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Design of Outfalls for Surface Water Channels

Summary: This Advice Note gives guidance on suitable outley layouts for different types of surface water channels and provides methods for designing each type according to the flow rate in the channel.

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PART 1

HA 78/96

DESIGN OF OUTFALLS FOR SURFACE WATER CHANNELS

Contents

Chapter

1. INTRODUCTION

General

1.1 Surface water channels for drainage of runoff from highways can be a suitable alternative to conventional kerbs and gullies or filter drains. Amongst other advantages, such as providing separate systems for drainage of surface and sub-surface water, they allow greater distances between outlets when compared with conventional gully systems.

1.2 HA 37 "Hydraulic Design of Road-edge Surface Water Channels" (DMRB 4.2.1) provides a method of determining the required spacing between outlets for surface water channels. The channel cross-falls should not normally be steeper than 1:5 but in very exceptional cases cross-falls of 1:4 are allowed. The maximum design depth of the channel is restricted to 150mm because of safety considerations.

1.3 Channels with steeper cross-falls or deeper than 150mm can be used behind safety barriers. In these locations cross-falls exceeding 1:4 are allowed.

1.4 Flow rates in surface water channels are generally much higher than in equivalent kerb-and gully systems. Therefore, special designs of channel outfall are needed to obtain a satisfactory level of performance. In this Advice Note, the outfall is defined as the drainage system that collects and removes water from the surface water channels and conveys it to a downstream point of discharge. The transition section in the channel that collects the water and the set of gully gratings or the overflow weir that removes the water from the surface are collectively termed the "outlet". The chamber below the outlet and the arrangements for conveying the water to a collector pipe, a soakaway or a watercourse are collectively termed the "outfall structures".

1.5 The designs of outlets recommended in this Advice Note were developed from laboratory tests. Details of the test data are given in HR Report SR 406, 1995.

Scope

1.6 This Advice Note describes suitable layouts for outlets from triangular and trapezoidal surface water channels and provides methods of designing each type according to the flow rate in the channel. Some general recommendations regarding the design of the outfall structures are also given in the Advice Note (Chapter 6).

1.7 The design methods enable the performance of the outlets to be assessed for channel-full conditions and for surcharging conditions when the flow may extend to the edge of the carriageway. The channel-full conditions are normally specified to correspond to storms with a return period of 1 year whereas the surcharged situation typically refers to storms with a return period of 5 years. It should be noted that surcharging is not allowed for channels built in the central reserve.

1.8 The design methods apply to symmetrical triangular channels with cross-falls of 1:5 and also channels with a trapezoidal cross-section and cross-falls of 1:4.5 or 1:5.

1.9 High capacity channels are required for drainage of wide roads and long lengths with flat gradients. In such situations, trapezoidal cross-sections provide higher capabilities than triangular channels of the same depth and surface width. The trapezoidal channels considered have a base width equal to twice the channel-full depth. In order to promote self-cleansing conditions, the base of the channel has a cross-fall of 1:40 towards the verge (or central reserve). The channel shape can be modified at the outlet to accommodate gratings in the invert by steepening the sides of the channel locally to slopes not exceeding the allowable limit of 1:4 (see Paragraph 1.2).

1.10 Figures B1 and B2 show the cross-sectional shapes of the recommended channels. As shown in these figures, y_1 is the depth of the channel from the lower edge of the carriageway, y_2 is the depth of the channel from the upper edge of the carriageway, and y_3 is the overall depth of the surcharged channel. The allowable width of surcharging should not exceed 1m for hard-strips or 1.5m for hard-shoulders.

1.11 Three alternative geometries of outlet are recommended. One is an in-line outlet, where the water is essentially collected symmetrically either side of the channel invert. Another type is an off-line outlet, where the channel is widened away from the carriageway and the outlet is off-set from the centreline of the channel. A third type of outlet, a weir outlet, is recommended for steep slopes (typically >1:50) where the water is made to curve towards a side-weir.

1.12 As described in HA 37, Sections 2.2 and 2.3, the longitudinal gradient of the channel may be zero at the upstream or downstream end of the channel but all intermediate points must have a positive slope towards the outlet.

1.13 This Advice Note does not cover the structural design of the outlets or of the flow-collecting chambers underneath the outlet gratings. However, diagrams of possible configurations of the chambers are included for illustrative purposes [see Annex C].

