VOLUME 4 GEOTECHNICS AND DRAINAGE

SECTION 2 DRAINAGE

PART 7

HA 107/04

DESIGN OF OUTFALL AND CULVERT DETAILS

SUMMARY

This Advice Note gives guidance on detailing of outfall structures to highway drainage systems and design of culverts including scour and hydrology but excluding hydraulic design.

INSTRUCTIONS FOR USE

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1. Remove Contents page from Volume 4.
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Design of Outfall and Culvert Details

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DESIGN OF OUTFALL AND CULVERT DETAILS

Contents

1. INTRODUCTION

General

1.1 This Advice Note gives guidance on detailing of outfall structures to highway drainage systems and design of culverts including scour and hydrology but excluding hydraulic design. Advice on the hydraulic design of culverts is given in Chapters 5 and 6 of CIRIA Report 168: Culvert Design Guide (Ref 1). The advice given in this Advice Note relates to adapting the guidance, given in the CIRIA document, specifically for highway applications. Although the advice should be fully taken into account in the design of new schemes (see 1.7), this Advice Note contains no mandatory requirements.

1.2 Investigations, following the large scale flooding that occurred over much of England during the Autumn and Winter 2000, showed that some of the drainage outfalls suffered from submersion. Maintenance during these conditions, in particular screen clearing, proved problematical and in some circumstances posed a serious hazard to the safety of operatives.

1.3 This Advice Note contains guidance on the construction of outfalls from highway drainage systems to, principally, natural channels, watercourses, or purpose made drainage channels. It is not applicable to the outlets of edge of pavement run-off discharges to a piped drainage system. Advice given in HA 78, Design of Outfalls from Surface Water Channels (DMRB 4.2) (Ref 2) is not relevant to the outfalls within the scope of this document.

1.4 The guidance given in this Advice Note supplements the guidance given in the CIRIA Report 168 on the design of culverts and is applicable to those constructed as part of highways works. In assessing the hydraulic design, reference should be made to Chapters 5, 6 and 7 of the CIRIA report, except that for flood estimation purposes, reference should be made to the formulae in the Flood Estimation Handbook, FEH, (Ref 4).

1.5 The advice contained here does not apply to the design of flood alleviation culverts. Where a highway is constructed across a floodplain, HA 71: The Effect of Highway Construction on Floodplains (DMRB 4.2), should be consulted.

Scope

1.6 The principles outlined in this Advice Note apply to all schemes on trunk roads including motorways. They may also be applied generally to other new highway schemes and by other highway authorities for use during the preparation, design and construction of their own comparable schemes.

Implementation

1.7 This Advice Note should be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

2. HIGHWAY DRAINAGE OUTFALLS

General

2.1 The term outfall is applied to the point where the highway drainage system discharges into a different type of drainage system. This may be a sewer, ditch or watercourse. For the purposes of this Advice Note, outfalls are to either ditches or receiving watercourses.

2.2 Where the outfall is to a watercourse, the arrangement detail should be determined in consultation with the relevant environmental protection agency as follows:

(a) England and Wales - Environment Agency (EA);

(b) Scotland - Scottish Environmental Protection Agency (SEPA); or

(c) Northern Ireland - Rivers Agency (RA).

Outfall to Ditch

2.3 The ditch will probably drain the carriageway, verge and the adjacent unpaved area. However, water from the highway drainage system is likely to discharge to the ditch long before that from the adjacent land, the time of concentration being a matter of minutes for the highway drain and hours for the adjacent unpaved areas.

2.4 Outfalls to ditches and watercourses will generally be either from individual pipes or the outlet from an upstream system. Individual pipe outlets can be formed from concrete bagwork in accordance with Clause 519 of the SHW (MCHW 1), brickwork, cast in situ concrete, pre-cast concrete units, or other suitable proprietary products. Typical details are shown as Figure A1 and Figure A2 in Appendix A.

2.5 The components of the outfall structures are described in greater detail in Chapter 3.

Outfall to Watercourse

2.6 It is important to determine the top water levels of the receiving watercourse both in dry and wet weather conditions. The highway pavement is much more responsive to rainfall run-off than the surrounding natural catchment so, generally, the peak discharge from the drain occurs before that in the watercourse. It may therefore be necessary to protect the bed and banks from scour, (see Chapter 3).

2.7 It is possible that during periods of prolonged heavy rainfall the flow in the receiving watercourse may rise above the invert level of the drain. The design of the highway drainage system should therefore be assessed to investigate the effects of a drowned outlet.

2.8 If recent flooding has been experienced, then data relating flow depth in the channel to flow rate may be available. The designer should be aware of the accuracy of such information and also the difference between the calculated design flow and the flow depth obtained from the recorded data.

2.9 The water surface profile can be calculated from the backwater length formula:

$$L_{bw} = 0.7D/s$$

where D is the bank full depth and s is the slope of the water surface (or bed surface where that of the water is unavailable). The designer should refer to the CIRIA Report 168 (Ref 1) Boxes 8.1 and 8.2 for worked examples on the normal calculation method and the backwater calculation method respectively, and HA 71 Chapter 5: Hydraulic assessment of existing water levels (DMRB 4.2).

2.10 Typical Manning's n values for channel roughness are tabulated in Table 2.1. This table is more comprehensive than that forming Table D3 of the CIRIA Report 618 and it is recommended that designers use Table 2.1 values in their calculations.

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Natural Stream Lowland Streams	Min	Normal	Max
1. Clean, straight, full stage, no rifts or pools	0.025	0.030	0.033
2. As above with more stones and weeds	0.030	0.035	0.40
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. As above with some weeds and stones	0.035	0.045	0.050
5. As above, lower stages, more ineffective slopes & sections	0.040	0.048	0.055
6. As 4 above with more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools & heavy timber stand	0.075	0.100	0.150
Mountain Streams			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
Excavated Channel			
1. Gravel, straight uniform, clean	0.022	0.030	0.033
2. Straight, uniform, short grass and weeds	0.022	0.027	0.033
3. Winding and sluggish, grass some weeds	0.025	0.030	0.033
4. Winding, sluggish, dense weeds or plants in deep channels	0.030	0.035	0.040
5. Winding, sluggish, earth bottom, rubble sides	0.028	0.030	0.035
6. Winding, sluggish, stony bottom, weedy banks	0.025	0.035	0.040
7. Winding, sluggish, cobble bottom, clean sides	0.030	0.040	0.050
8. Dredged light brush on banks	0.035	0.050	0.060
9. Rock smooth and uniform	0.025	0.035	0.040
10. Rock jagged and irregular	0.035	0.040	0.050
Unmaintained excavated channel, weeds/brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on both sides	0.040	0.050	0.080
3. As 2, highest stages of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140

Table 2.1: Typical values for Manning's "n"

2.11 The use of Ordnance Survey maps to determine watercourse channel gradients should be sufficient, however accurate cross-sectional dimensions will be necessary.

Outfall Design

2.12 Determine or estimate the top water level in the receiving watercourse channel for the design storm used for the design of the highway drainage system, (HD 33 DMRB 4.2). The invert level of the outfall pipe should be at or above this level.

2.13 The top water level of the receiving watercourse should then be assessed for more intense storms than used to design the drainage system and compared with the levels of the proposed design. A 1 in 30 year storm profile is recommended. Under these conditions the outfall should not become submerged nor should there be a risk of water flowing back into the drainage system. If this occurs during the design of a new highway drainage system then redesign of the system is required. This should also be considered when improving existing systems but improvement may not always be feasible.

2.14 Should the outfall pipe be partially submerged under these conditions, then the diameter of the outfall length of pipeline may be increased to allow a greater volume of flow to pass. The part-full flow characteristics of the partially submerged pipes should be assessed using the Tables for the Hydraulic Design of Pipes, Sewers and Channels (Ref 8).

3. OUTFALL DETAILS

General

3.1 How the outfall is constructed and the details that need to be considered depend on the size of the watercourse and also the range of flow depths within the watercourse. In some instances the highway drain may be the major contributor of water to the channel.

3.2 The outlet pipe should, wherever practical, be directed to discharge in the general direction of flow in the receiving watercourse (see Figure A1). Discharge at right angles to the direction of flow should be avoided if at all possible. The outlet should never discharge against the oncoming flow.

3.3 Consideration should be given to the provision of scour protection to the opposite bank. Where the outfall is at an angle greater than 45° to the direction of flow then scour protection should be provided.

3.4 Scour protection to the watercourse bed may also be necessary where the flows in the watercourse are low, even during storm conditions, relative to the volume and velocity of the highway drainage discharge (see Chapter 7).

