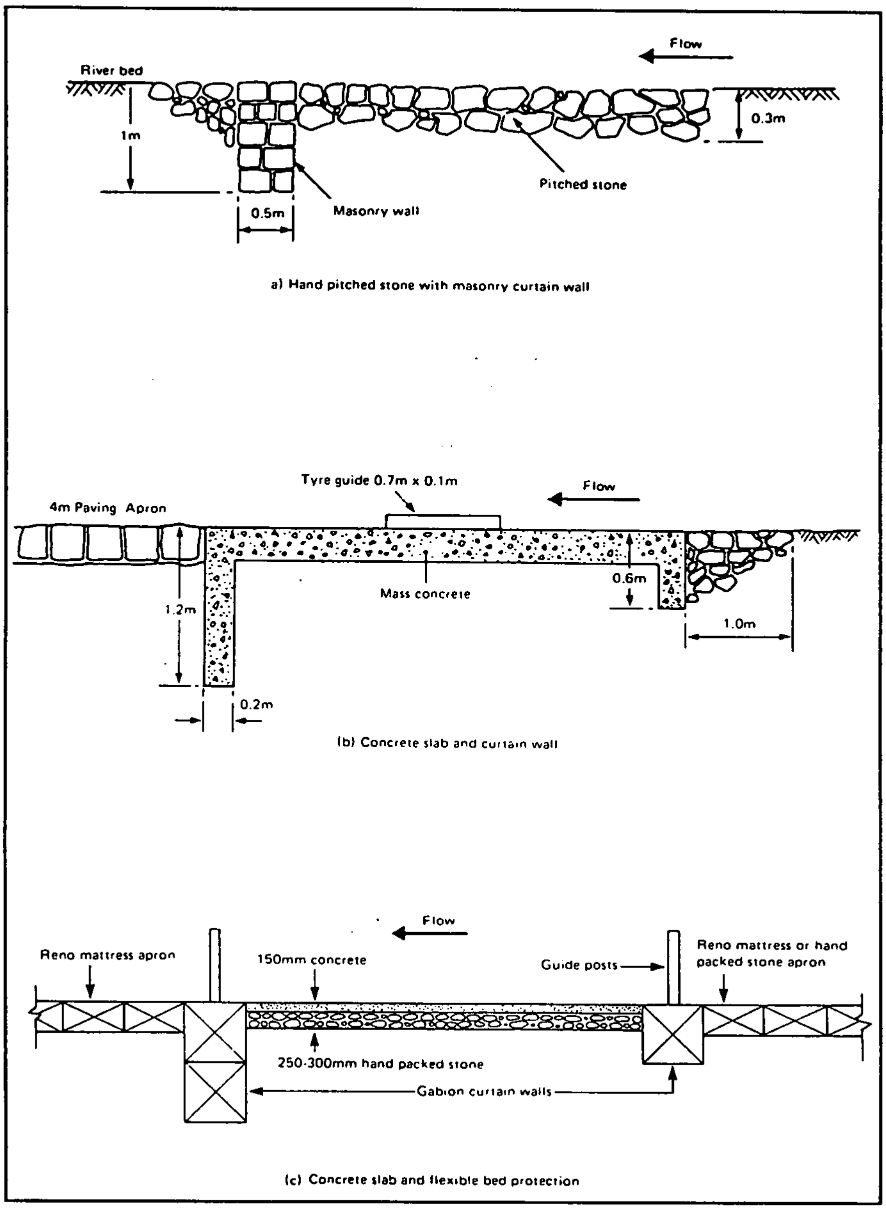
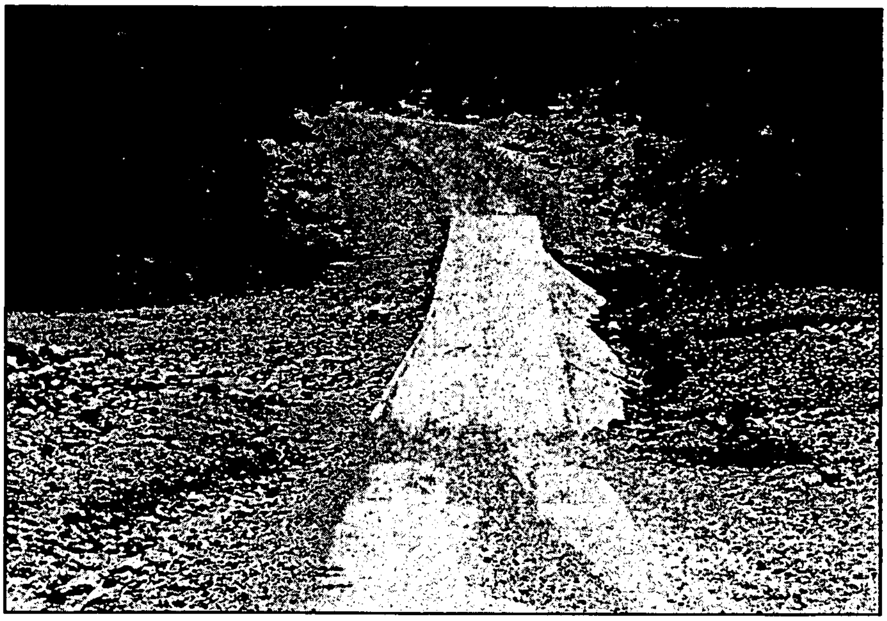


