LABOUR-BASED TECHNOLOGIES AND METHODS FOR EMPLOYEMENT INTENSIVE CONSTRUCTION WORKS

BEST PRACTICE GUIDELINE 4-1

Labour-Based Open Channel Flow Technology

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Note: Open channel construction is by its very nature labour-based. This guideline has been compiled to present the technology, with direction for design, materials selection and construction against the background of experience gained to date in Southern Africa.

1. Introduction

Storm water drainage to overcome flooding was introduced to minimise the inconvenience and disruption of activity caused by the runoff from frequent or minor storms. It is also provided to minimise the danger to life and property by control of runoff from infrequent or major storms. This concept can be achieved by the use of two separate but inter-related systems: the minor and major drainage systems.

The minor system forms the conventional urban drainage system that collects runoff from storms of up to 10 year return periods. As the minor system is designed in conjunction with a major system, less reliance need be placed on its function and it can be designed for smaller storms, thus saving on construction costs. The design of the major system requires working with nature to provide an orderly drainage system for major flood runoff. It consists of water carrying routes that include natural watercourses, streets and servitudes. The major system is usually designed for storms of return periods of 50 years or more.

In practice, the application of the minor / major drainage concept requires the construction of overflows at critical points, where the underflow is carried by the minor system and the overflow is directed into the major system. It has also been found necessary to be generous with allocating freeboard in the design of major systems, as the calculation of storm flows for long term flood events is imprecise.

2. Design Considerations

2.1 Storm Flows

Comprehensive guidance can be obtained from the Roads Drainage Manual (Rooseboom, 1993) in the different design methods applicable to the calculation of storm flows. For small catchments (less than 15 km2) the "rational method" is recommended as it is based on simplified representative processes involved in runoff. The data collection needed to give the rational method a reasonable level of accuracy is not onerous and can be done during a site inspection, as long as the inspection can be supplemented with information found on orthophoto maps. As the maps are based on aerial photography, some catchment characteristics can be deduced from them.

Other methods of estimating runoff can be used, if sufficient data can be gathered. Most methods require large amounts of data on catchment characteristics, that can be time-consuming to gather and are rarely justified.

2.2 Open channel design flow

Open channels are the preferred conduits for the conveyance of storm runoff for several reasons:

- If the channel has been correctly situated in a valley line or low point, its carrying capacity is large, as the designed high water levels can be exceeded, even though some damage may occur when the banks overflow. In contrast, the carrying capacity of a pipe culvert increases steadily as the flow increases to about 70% of its maximum depth and then reduces by at least 7% as the pipe fills and water reaches the top of the pipe. A box culvert will show a more abrupt loss of capacity as the water surface reaches the soffit, due to the additional friction. Both pipe and box culverts will then only increase in capacity after surcharging has taken place. This change to a pressurised system is not a normal design criterion for stormwater systems.

- Closed drainage systems must have access points for maintenance: these are normally manholes. Manholes, unless very carefully designed and constructed, are a major source of head loss due to turbulence. Unbenched manholes will collect sediment, stones and even boulders. The head lost at each manhole can severely reduce the flow capacity of the closed system. An open channel is accessible for maintenance throughout its length.

- Closed conduits conceal blockages, which only become apparent when flooding occurs, by which stage it is too late. Clearing of the blockage may then be difficult. Blockages in open channels can easily be seen and immediately cleared. Their capacity is not as critically dependent upon regular inspection as that of closed conduits.

2.3 Safety

The easy accessibility of open channels may have a negative side. Because they are so accessible, children may play in them, especially when water is flowing. In this regard, a lesson from the Laingsburg flood should be borne in mind: a person is able to wade through fast-flowing water until the depth reaches knee-deep and the flow velocity reaches three metres per second. This is the critical combination of depth and velocity at which a person is swept away. The problem of designing an open channel so that the depth and flow velocity are safe may not be amenable to solution. Other safety measures must then be looked at. Fencing off the channel may cause more problems than it solves. A fence can act as an efficient debris filter and eventually deflect overland flows away from the drain, to cause considerable damage.

2.4 Channel lining

Flow velocities in open channels will dictate the type of channel or channel-lining required. Sensible limits to the flow velocity must be applied in order to limit erosion damage. The maximum flow velocity which can be withstood by various soil types and ditch linings is approximately as follows:

fine sandy soil	0,6 m/s
gravelly soil and stiff clays	1,2 m/s
cement grouted rock lining	3,0 m/s
concrete	over 5.0 m/s

Further guidance can be found in the Road Drainage Manual (Rooseboom, 1993).

Typical roughness coefficients for various channel materials and various linings can also be found in the Road Drainage Manual (Rooseboom, 1993).