Headwall

3.5 The outlet structure should be designed taking account of relevant environmental protection agency recommendations. Ideally the invert of the outfall pipe should be at or close to the top water level of the receiving watercourse to prevent submersion during storm conditions (see 2.7).

3.6 Where the velocity of the peak outflow is in excess of 1.0 m/s then some form of energy dissipation will be required (see Figure A3 and 3.13). The pipe line design should be checked to ensure that velocities at peak discharge do not exceed 1.4 m/s. Where higher velocities occur and cannot be reduced within the drainage system, the advice of the Overseeing Organisation should be sought.

3.7 The headwall should be keyed into the banks and bed to prevent erosion. The apron should have a vertical toe that extends 500mm below the bed of the receiving watercourse. This is to reduce the risk of scour undermining the structure (See Chapter 7).

3.8 Headwalls may be constructed from either brickwork or reinforced concrete both having a reinforced concrete apron. Brickwork for headwall construction shall be in accordance with SHW Clause 507.3. Headwalls to pipes discharging to ditches may also be formed from concrete bagwork in accordance with SHW Clause 519, (see Chapter 2 and Figure A2).

Security Screens

3.9 Security screens to the outlet pipe are recommended where there is a risk of access to the drainage system by children and the pipe is of diameter greater than 375mm. The screen should comprise mild steel flat section welded to form the screen and hot dip galvanised (see Figure A5).

3.10 The screen should be positioned so that the maximum angle to the horizontal is 60° and ideally it should be 45°. A flat section at the top of the screen should be provided to facilitate clearing. The screen should be securely fixed to the headwall using locking nuts.

Flap Valves

3.11 Flap valves prevent the back flow of water from the receiving watercourse into the highway drainage systems. Their presence may cause a significant head loss to the discharge flows and hence the capacity of the latter sections of the system. An allowance should be made during the hydraulic design. Where any pipeline is at risk of being submerged by the flows in the watercourse or where the drainage system discharges to a tidal reach, then a flap valve may be installed. The designer should assess the possible adverse effects that may arise due to the use of a flap valve.

3.12 Where the outlet may be accessible to members of the public, coplastics (composite plastic) valves rather than cast or ductile iron may be less susceptible to vandalism.

Energy Dissipation

3.13 The velocity of the flow within the highway drain may be sufficient to cause erosion of the bed and bank of the receiving watercourse. This is more likely to occur where the gradient of the highway drain is steep and/or where the peak volume of the flow within the highway drain is similar to or greater than that of the receiving watercourse. Note that the peak rate of discharge from the highway drain will usually occur well before the peak flow rate of the watercourse.

3.14 Where the peak discharge velocity of the highway drain is in excess of 1.0 m/s, some form of energy dissipation will be required. The relevant environmental protection agency should be consulted as to the preferred method for the particular watercourse.

3.15 The two principle types are:

- **Stilling basin:** see Figure A3, is the preferred option from a maintenance aspect although this requires a longer structure and hence its use may be precluded due to land take considerations.

- **Concrete baffle blocks:** see Figure A4, uses concrete blocks or teeth cast on to the apron to interrupt the flow and hence dissipate energy. Stone blocks may be used in preference to concrete. There is a maintenance issue in that the blocks will trap debris, especially from the watercourse.

3.16 It is often appropriate to reinforce the watercourse bank opposite the point of discharge in order to reduce the risk of erosion. Concrete revetment or stone pitching are the preferred methods rather than a wall or stone gabions. The relevant environmental protection agency should be consulted to ensure use of the most appropriate method.

3.17 Stone pitching or concrete revetment may be appropriate where there are low flow volumes or velocities in the receiving watercourse during dry conditions. Again the relevant environmental protection agency should be consulted.

4. CULVERTS: INTRODUCTION

General

4.1 The following features are considered good practice:

(i) Adequate size to ensure that design flows are accommodated without surcharge and that debris can pass through the culvert.

(ii) No changes of direction within the culvert or steps in the invert.

(iii) Constant gradient through the culvert, maintaining the gradient of the watercourse.

(iv) Self cleansing, to ensure that no silt is deposited.

(v) Free from internal fittings that may snag debris.

(vi) Accommodates wildlife and fish migration.

(vii) Is aesthetically complementary to the adjacent surroundings.

(viii) Presents no safety hazard to maintenance workers or the public.

(ix) Lowest whole-life costs.

4.2 Culverts for conveying a watercourse from one side of the carriageway to the other have greater design requirements than those forming part of the highway drainage system. Most of the foregoing conditions are also applicable to highway drainage culverts, however due to the fluctuating nature of flows, deposition of silt is inevitable. The collection of debris is also more likely and hence trash screens should be considered as a means of reducing this risk, (see Chapter 8). The diameters of this type of highway drainage culvert tend to be small and hence access for maintenance should be incorporated into the design, (see Chapter 10).

Culvert Shape

4.3 Culverts can be Circular, Rectangular box, Piped arch, Arch or Complex, see Table A1.

4.4 Cover beneath the carriageway and the top of the pipe is an important factor influencing the choice of culvert type. Where cover is limited a rectangular section will offer greater flow area than a circular pipe without compromising the cover to the structure.

Pipe Culvert

4.5 Pipe culverts are more applicable to highway drainage systems, ditch courses and small watercourses. Concrete pipes are not normally available in diameters greater than 2.4 m. Helically wound plastic pipes can be manufactured to greater diameters. Helically wound corrugated steel pipes are available up to 4.0m in diameter.

4.6 However large diameter pipes may be inappropriate for use as highway culverts when the watercourse is wide and shallow and the carriageway level is similar to that of the adjacent natural terrain.

4.7 Culverts longer than 12m should be a minimum of 1.2m in diameter to facilitate access for maintenance. Culverts with diameters of 900mm, and above are classified as structures (Series 2500, MCHW) (see Table B1 of Appendix B). The minimum culvert diameter should be 450mm as smaller sizes are prone to blockage.

4.8 All plastic pipes are designed to be flexible and therefore rely on the resistance of the surrounding fill to achieve their structural integrity. The likely method of construction of the surrounding material such as an embankment should be considered during the design. Where plastic pipes in excess of 900mm are proposed, these may be at a greater risk of vandalism.

Box Culvert

4.9 These may be either cast in situ concrete or pre-cast concrete units and used as either single or multiple bores.

4.10 The joints between pre-cast concrete units can be difficult to seal and make watertight. The risk of exfiltration into embankment foundations should be considered during the culvert design. If there is a significant risk of water from leaking joints either softening or washing away the highway foundation, then the designer should consider an alternative form of pipe system.

4.11 Pre-cast concrete box culverts are manufactured in sizes from 900mm x 900mm up to 6.0m x 6.0m, as in Table A1 of Appendix A. The minimum size of box culvert may be appropriate for use on highway schemes but the designer should be aware of the freeboard requirements (see 6.13) and also the need for maintenance access.

4.12 Culverts should be designed to be free flowing. Culverts on larger streams and rivers should be designed to accommodate 600mm freeboard (the difference between the top flood water level and the culvert soffit) to allow floating debris to pass through.

Pipe Arch

4.13 Formed from corrugated steel, piped arches can provide an efficient structural and hydraulic solution. The design of corrugated steel culverts should be undertaken in accordance with Series 2500 Special Structures of the SHW and BD 12 (DMRB 2.2).

4.14 Corrugated steel structures may be constructed up to 8.0m span to BD 12 standard. The ends of the structure should be shaped to the ground profile of the embankment negating the need for inlet and outlet structures. A structural ring is still required as scour protection unless the bed level is high.

Complex Structures

4.15 These may be multiple barrel structures or single barrel with a composite invert incorporating, for example, a dry weather channel.

4.16 Multiple barrel culverts may be appropriate where there is limited headroom due to relative carriageway and channel levels or where the channel profile is particularly wide. Where the channel cross-sectional area is greater than 5m^2 multiple bores should be considered.

4.17 To avoid problems associated with low flow velocities, such as silt deposition, that may occur due to significant variations between dry and wet weather flows, it may be desirable to restrict dry weather flows to a single channel.

4.18 Multiple barrels also give the opportunity to divert flows into a single barrel to facilitate maintenance.

4.19 There will be a hydraulic head loss at the inlet to a multiple barrel structure that may be minimised by providing cut-waters between the pipes at the culvert entry. BD 12 (DMRB 2.2) Chapter 15 requires multiple corrugated steel arches to be separated by a minimum of 1m.

4.20 Composite structures incorporate a separate channel section within the invert of the culvert. This can be by forming a cast in situ base with a channel in the invert or by forming a shelf to one side, see Table A1 (Appendix A).

4.21 Alternatively the culvert may be constructed with a depressed channel invert filled with gravel. This will be more suitable for allowing the passage of fish.