Fig 4. Bed-level causeways.



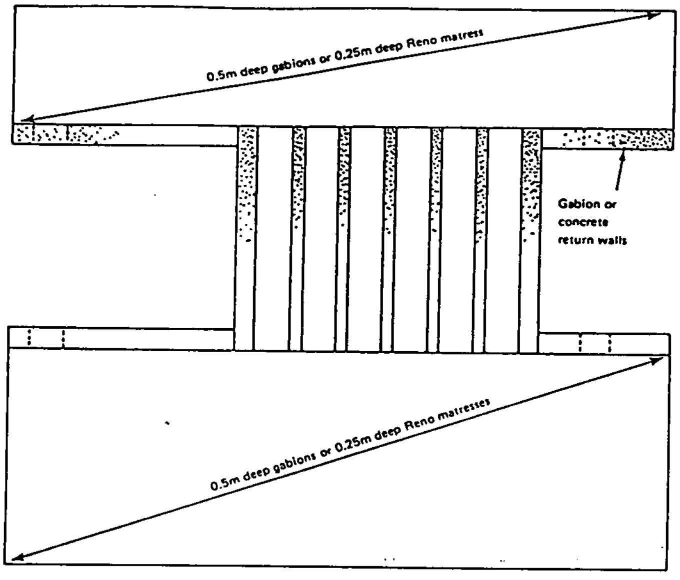
Irish bridge in central Kenya

Vented causeway in Zimbabwe

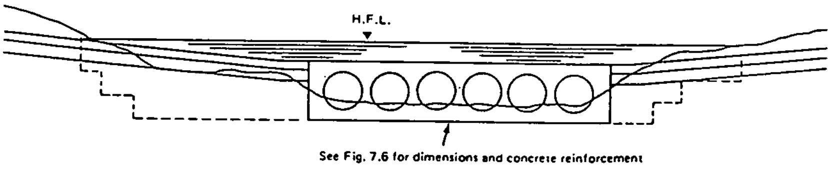
these must continue up the approaches to the height of the design flood.

It is recommended that if aprons are not installed curtain walls should be 1m deep on the upstream side and at least 2m deep on the downstream side unless a rock strata is reached before that depth. If the bed is inerodible, the causeway need not be provided with curtain walls, but the bed on both the upstream and downstream sides of the crossing should be trimmed flat to reduce turbulence.

Fig 4a (Gillett 1979) shows a section through a basic bed-level causeway suitable for maximum water flows below 2m/sec and for light traffic. The crossing shown in Fig 4b (Metschies 1978), requires good concrete technology and may sustain damage to the apron that is difficult to repair. Fig 4c shows a design employing a practical combination of concrete pavement with flexible protection that is more suited to routine repair than the rigid concrete curtain wall.



(a) Horizontal section



(b) Elevation

Fig 5. Vented causeway.

Generally, a 1:2:4 concrete, by volume, is used and slabs are jointed using crack inducers every 5m. The concrete should be laid on non-erodible material.

Vented causeways

Vented causeways are designed to pass what may be called an ordinary flood with very little water overtopping the carriageway, but may still be inundated and unusable for a few days each year.