The chosen lining should be labour-friendly, that is, it should be readily amenable to construction by labour. For open channels virtually all lining materials can be laid by hand, so this requirement is hardly a restriction. However, for reasons of economy, the chosen channel lining should make maximum use of local materials.

2.5 Road crossings

Culverts are generally chosen as the means by which open channels cross beneath roads. Adequate waterway area is probably the most important and the most difficult criterion to meet. Normally headroom is strictly limited which may severely limit the culvert waterway that can be constructed. If the traffic using the road is such that flooding can be tolerated for short periods, then a drift can provide the additional waterway needed to accommodate a long return period flood. The drift should be designed as a broad-crested weir. Generous freeboard should be provided to enable a larger flood to pass safely. If flow depths can be limited to 200 mm for the design flood, then traffic will seldom be hindered from using the crossing. However, if space does not permit a long drift and flow depths are larger than 200 mm, consideration should be given to the placement of 200 mm high blocks or pillars at intervals along the drift edges to act as depth indicators. A sign should be erected advising that the drift should not be attempted when the depth indicators are under water. (The drift will provide a measure of safety against blockage of the culvert beneath.)

As flow velocities over a broad-crested weir at 200 mm depth are quite small, no special provision need be made to prevent scour of the road surface. However, the downstream flow velocities can increase significantly and will require armour to prevent erosion. Gabions are usually a viable solution. A major advantage of gabions is that pore-pressures cannot build up at the face, as they would upstream of a masonry wall. Gabion walls can support the edge of the roadway, can provide a hydraulic cill preventing downcutting by the floodwaters and can prevent undercutting by the falling water, provided that a gabion mattress is strategically placed for this purpose. (See Figure 1)

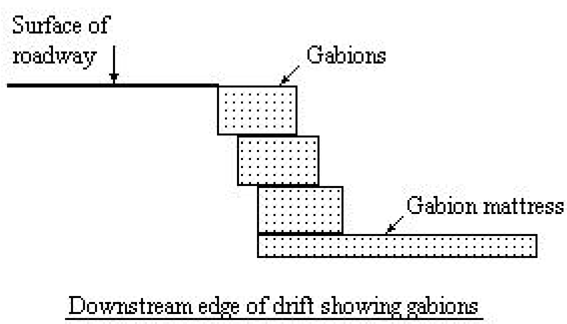

Figure 1: Gabions

If a drift cannot be constructed, then the culvert should be made with openings as large as possible, with a generous allowance for blockage by debris. Storms as large as the 50 year return interval design storm frequently uproot trees and bushes and drag along large quantities of debris. A culvert can be plugged quite rapidly, causing the flow to overtop the structure and damage the road.

3 Materials requirements

Open channel drains may comprise lined or unlined channels, depending on the ground conditions and the flows that have to be carried. Linings are costly and should only be used after the conditions for a channel have been properly assessed. Scour checks can control flow velocities to a limited extent and are usually cheaper than lining.

Typical channel lining materials include:

- Vegetation: low-growing vegetation like matted grasses are the only suitable types for channel linings. Kikuyu grass should be avoided as it needs fairly large quantities of water for its establishment and continued growth in arid climates; in wetter climates kikuyu grows too vigorously and chokes the waterway, requiring regular cutting. The preferred grass is cynodon dactylon variety transvaalensis, or "transvaal kweek", which is hardy, well adapted to arid conditions and is not usually vigorous enough to present problems.

- Masonry linings are rarely appropriate for large channels carrying high flows, however, for small channels brick linings are technically adequate and can have positive aesthetic qualities that are difficult to equal in other materials.

- Precast concrete units are available in many shapes and sizes and can give a channel lining with many desirable properties. Paving units are suitable for small channels and can have positive aesthetic qualities. Vertically interlocking units are resistant to higher flow velocities and can be used to provide greater roughness by alternating blocks of different thickness. Wired interlocking units are suitable for high flow velocities and the openings between the blocks encourage the establishment of vegetation. Grass blocks (precast concrete units with openings) are often suitable for lining channel bottoms and allow the establishment of vegetation. They combine well with "loeffel blocks" used to support the channel sides. With all such linings, care must be taken that turbulent flow does not erode the soil behind the lining or through gaps in the lining and cause the lining to collapse. Geofabrics are generally used to counter erosion behind the lining, while allowing free drainage of groundwater. Abrasion of debris-laden water requires high unit strength.

- In situ concrete as a lining is costly, but used in the right circumstances can be cost-effective. It can resist high flow velocities when carefully detailed and properly constructed. Drainage behind the lining must receive attention, as high ground water levels after storm runoff has been passed, can cause the lining to be lifted. The surface can be made very smooth to reduce sedimentation at low flow velocities, but it is more difficult to make the surface sufficiently rough to control high flow velocities. High flow velocities are perhaps better controlled by means of a series of steps or stepped pools, that induce a hydraulic jump at every step (Rooseboom, 1993). Abrasion of debris-laden water requires high concrete strength.