4.22 In particular situations a gravel filled invert can provide additional capacity during severe flow conditions as the gravel will tend to be scoured out thereby increasing the capacity of the channel. Note that the displaced gravel will be deposited downstream, causing additional maintenance to be undertaken if hydraulic performance downstream is to be maintained.

4.23 There are maintenance implications wherever gravel filled inverts are constructed and the designer should ensure that their whereabouts are inserted into the asset database and recorded in the health and safety plan.

5. CULVERTS: LOCATION AND LAYOUT

General

5.1 The position of a culvert is dependent on its intended purpose. Although often used for traversing a watercourse in place of a bridge, culverts are also used to facilitate crossings of ditches or to transfer the drainage run from one side of the carriageway to another.

5.2 Culverts to streams or small rivers are of necessity larger than those to channels that form part of the highway drainage system. The transition from watercourse to culvert should take account of the existing landscape features to ensure that the culvert and structures are not visually intrusive, see DMRB 10, Part 1, Chapter 22.

Culvert Alignment

5.3 The alignment of the culvert relative to that of the road should aim to minimise its length. Ideally the crossing would be as direct as possible. However there are a number of factors to be considered, see Appendix C, Figure C1:

- maintenance of channel flows during construction;
- effects on the watercourse of realignment;
- scour or sedimentation problems;
- design and cost of river training works;
- maintenance access and working area.

5.4 A culvert constructed along the line of an existing watercourse is the better option for maintaining existing hydraulic conditions. However the problems associated with on line construction must be addressed during the design stage, and the options are, briefly:

- pumping or temporary channelling of the watercourse;
- removal of the channel bed and in-filling of soft spots. Care must be taken during construction to ensure that there is no localised settlement of the culvert.

5.5 Off-line construction has advantages of maintaining the existing channel flows and working in the dry. However diversion of the watercourse through the new culvert may require the introduction of short radius bends, particularly where the culvert crossing is close to 90º to the carriageway.

5.6 The introduction of bends will probably result in either erosion of the bank on the outside of the bend or silt deposition on the inside. Watercourse training works may entail significant structures, either independent of the culvert or forming part of it. Where possible these structures should be avoided and the guidance given in HA 81: Nature Conservation Advice in Respect of Otters (DMRB 9.1) followed.

5.7 Option 3 shown in Figure C1 of Appendix C probably offers the better solution, being off-line but minimising deviation of the channel alignment. The advice in Chapter 4 should be followed with regard to the length of the culvert.

5.8 Whichever option is chosen, the designer should ensure that access for maintenance can be readily obtained and that the area both upstream and downstream of the culvert provides sufficient space for the maintenance activities to take place.

Ditch Culverts

5.9 A typical example of a ditch culvert would be where the highway drainage ditch at the edge of a rural trunk road is crossed by a field access. The flows in the drainage system will tend to be low both in volume and velocity and the channel will also be relatively shallow.

5.10 The culvert in this location will be short, generally a pipe of moderate diameter and have a minimal cover. It will also be prone to obstruction by vegetation growth.

5.11 The pipe should be designed to accommodate the design peak flow in the channel without surcharging, ideally having a greater capacity to allow for sediment deposition within the bore. Advice on channel design is given in HA 106: Drainage of Runoff from Natural Catchments (DMRB 4.2). The invert of the pipe culvert should ideally be at least 75mm below the bed of the channel. This is to ensure that water does not pond in front of the culvert. There are a number of features to take into account at this point:

(i) The sides of the ditch channel should be higher than the soffit of the culvert pipe.

(ii) The headwall to the culvert should extend into the banks of the ditch over the full depth. The headwall may be a simple brick structure, cast in situ reinforced concrete or concrete bagwork. All should be adequately founded below the invert of the channel to prevent ingress of water and consequent erosion.

(iii) A small concrete apron should be constructed in front of the headwall to suppress vegetation growth immediately upstream of the inlet, and ideally also at the outlet. On small diameter culverts, this can be simply achieved using pre-cast concrete paving slabs.

(iv) Screens to pipes of 600mm or less should not be necessary in rural locations, however in urban areas there is a greater risk of children entering the culvert.

(v) Ensure that the pipe has adequate cover and is of the appropriate class. Reference to HA 40: Determination of Pipe and Bedding Combinations for Highway Drainage (DMRB 4.2), the Simplified Tables of External Loads on Buried Pipelines (Ref 5) and A Guide to Design Loadings for Buried Rigid Pipes (Ref 6).

(vi) The height of the headwalls should adequately support the fill material over the culvert pipe.

Carriageway Crossings

5.12 The alignment of the carriageway relative to the watercourse can have a significant effect on the design of the culvert. The length of the culvert should be kept as short as possible for reasons of:

(i) hydraulics;

(ii) cost;

(iii) habitat migration;

(iv) ease and effectiveness of maintenance.

Culverts to Larger Watercourses

5.13 Culverts constructed in floodplains should also meet the requirement of HA 71: The Effects of Highway Construction on Floodplains (DMRB 4.2).

5.14 Culverts to large watercourses such as rivers are likely to be multiple barrel due to the relative width of the channel to the depth of the structure, (see 4.15).

5.15 The culvert invert should be set below the bed level by around 25% of the pipe diameter or not less than 150mm for other structures.

6. CULVERTS: FLOOD ESTIMATION

General

6.1 This Advice Note is not intended to set out the procedures for the hydraulic design of culverts, but aims to supplement the guidance given in CIRIA Report 168 (see 1.4) by giving specific guidance on aspects of culvert design that should be taken account of in the design process.

6.2 Culverts beneath highways tend to be relatively short but may have to accommodate restrictions imposed by carriageway alignment and road construction, ie. cover to the top of the culvert. The presence and probable size of culverts must be determined early in the highway design process.

6.3 The design of the culvert should be appropriate for the life of the structure. Lower flow velocities through the culvert require proportionally greater spare capacity. The design should consider measures to increase the flow velocity through the structure in these instances.

6.4 The capacity of the culvert should be designed to accommodate flows which are anticipated to have between a 1% and 4% risk of occurring annually. The anticipated flood frequency should be agreed with the relevant environmental protection agency, whose requirements are normally those shown in Table 6.1 Flood return periods.

1 in 100 years	Urban areas and villages
1 in 50 years	Agricultural land of high value and isolated properties
1 in 25 years	Agricultural land (minimum level of protection)

Table 6.1 Flood return periods

6.5 The maximum discharge velocity under design flood flow conditions should not exceed 1.2 m/s unless erosion protection is installed (see 6.9).

Estimating the Flood

6.6 Before estimating the design flood, the Mean Annual Flood (MAF) should be calculated. For large catchments, areas greater than 0.5 km^2 (50 Ha), the formulae in the FEH (Ref 4) should be used but for small catchments, measuring less than 50 Ha (hectares) then the procedures for small catchments in HA 106 Drainage of Runoff from Natural Catchments, (DMRB 4.2) should be followed. Note that HA 106 contains guidance on the use of both methods.

Afflux

6.7 This is defined as the increase in the depth of water at the upstream end of the culvert due to the constriction of the flow width. The allowable afflux should be determined in consultation with the relevant environmental protection agency or relevant drainage authority.

6.8 The depth of flow is a function of the cross-sectional area and hence a reduction in channel width will result in a corresponding increase in upstream flow depth and velocity.

Scour Protection

6.9 The outlet in particular will need to be protected from the effects of scour, principally, the erosion of the downstream bed. By providing an apron to the outlet, turbulence caused by the transition from culvert to channel may be contained. Providing scour protection beyond the apron will minimise any risk of scour downstream of the structure, (see Chapter 7).

6.10 Scour to the inlet may also occur especially where there is a change of alignment between the stream and the culvert. Scour here can undermine structural integrity.

Tail Water Effects

6.11 The tail water depth is the depth of water above the culvert invert at the outlet. For free flow conditions the tail water depth should be less than the diameter or vertical dimension of the culvert.

6.12 If the tail water level rises above culvert soffit, the system will operate under surcharged conditions. The design must be checked to ensure that the correct procedures in CIRIA 168 are followed.

Freeboard

6.13 This is defined as the height of the culvert soffit over the flood water level. Where the culvert is located on a watercourse that, in England and Wales, is classified as “Main River”, by the Environment Agency, a minimum freeboard of 600mm is normally required. This will enable the passage of large, floating debris through the culvert. Elsewhere, the designer should ascertain the requirements of the relevant environmental protection agency.

6.14 For smaller culverts, a freeboard of 300mm should be adequate. For freeflow conditions, i.e. when neither the inlet nor the outlet of the culvert is submerged at peak design flow, a rough guide is that the freeboard should be D/4 where D is the diameter for circular culverts or height, for non-circular.