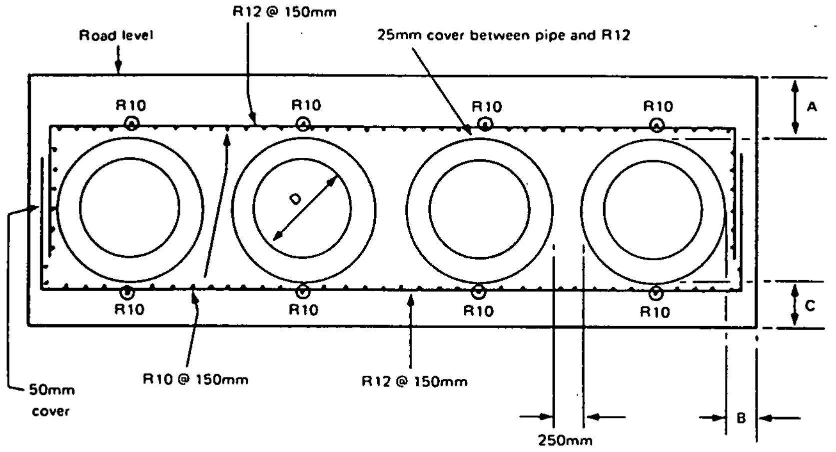
These structures present a considerable obstacle to the free flow of both normal flow and the design flood, so they must be built massive enough to withstand water pressure and debris impact. They must also be provided with adequate scour protection where the bed is erodible, and marker posts.

Fig 5 shows a typical section and elevation, Fig 6 gives dimensions for concrete cover and reinforcement (Parry, 1992).

The vents are usually concrete or corrugated steel pipes from 0.6 to 1.0m diameter, set in a block of concrete or masonry. Where prefabricated pipes are not available, vaulted masonry tunnels have proved successful. Concrete or masonry retaining walls and aprons are required to channel the flow and prevent scour at both entrance and exit. For this reason too, the vents should be distributed all along the structure so that flow parallel to the roadway is avoided.

In order to prevent blockage of the stream by debris or silting, careful attention is required to setting the pipes level with the stream bed and at the same gradient. No part of the vents should be narrower than the entrances and wedge-shaped deflector ramps may be required on the upstream side to guide large floating debris above the vents. Alternatively, a grill of posts installed upstream of the causeway will collect tree branches before they reach the structure.

The capacity of the vents is sufficient to pass all ordinary floods without damage and with no more than 150mm of water over-topping the structure. The



Concrete strength 30 N/mm² (28 day cube)			
Dimensions (mm)			
D	A	B	C
600	250	175	150
750	250	175	150
900	275	200	175
1000	300	225	200

Fig 6. Vented causeway dimensions and reinforcements.

maximum capacity of the vents is reached when water on the upstream side of the embankment stands at its highest safe level. Under this condition, the outlet will normally be submerged.

The operating head h is the difference between the upstream and downstream levels, and consists of the following three elements:

$$h = h_e + h_f + h_o$$

where

h_e is the loss at the entrance

h_f is the friction loss and

h_o is the loss at the outlet

The entrance and outlet losses are expressed in terms of the Velocity head:

$$h_e = k_e \frac{V^2}{2g}$$

$$h_o = k_o \frac{V^2}{2g}$$

where V is the average velocity in the pipe, k_e for bevelled entrances to pipes and box culverts can be taken as 0.15 but for corrugated metal pipes projecting from the fill the k_e value can be as high as 0.9 (Farraday and Charlton, 1983). Use of headwalls forming a square entrance can reduce this to 0.5.

Ko is 1.0 for all types of pipe.
The friction loss

$$h_f = f \frac{LV^2}{D2g}$$

where

L = pipe length (m)

V = flow velocity (m/sec)

D = the pipe internal diameter (m)

g = acceleration due to gravity (m/sec²)

f = 0.016 for concrete pipes and 0.075 for corrugated metal pipes.

Submersible bridges

Where the traffic is dense enough to justify a dry crossing of a substantial ordinary flood and the design flood is much greater, a submersible bridge is an alternative to a vented causeway. Submersible bridges are able to pass a larger flow than the vents of a causeway of the same height but are more susceptible to damage by the design flood. The overturning moment at the pier foundations becomes very large unless the piers are kept short, and the horizontal and vertical forces on the deck require solid restraint.

Because of these difficulties, submersible bridges are not recommended for any foundation other than rock, and even then a vented causeway or conventional bridge may be a more durable alternative.

Construction is usually of reinforced concrete with continuous reinforcement between the sub-structures and the deck.