- In situ concrete cast into "Hyson Cells" combines the advantages of in situ concrete with the flexibility of discrete blocks. (Reference should be made to the literature from the supplier.)

- Rock is an excellent channel lining material and can often be obtained locally. Rock can be used in many forms:
  - **plain stone pitching** comprises laying of hand stone onto a compacted area, the stones are driven into the earth and the gaps between the stones are filled with spalls or with topsoil and rooted grass shoots;
  - **grouted stone pitching** comprises plain stone pitching with the interstices filled with a 1:6 cement: sand mortar instead of spalls or topsoil;
  - **wired and grouted stone pitching** comprises a wire net of 150 mm mesh beneath and above the stone pitching with vertical wire ties at 600 mm centres; when laid and tied together, the area is grouted with a 1:6 cement: sand mortar.

  (Quality of stone is required to be sound, tough and durable, generally with a 200 mm minimum dimension. (Some specifications permit stone with a diameter of upto 600mm to be used). Wire should be 4 mm galvanised wire.)

- Various membranes are in use for channel linings, generally for waterproofing to cut infiltration into the ground. None are, however, robust enough for township or rural settlement use.

4 Plant and equipment requirements

Compaction equipment comprising hand-guided vibrating rollers or plate vibrators are adequate for all but the largest channels. Compaction with hand stampers is adequate for small areas, especially in restricted spaces, but cannot be recommended for general use. Concrete and cement mortars can be mixed by hand or by machine, depending upon the size and speed of the lining project. Hand mixing can produce high quality concrete and mortar, but requires that the mixing team receive intensive training in technique and quality control. If this is neglected the results will be poor.

Tools needed for channel linings will depend on the type of lining. Tools commonly required include spades, shovels, picks, rakes, hand stampers, garden forks, club hammers, spirit levels, straight edges, watering cans, ditch templates, string lines, measuring tapes, boning rods and wheelbarrows.

5 Construction technique

Open channels are readily constructed by hand as the requirements for accuracy and quality are generally not particularly onerous. The essential elements in the construction of open channels are the following:

- Comence work at the lower end so that any water flowing into the channel will drain away immediately and not accumulate to saturate the soil.

- Approach the final excavation level with caution so as not to over excavate. (Overbreak requires costly backfilling that seldom matches the strength and stability of undisturbed soil, especially in the case of unlined earth channels.)

- The use of templates is encouraged, as unskilled labour will quickly learn how to use them to ensure correct shape and side-slope of the channel excavation. Boning rods used in conjunction with profiles will ensure correct longitudinal gradients.

- When linings are to be constructed, the channel bottom and sides must be compacted to at least 90% of ModAASHTO maximum density. Poor soils exposed during excavations should be removed and replaced with better quality gravelly soils Considerable effort is needed to ensure good preparation before lining, as uneven settlement may destroy the lining and negate its purpose. (Remedial work is more costly than doing the job properly in the first place.)

- Stone pitching and block-laying is always started at the low side and worked upstream. The units should be tightly packed.

- Grouting of stone pitching should be undertaken as the job progresses. If grouting is delayed, storm flows carrying sediments can fill the voids in the pitching. Should this happen, the pitching will have to be taken up, the sediments cleaned out and the stone re-laid.

- Attention must be given to the surface finish of linings, in order to fulfil the design requirements. If the design relies on a finished surface with absolute roughness (k) of 0,01 m to control the flow velocity, then a steel-trowelled finish is not desired.

- Drainage of the space behind the lining may be crucial and attention must be focussed on getting the details to work. Filter layers and the installation of flap-valves to relieve groundwater pressures may require specialist inputs.

- Concrete work must be properly cured for at least four days. Poorly cured concrete will not have the abrasion resistance needed to withstand high velocity debris-laden flows.

- Careful backfilling of spaces along and behind structures is essential to the correct functioning of the drain constructed. Adequate quality control measures must be in place.

6 Specialist literature

1. Committee of Land Transport Officials. Standard Specifications for Road and Bridge Works for State Road Authorities. 1998 edition.
2. SABS 2001 BE 7: Standardised Specification for Construction Works: Gabions and Pitching.
3. Miles, L C; "Design philosophy for stormwater drainage". Sixth Quinquennial Convention of the South African Institution of Civil Engineers, Session 2: Stormwater Hydraulics, Durban, June 1978, pp 20 to 24.
4. Rooseboom, A et al, Editors; "Road drainage manual". South African Roads Board, Department of Transport, Pretoria, revised and reprinted 1993.