7. CULVERTS: SCOUR ISSUES

Estimation of Scour Depths

7.1 Flow from outfalls or culverts will generally have a higher velocity than that of the receiving watercourse and this can result in erosion of the bed and banks of the receiving channels. When the depth and/or extent of the scour hole is such that it undermines the foundations of the outfall structure or its outlet wing walls, structural damage can occur leading to collapse. Measures are usually necessary to minimise this risk and can be grouped into the following categories (CIRIA Report 168, 1997, gives examples of good practice) (Ref 1):

- Optimisation of layout (in plan, where possible, the discharge of the outfall or culvert should be angled in the downstream direction at about 45°).
- Introduction of outlet arrangements (for example angled wing walls help expand the flow in a gradual manner).
- Inclusion of energy dissipation devices (these may be needed for steep outfalls or culverts and may consist of baffles across the outfall structure or of stilling basins for larger, high energy culverts).

7.2 The potential for scour should be assessed for all outfall structures. Formulae for estimating maximum scour depths are given in CIRIA Report C551 (Ref 10), among other publications. The maximum scour depth should be determined for the natural bed material and then compared with the depth of the outfall or culvert foundation level to assess the risk of failure. The following design formulae are suggested for estimating maximum scour depths, y_s, and the extent of the scour hole, L_s, for the two distinct cases of rectangular culverts or pipes producing two dimensional, 2D, jets and circular or square culverts producing three dimensional, 3D, jets:

2D Jets

Scour Depth

7.3 Use the equation due to Hoffmans (1997) (Ref 11):

$$y_s = \left(\frac{50}{k}\right)\left(1 - \frac{U_2}{U_1}\right) y_1$$

where y_s is the depth of scour below the invert of the culvert (in m), y_1 is the vertical thickness of the jet (in m), U_1 is the depth-averaged velocity in the jet and U_2 is the depth-averaged velocity in the receiving channel (both in m/s). k is a non-dimensional scour factor dependent on the d_{90} size of the sediment (for which 90% of the material by weight is fines) in the channel bed (in mm) and is defined as:

$k = 2.95\, d_{90}^{\ 1/3}$ for $0.1\text{mm} < d_{90} < 12.5\text{mm}$

$k = 6.85$ for $d_{90} > 12.5\text{mm}$

Scour Extent

7.4 The overall length of the scour hole can be estimated to be 5 to 7 times the scour depth.

3D Jets

Scour Depth

7.5 Use the equation due to Ruff et al (1982) (Ref 13):

$$y_s = 2.07\, D \left(\frac{Q}{\sqrt{g\, D^5}}\right)^{0.45}$$

where y_s is the depth of scour below the invert of the outfall or culvert (in m), Q is the flow rate (in m^3/s), g is the acceleration due to gravity (m/s^2) and D is the diameter of the pipe (in m).

Scour Extent

7.6 The overall length of the scour hole will be approximately 7 times the scour depth.

The above formulae apply to horizontal jets.

Design of Scour Protection

7.7 Scour protection measures reduce the vulnerability of a structure to failure by lining the bed material with a more erosion-resistant surface. Together with optimisation of the outfall layout, this is one of the most common means of avoiding or controlling scour problems. One of the most common materials used is riprap, or loose quarry stone that is placed in a controlled way to provide a blanket for scour protection.

7.8 There is a wide range of proprietary and non-proprietary scour protection materials and the choice depends on a range of factors: construction cost/availability, environmental considerations, accessibility and construction restraints, underwater or dry construction, maintenance issues, etc. It should be noted that scour protection may need to be extended beyond the immediate vicinity of the predicted scour hole since residual turbulence can affect the stability of the bed and banks of the receiving channel (Refs 9 and 10).

Riprap

7.9 Simple guidelines for sizing riprap downstream of culverts (or outfalls) are given by Bohan (1970) (Ref 14):

$$\frac{d}{D} = 0.25\,F_c \qquad \text{for } y_T < D/2$$

$$\frac{d}{D} = 0.25\,F_c - 0.15 \qquad \text{for } y_T \geq D/2$$

where d can be taken as the d_{50} size of the stone, D is the pipe diameter, y_T is tailwater depth and F_c is the Froude number of the flow discharging from the outfall or culvert:

$$F_c = \frac{U_1}{\sqrt{g\,D}}$$

where U_1 is the mean flow velocity at the culvert outlet and g is the acceleration due to gravity. The length of the scour protection blanket, Lp is dependent on the value of F_c:

for $F_c \leq 1$

$$\frac{L_p}{D} = 8$$

for $F_c > 1$

$$\frac{L_p}{D} = 8 + 17\log_{10} F_c \qquad \text{for } y_T < D/2$$

$$\frac{L_p}{D} = 8 + 55\log_{10} F_c \qquad \text{for } y_T \geq D/2.$$

7.10 In order to secure the scour protection blanket in place, this should be turned downwards into the bed at its downstream end for a distance of at least one pipe diameter.

7.11 In some cases it may be more economical to include an energy dissipation measure downstream of the pipe or culvert to reduce the energy of the flow (see, for example, Peterka, 1978, for design guidance and layout details) (Ref 12).

Other Methods

7.12 For a detailed description of these and alternative methods refer to Section 8.10 in CIRIA 168 (Ref 1) and to CIRIA Report C551, (Ref 10) and proprietary literature.

8. CULVERTS: SCREEN DETAILS

General

8.1 The provision of screens to culverted watercourses should be discussed and agreed with the relevant environmental protection agency. Screens are not normally necessary for large culverts.

8.2 Screens can serve two purposes; as a trash screen to retain floating debris and as a security screen to restrict access to the culvert by unauthorised persons. The screen should be readily and safely accessible for maintenance. Note that a screen must be provided at the inlet to the culvert if a security screen is installed at the downstream end.

8.3 The screen should be inclined at 45^{o} to the horizontal, however in circumstances where available space is limited, 60^{o} should be considered as the maximum. The screen should have a horizontal section between the inclined face and the headwall. This will enable debris to be racked up over the screen during maintenance. A typical screen detail is shown as Figure A5 in Appendix A.

8.4 Screens must never be fitted vertically to the head wall structure. Vertical screens easily trap debris and the consequent increase in water level/pressure can cause the screen to deform if installed at the upstream end. Vertical screens are difficult to clear and may require operatives to lean over the headwall above the retained water; this is dangerous. At the downstream end, vertical screens can trap debris within the culvert leading to blockages and the deposition of sediment. Clearing debris from behind such a screen can be difficult and dangerous.

8.5 It is preferable that vertical screens are positioned in the channel immediately upstream of the culvert inlet. These should be of restricted height so that, if blocked by debris build up, water may flow over the top.

8.6 A screen in the channel will cause an increase in water level upstream.

Bar Spacing

8.7 Where used as a security screen, the bar spacing must not exceed 150mm centres.

8.8 Where used as a debris screen the bar spacing must not be less than 75mm centres.

8.9 The individual bars of the screen should not be less than 25mm diameter or, 8x75mm where flats are used. Bars of circular cross-section offer the better hydraulic performance but flat bars may provide a more rigid structure. The maximum bar length before bracing is necessary is 1.5m. Any bracing must be on the inside face of the screen for ease of raking.

Security

8.10 To prevent unauthorised removal, the screen should be fixed to the headwall or to the headwall and wing-walls. All bolts and nuts used for fixing should be vandal proof.

8.11 Nuts should be tack welded to the bolts.

8.12 Screens large enough to permit man entry should have an access panel secured with a heavy duty padlock. A sliding bar with padlock may afford greater security than the use of chains (Refer to Plate A5).

8.13 There should be a gap of 150mm between the bottom of the screen and the apron.

9. CULVERTS: ENVIRONMENTAL ASPECTS

General

9.1 The effect a culvert has on the wildlife must be taken into consideration. Refer to Volumes 10 and 11 of the DMRB.

Fish

9.2 The presence of fish within the watercourse should be established prior to design work and the Fisheries Officer at the relevant environmental protection agency consulted. Fisheries protection advice is given in DMRB 11, Part 10, Chapter 5.

9.3 Fish are reluctant to pass through dark waterways and consequently fish migration may be impeded should the culvert be inappropriately designed. Designers should be aware that the light penetrating the culvert is a function of its length and diameter.

9.4 Streams and rivers that support fish are generally too large to be culverted using pipes. Long culverts and changes of direction within the culvert should be avoided.

9.5 Without compromising the flow characteristics, the headwall structures should allow light into the culvert without casting shadows across the inlet and outlet.