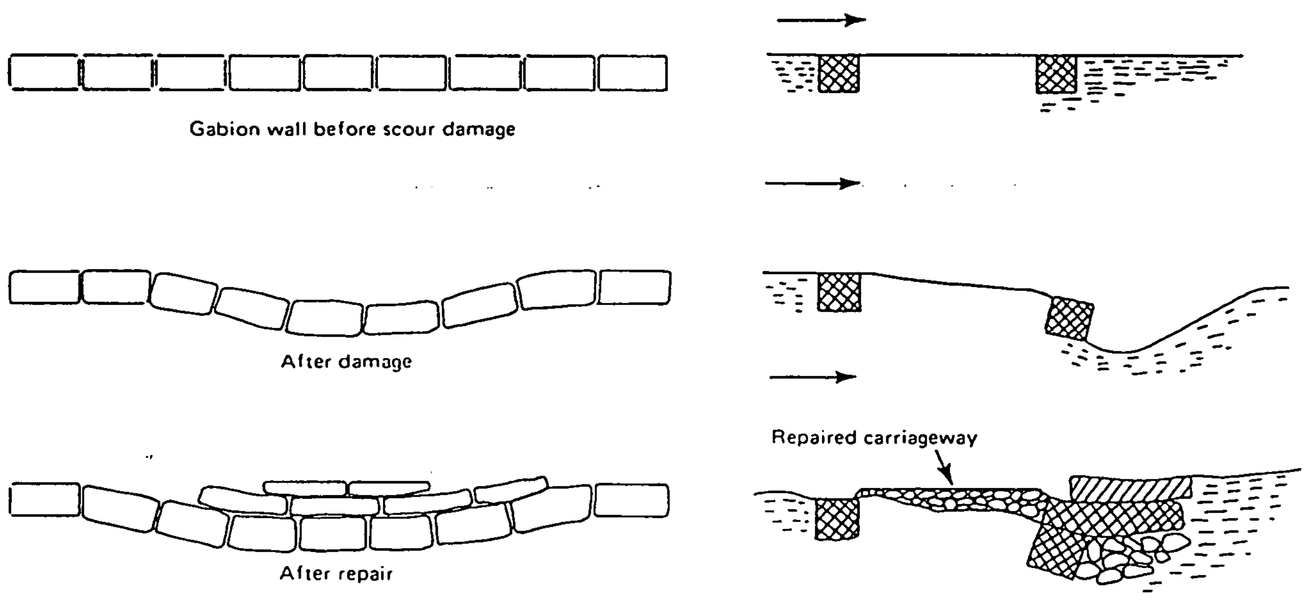


Fig 7. Repairs to gabion causeway.

Signs and markers

All water crossings should be well signed in advance. Low level crossings present more of a hazard to traffic than conventional bridges because of the change in vertical alignment as well as the possibility of encountering water on the carriageway.

Depth gauges should indicate the depth of water at the lowest point of the crossing. Simple black and white markings are best with an indication of the units used. Posts should be about 300mm diameter or square, placed within easy vision of the approach but well away from possible impact damage by vehicles.

Guide posts should be set each side of the carriageway between 2 and 4m apart, according to the probability of catching floating debris. There are two opinions about their height:

a) They should be high enough to be visible during the highest expected floods.
b) They should be visible only when the water is shallow enough for vehicles to cross.

The posts may be of durable timber, metal or concrete, according to the materials used for the carriageway surface and curtain walls; eg concrete posts on concrete bases and timber posts set into gabions etc.

An additional guide for vehicles may be provided by building a ridge down the centre of a concrete causeway, as shown in Fig 4b. This also offers restraint against sideways drifting in strong currents but is an additional restriction to flow.

Maintenance

Submersible crossings of all types require more frequent maintenance than most conventional bridges. Therefore the structural design should allow for easy repair of anticipated damage, which is usually caused by scour. On very erodible beds it is often more successful to build gabion curtain walls and use reno mattress aprons rather than a rigid concrete structure, and to accept that some rebuilding will be required each year. Fig 7 from BCEOM (1975) illustrates the principle.

Summary

Properly designed submersible crossings can be an economical solution to river crossings with low levels of traffic. They are only viable where normal daily flow over the structure is less than 150mm deep and where flooding occurs for no more than about two weeks per year. Hydraulic design is of primary importance because most damage to the structures results directly from scour. For this reason it is also recommended that the design includes provision for ease of maintenance.

Acknowledgements

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