Otters and Other Mammals

9.6 Mammal runs are required where the watercourse forms the natural passage from one side of the road to the other. Refer to HA 81 (DMRB 10.1 Part 9).

9.8 Where larger culverts have a dry weather channel, the wet weather channel can form the mammal run. Where no dry weather channel is featured, a run should be attached to one or both walls. Note that the run should be accessible from the watercourse edge, see Figure A6 of Appendix A.

9.9 Culverts, the headwalls and adjacent vegetation can become roosts for bats. The designer should refer to DMRB 10.8, Chapter 9 Mitigation Measures. Culverts of diameter greater than 1.0m can become fly through routes for bats if located adjacent to roosts or feeding areas.

Public Access

9.10 Culverts positioned at or close to the highway boundary will be vulnerable to vandalism, investigation by children, and the accumulation of litter where adjacent access is available to members of the public. Screens should be provided, (see Chapter 8).

9.11 Maintenance inspections may need to be more frequent in these circumstances and hence, where possible, a means of access should be constructed, (see Chapter 10).

10. CULVERTS: MAINTENANCE ISSUES

General

10.1 To reduce operation and maintenance requirements Section 4.1 should be adhered to during the design.

Safety

10.2 The culvert and its associated structures should be designed to facilitate safe access for inspection and maintenance.

10.3 The design must enable the provisions of the Health and Safety at Work Act to be met. Provision must be made for securing safety harnesses.

Access

10.4 Access for inspection and cleaning must be safely attainable from within the highway boundary unless there is a specific right of access through adjacent property. Adequate space should be made available for carrying out maintenance. The design must not proceed on the assumption of such a wayleave subsequently being granted. See Appendix D.

10.5 Where the culvert is located entirely within the highway boundary, a handrail or balustrade should be provided across the top of the culvert. This should be secure and if the headwall is of brick construction, should not be fixed to the top of the headwall.

10.6 Where the embankment slopes directly down to the top of the outfall or culvert headwall a handrail must be provided either along the headwall parapet or between the slope face and the headwall. Access steps should be constructed on the embankment above the headwall to minimise the risk of falls or slips. The step treads should be textured for grip and a handrail provided.

Desilting

10.7 Culverts with low dry weather flows may be isolated using stop logs (suitable frame required), plastic sheet and frame, a portable dam or sand bags The dam should not be much higher than the water level and not above the soffit of the culvert so that, in an emergency, water may flow over the top.

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BD 12	Design of Corrugated Steel Buried Structures with Spans not Exceeding 8m Including Circular Arches (DMRB 2.2)
BD 31	Buried Concrete Box Type Structures (DMRB 2.2)
HD 33	Surface and Sub-surface Drainage Systems for Highways (DMRB 4.2)
HA 37	Hydraulic Design of Road Edge Surface Water Channels (DMRB 4.2)
HA 39	Edge of Pavement Details (DMRB 4.2)
HA 40	Determination of pipe and bedding combinations for drainage works (DMRB 4.2)
HA 55	Landform and Alignment (DMRB 10.1.1)
HA 71	The effects of highway construction on floodplains (DMRB 4.2)
HA 78	Design of Outfalls from Surface Water Channels (DMRB 4.2)
HA 81	Nature Conservation Advice in Respect of Otters (DMRB 10.4)
	Water Quality and Drainage (DMRB 11.3.10)
HA 106	Drainage of runoff from natural catchments (DMRB 4.2)

3 **Manual of Contract Documents for Highway Works (MCHW) (The Stationery Office)**

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14. BOHAN J.P. (1970). Erosion and riprap requirements at culverts and storm drain outlets. US Army Engineer Waterways Experiment Station. Research Report H-70-2.

12. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:

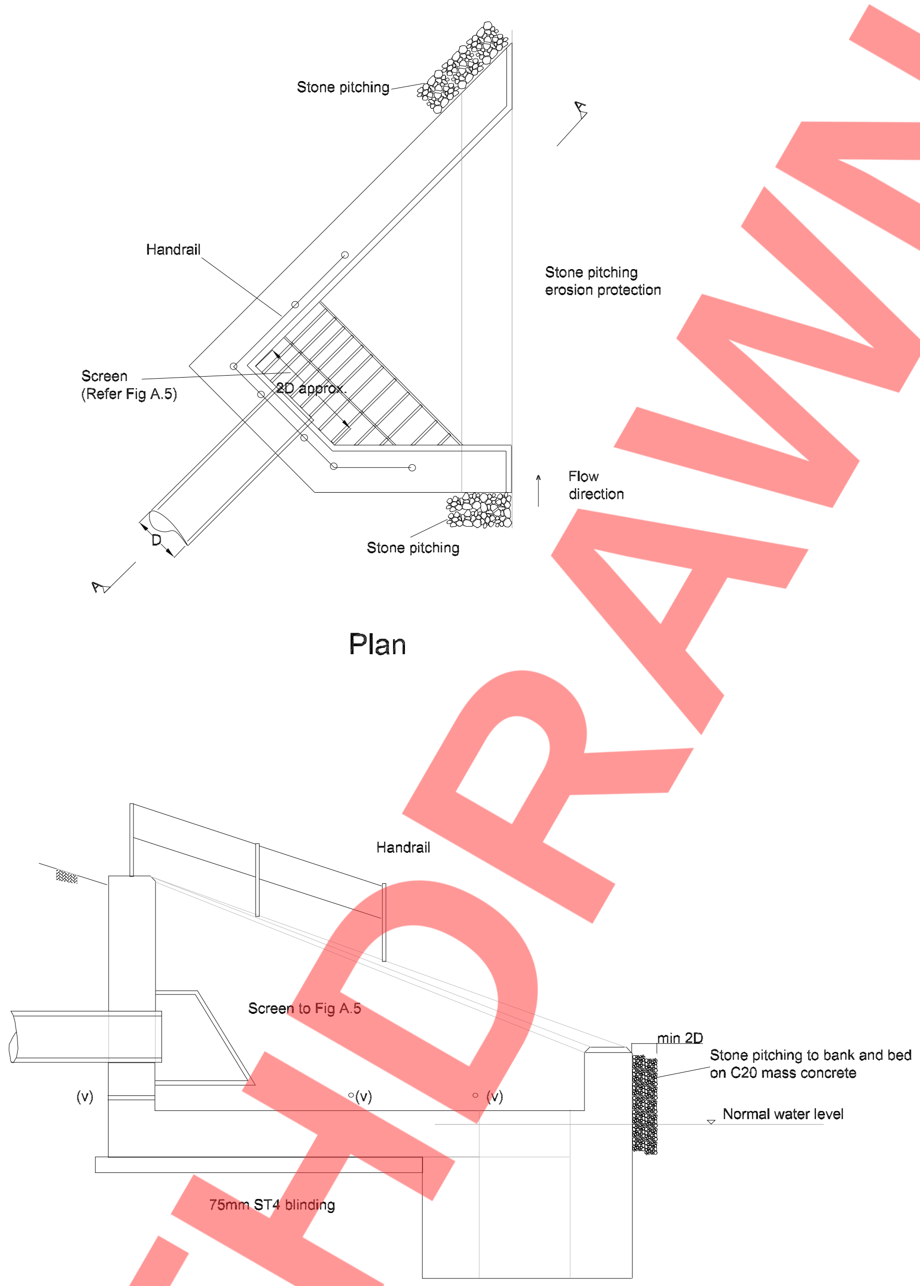
Chief Highway Engineer The Highways Agency 123 Buckingham Palace Road London SW1W 9HA	G CLARKE Chief Highway Engineer

Chief Road Engineer Scottish Executive Victoria Quay Edinburgh EH6 6QQ	J HOWISON Chief Road Engineer

Chief Highway Engineer Transport Directorate Welsh Assembly Government Llywodraeth Cynulliad Cymru Crown Buildings Cardiff CF10 3NQ	M J A PARKER Chief Highway Engineer Transport Directorate

Assistant Director of Engineering The Department for Regional Development Roads Service Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	D O'HAGAN Assistant Director of Engineering

APPENDIX A: CONSTRUCTION DETAILS



Notes:-

(i) Structure should not project into channel
(ii) Wall slope to correspond with bank profile but not steeper than 1:1
(iii) Handrail Ref. Clause 10.5
(iv) Screen Ref. Chapter 8 and Fig A.5
(v) Weep holes through wall if necessary
(vi) Screen may be replaced by a flap valve

Section 'A-A'

Figure A1: Typical Outfall Headwall

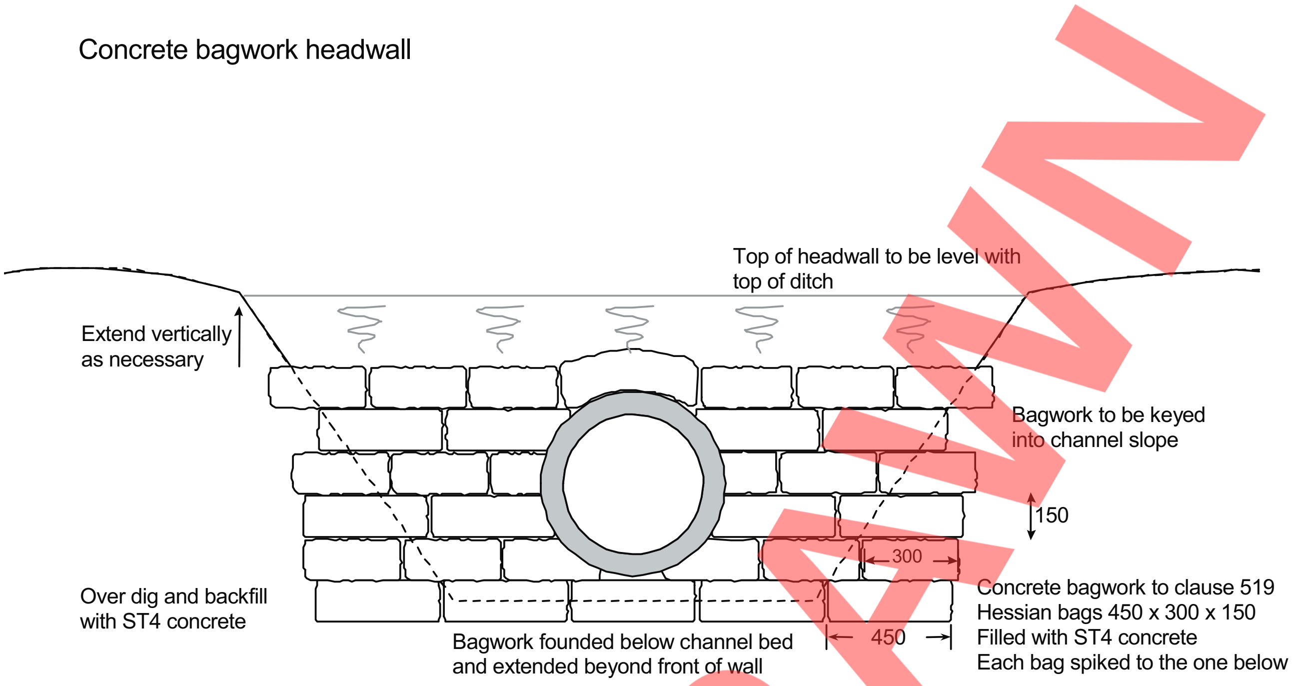
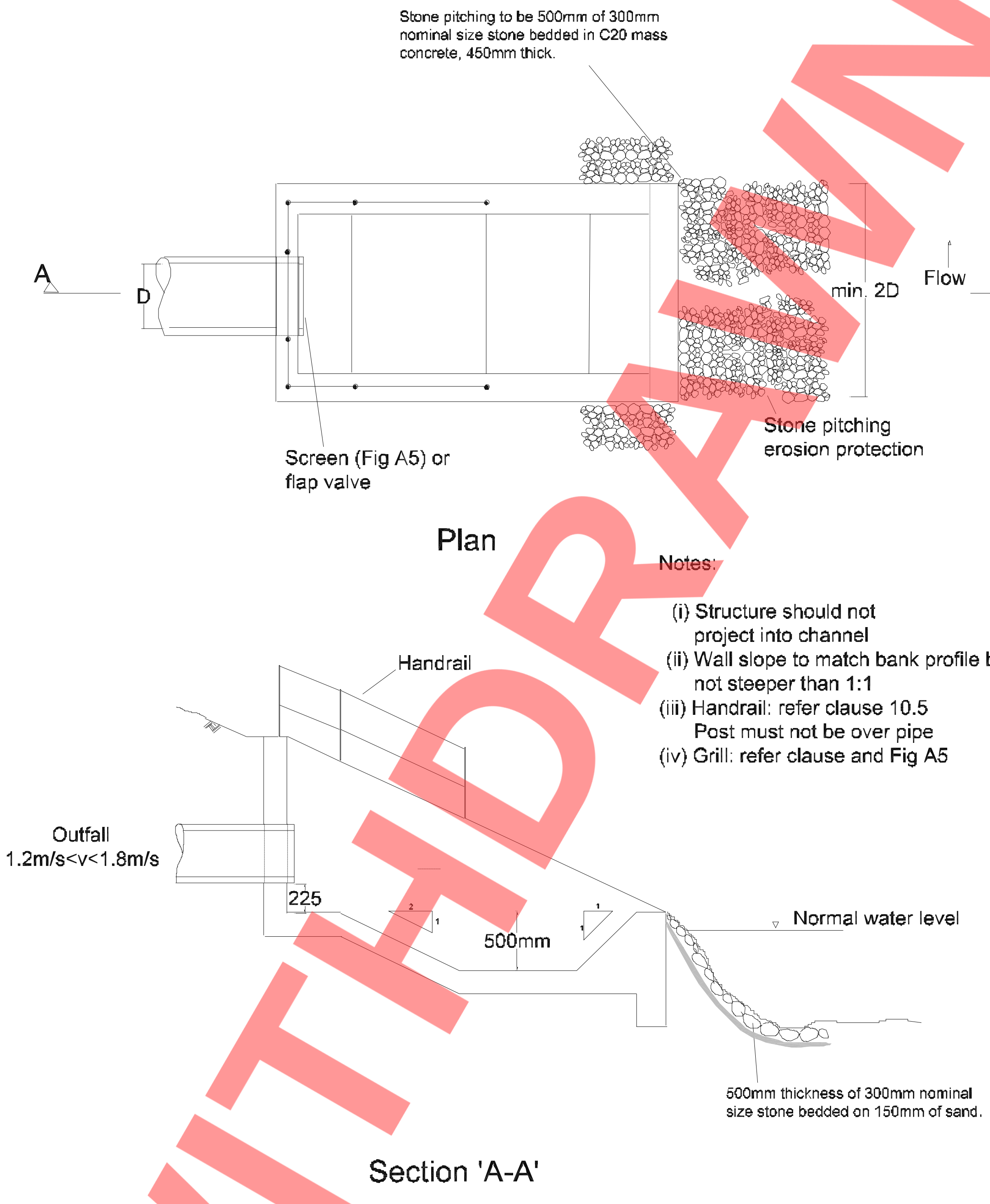


Figure A2: Concrete Bagwork Headwall

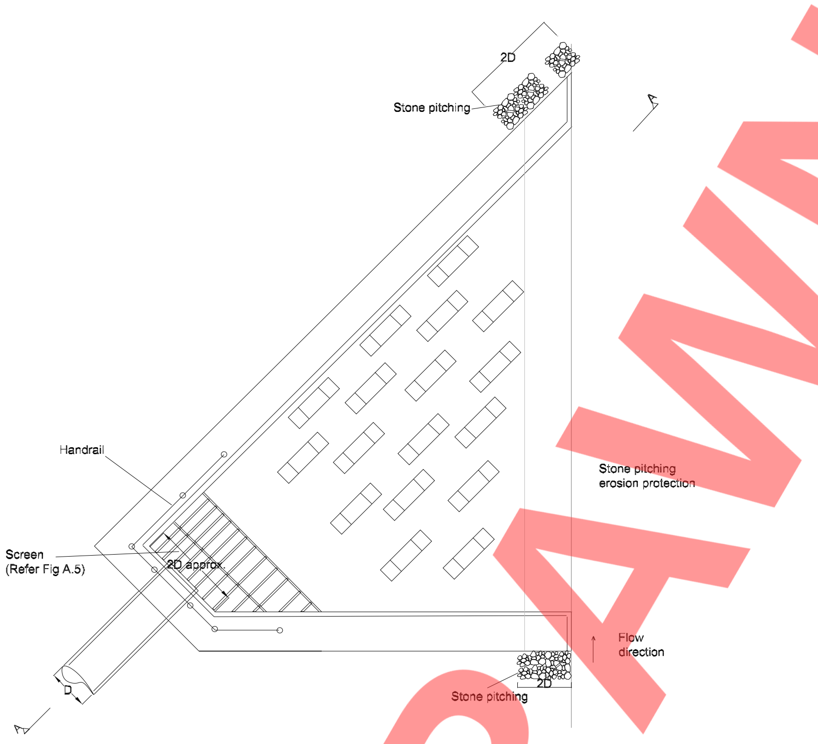
Plate A2: Concrete Bagwork Headwall



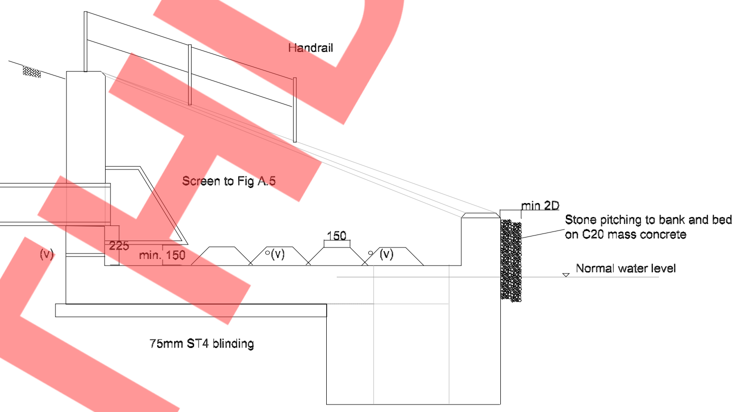
Notes:

(i) Structure should not project into channel
(ii) Wall slope to match bank profile but not steeper than 1:1
(iii) Handrail: refer clause 10.5 Post must not be over pipe
(iv) Grill: refer clause and Fig A5

Figure A3: Headwall with Stilling Basin



Plan



Notes:-

(i) Structure should not project into channel
(ii) Wall slope to correspond with bank profile but not steeper than 1:1
(iii) Handrail Ref. Clause 10.5
(iv) Screen Ref. Chapter 8 and Fig A.5
(v) Weep holes through wall if necessary
(vi) Screen may be replaced by a flap valve

Section 'A-A'

Figure A4: Headwall with Baffle Blocks

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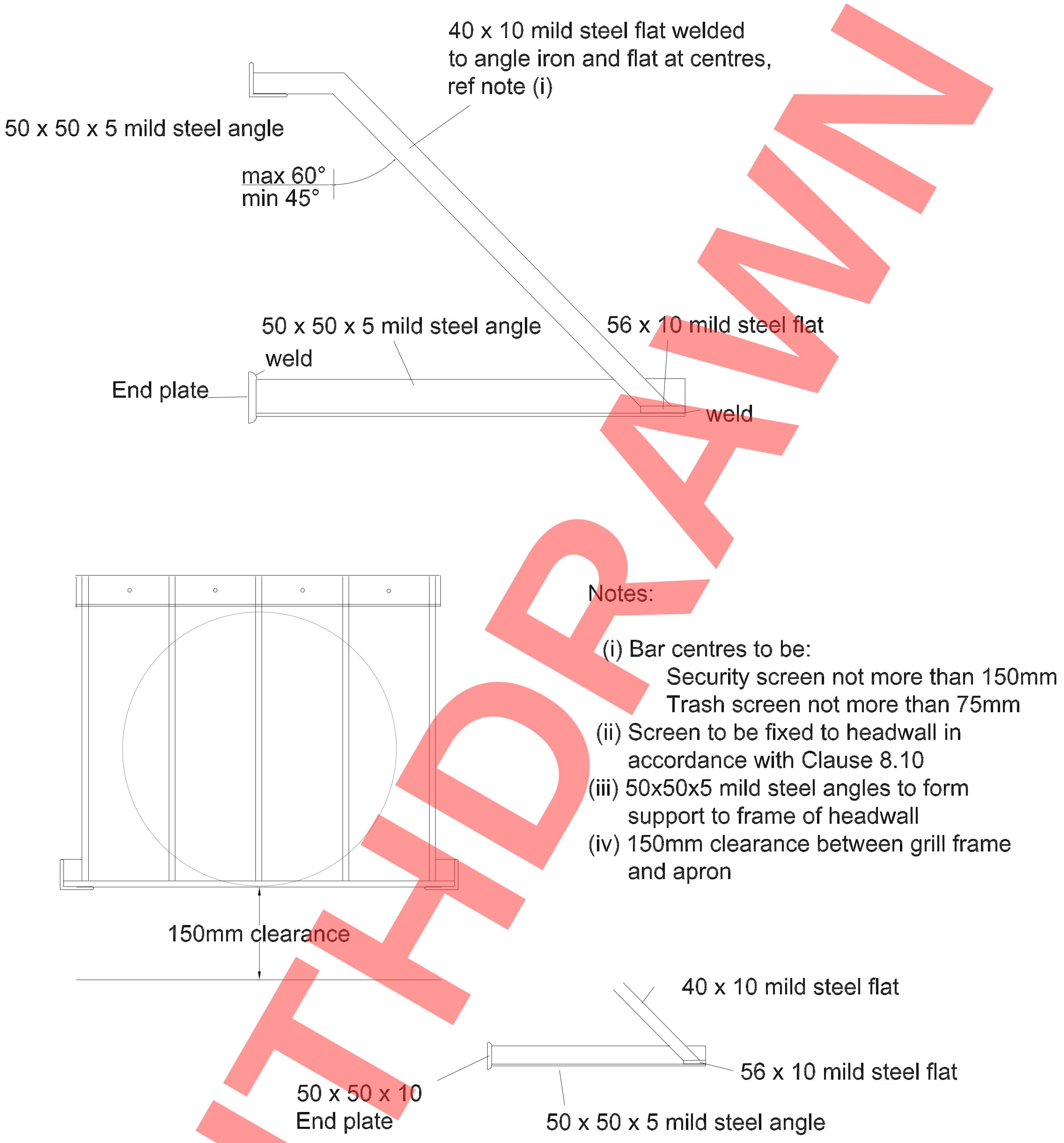


Figure A5: Typical Screen Detail

Plate A5: Example of a Screen to a Large Watercourse

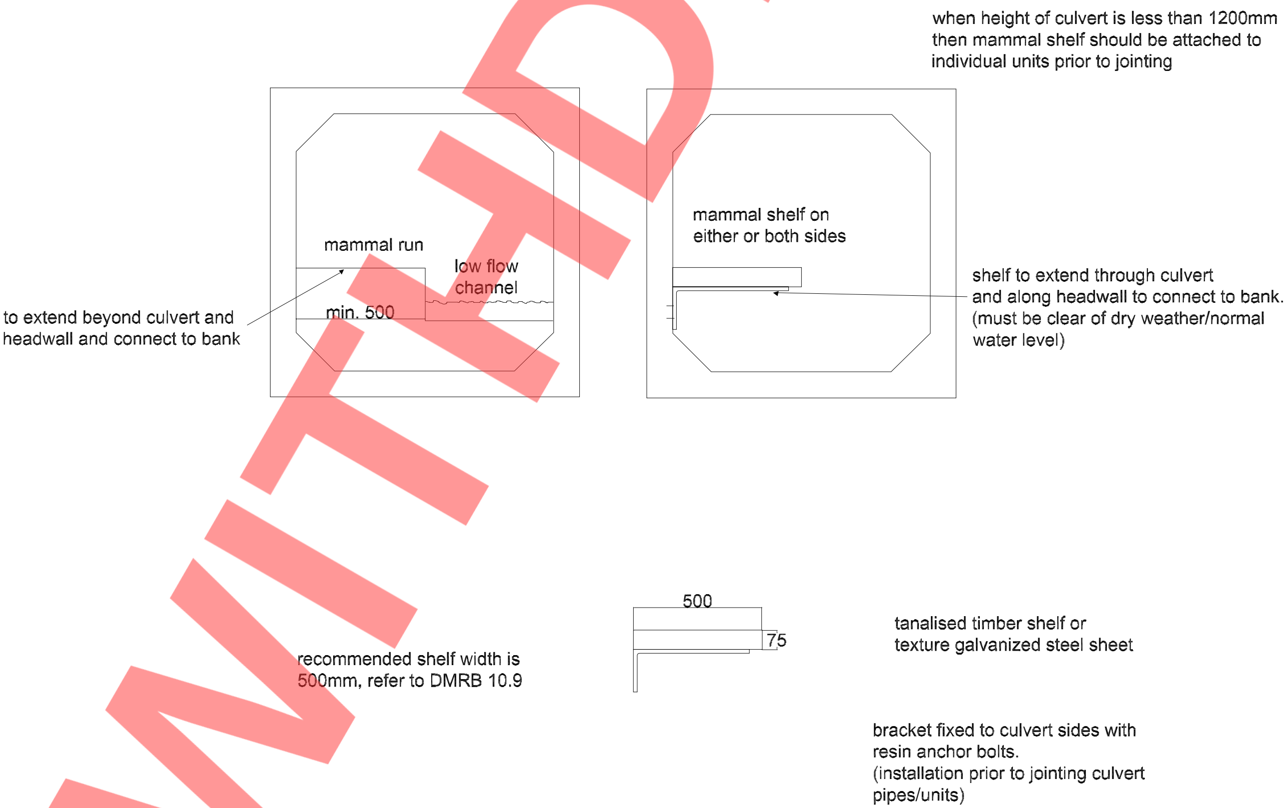


Figure A6: Typical Mammal Run Detail

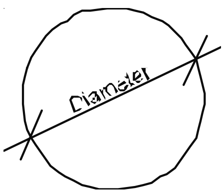
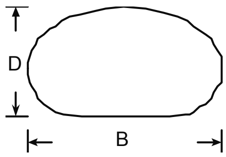
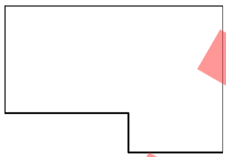
Type	Shape	Material	Dimension Range
Pipe		• Concrete • Plastic • Corrugated steel • Other	to 2.4m to 3.0m to 4.0m
Box		• Pre-cast concrete • In situ concrete	to 6.0 x 6.0m B < 12.0m
Pipe Arch		• Corrugated steel	to 8.05m span
Multiple Pipe Arch		• Corrugated steel	7.0 x 2.5m to 17.0m x 7.0m
Complex		• In situ concrete or • Pre-cast concrete with additions	B < 12.0m B < 6.0m

Table A1: Culvert Barrel Size Ranges

APPENDIX B: PIPES AND CULVERTS HAVING DIAMETER OR SPAN EXCEEDING 900MM

Material	Usage	Standard	Particular requirements
Vitrified clay	Surface and foul water drains	BS EN 295	Shall comply with Clause 2506
Concrete (with Portland cement or sulphate resisting cement when required in Appendix 25/5. Supersulfated cement shall not be used)	Surface and foul water drains	BS 5911: Part 100 or Part 103	Pipes having a concrete mix meeting the following requirement. (Testing in accordance with the relevant BS and sampling in accordance with sub-clause 28 of Clause 2506). A total chloride content not exceeding the values in Table 17/2, must comply with Clause 2506
Iron	Surface and foul water drains	BS EN 598 (Ductile iron)	
Corrugated steel	Surface water drains	BD 12	Type approval certificate and BBA Roads and Bridges Certificate. Shall comply with Clause 2501

Table B1: Pipes for Drains and Culverts Having Diameter or Clear Span Exceeding 900mm

APPENDIX C: CULVERT ALIGNMENT OPTIONS

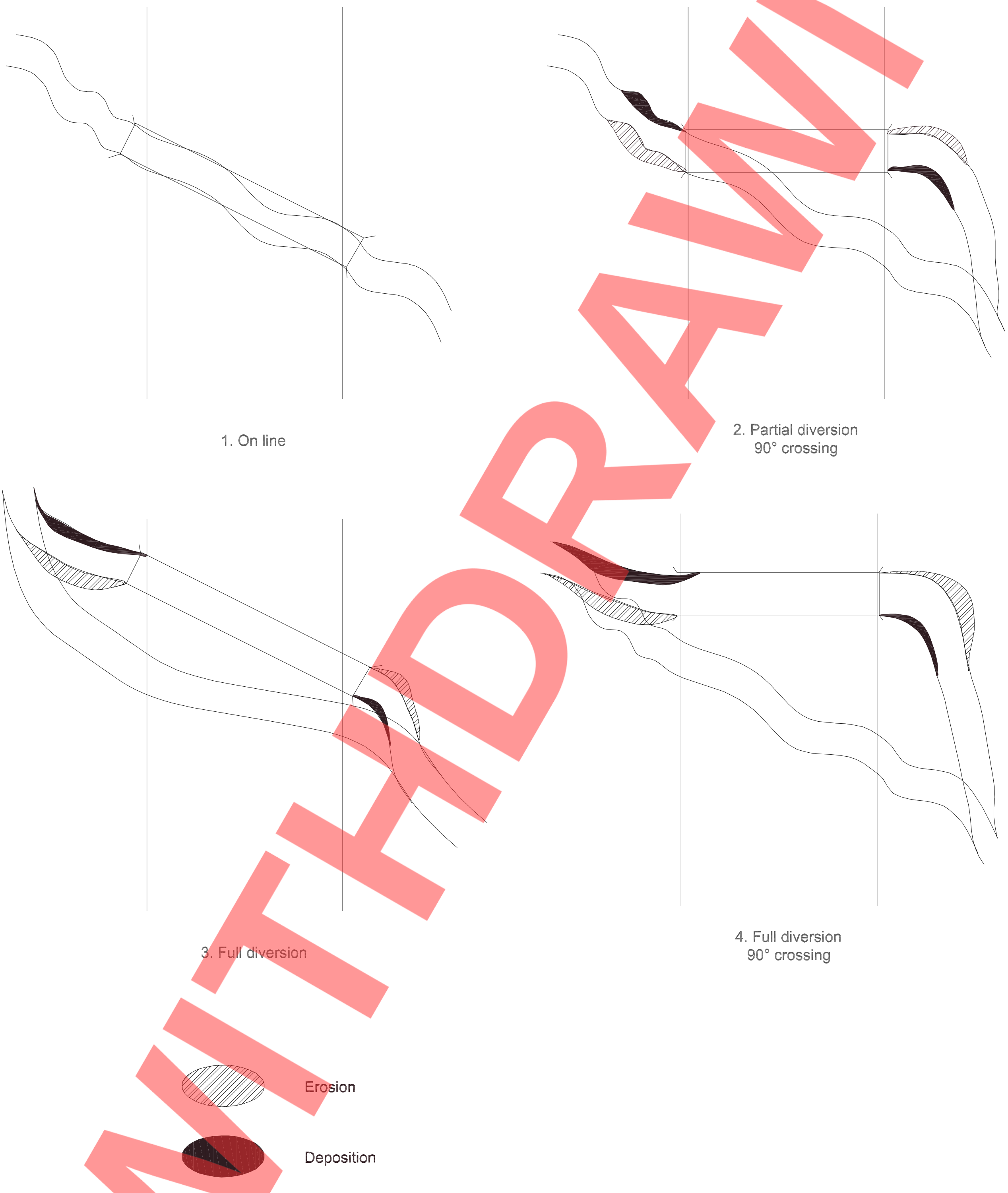


Figure C1: Culvert Alignment Options

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APPENDIX D: LEGAL ASPECTS FOR RIGHT OF ACCESS AND RESPONSIBILITIES FOR MAINTENANCE

Applicable Only to England and Wales

There are two classifications of watercourse in Land Drainage Legislation. These are Main River and Ordinary Watercourse.

Watercourses that are designated as Main River are identified on maps held by DEFRA, Department for Food and Rural Affairs, and the Environment Agency. Ordinary Watercourse is the term applied to all other watercourses. These may be the responsibility of Internal Drainage Boards, local authorities or private individuals, termed Riparian Owners.

Riparian Ownership is applicable to the bank adjoining a property where the watercourse forms the boundary or both banks where the watercourse is situated within a single ownership.

Duties and responsibilities in relation to Main River are defined in the Water Resources Act 1991. Consent, to work in, over or under a Main River must be obtained from the Environment Agency, under Section 109, by completion of the appropriate consent application form.

Works to Ordinary Watercourses are governed under the Land Drainage Act 1991. Under Section 23 of this Act, consent must be obtained from the Environment Agency or the Internal Drainage Board (IDB).

Powers under Highways Act 1980

Section 100 of the Highways Act sets out what a highway authority may undertake for the purposes of drainage works for a highway or for preventing flooding. Section 299 of the same Act relates to the highway authority's right to discharge drainage from a highway.

Under the provisions of Section 110 of the Highways Act, a highway authority may divert any part of non-navigable waterways for the purposes of highway construction and drainage. Sections 108 and 109 of that Act relate to the diversion of navigable waterways.

Where water from highway drainage is discharged to surface waters in accordance with powers provided by Sections 100 and 229 of the Highways Act 1980, construction of the necessary outfall will involve works that interfere with the receiving watercourses. Section 339 of that Act requires that consent for the works to be carried out in the watercourse be sought from the Environment Agency, the relevant land drainage body or the navigation authority. Their consent may not be unreasonably withheld. Such consent may also seek to impose a reasonable limit on the discharge flow from the outfall under specified storm conditions.

Drainage works for which consent is already required under Section 339, a separate application for consent under Section 109 of the Water Resources Act will not be required.

The Construction, Design and Maintenance (CDM) Regulations 1994, requires a duty of care by Clients, Designers and Contractors to ensure that health and safety issues are considered at all stages of a project.

Health and Safety Executive (HSE) regulations govern other aspects of works associated with culverts, such as working in confined spaces and potentially explosive atmospheres.