Implementation

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

2. FLOW CONDITIONS APPROACHING OUTLET

2.1 The flow rate to use in the design of the outlets should be calculated according to HA 37 which adopts Manning's resistance equation:

$$Q = \frac{A\ R^{2/3}\ S^{1/2}}{n} \qquad (1)$$

where Q is the flow rate (m^3/s), A is the cross-sectional area of the flow (m^2), S is the longitudinal gradient of the channel (m/m) and n is the Manning roughness coefficient. The hydraulic radius R is defined by:

$$R = \frac{A}{P} \qquad (2)$$

where P is the wetted perimeter, ie the perimeter of the channel in contact with the water flow. Values of Manning's n are given in Table 2 of HA 37.

2.2 If the longitudinal gradient of the channel is not uniform along its length, an equivalent value of the slope, S_e, should be used in the calculation of the flow rate. S_e should be evaluated as described in Section 8 of the HA 37.

2.3 When checking for surcharged conditions, the flow rate, Q_s, to use in the design of outlets can be estimated from Figure B3 for triangular channels and Figure B4 for trapezoidal channels. In these Figures B_d and Q_d are respectively the surface width of the flow and the discharge corresponding to the design capacity of the channel. Q_d is equal to the value of Q given by Equation (1) when A and R correspond to the design depth of flow, y_1, in the channel (measured from the invert centreline to the lower edge of the carriageway). The curves in Figures B3 and B4 are based on 1m width of surcharging of the carriageway at cross-falls of 1:30, 1:40 and 1:60. The value of Q_s/Q_d can be read off the curves and, with Q_d calculated using Equation (1), the value of Q_s can then be determined.

3. TYPES OF OUTLET

3.1 Channel outlets can be defined as intermediate or terminal according to their position along a channel. Terminal outlets are located at low points along a length of channel and should be designed to collect practically all the flow carried by the channel. Intermediate outlets are located at points part-way along a length of channel where the flow rate of water from the road reaches the carrying capacity of the channel.

3.2 The design methods in this Advice Note are based on a minimum value of the waterway area (defined as the total area of openings) in relation to the plan area of the grating. If G is the width of the grating, the minimum waterway area needed to produce the required hydraulic performance is $0.44G^2$. The efficiencies of outlets comprising gratings with bigger waterway areas and similar bar patterns will not be less than given by these methods. The laboratory tests, which are the basis of the present recommendations, were carried out with gratings having diagonal slots. Gratings with bar patterns consisting of longitudinal and transverse bars were also tested and their application is discussed in Chapter 4.

3.3 As mentioned in Paragraph 1.11, alternative designs of in-line and off-line outlets are recommended for each of the two types of channel. For triangular channels the in-line outlet recommended is generally more efficient than the off-line outlet but reasons for choosing between them will mainly depend on constructional aspects. Other aspects being equal, in-line outlets are preferable to off-line outlets since they require a smaller land take. However, in-line and off-line outlets are not suitable for steep channels where the high kinetic energy of the flow renders gratings less effective. In such situations the flow should be collected by curving it towards an off-line weir (see Chapter 5).

Triangular channels

3.4 The in-line outlet geometry recommended for this type of channel consists of pairs of gratings positioned on the side slopes of the channel (see Figure B5).

3.5 The number of pairs of gratings required will depend on the amount of flow in the channel (see Chapter 4). More than three pairs of gratings are likely to be uneconomical, and other measures should be taken to cope with higher flows (see Chapter 5).

3.6 The spacing between pairs of gratings should not be less than 1.7 G, where G is the width of the grating (see Figure B4). The size of the required gratings should be chosen so that the ratio of the width G over the depth of the channel y_1, is within the following limits:

$$4.5 \le G/y_1 \le 5.1 \qquad (3)$$

3.7 The lower limit corresponds to the minimum width of grating necessary to achieve the performance specified in Chapter 4. The upper limit corresponds to the widest grating that can be installed in the channel. The required length H of each grating is given by:

$$H \ge G \qquad (4)$$

3.8 The lower edge of each grating should be set as close as possible to the invert of the channel in order to maximise flow interception, ie distance in Figure B5 should be minimised. A design of in-line outlet with gratings set flat in the channel invert is not included because the limit on maximum cross-falls of 1:4 would allow the use of only small gratings with insufficient flow capacity.

3.9 The recommended geometry for off-line outlets is shown in Figure B6. The number of gratings may vary from one to three depending on the amount of flow approaching the outlet (see Chapter 4). However, outlets formed by a single grating may have the disadvantage of being easily blocked by debris, particularly when the outlets are widely spaced. Consequently, a second grating would reduce the likelihood of local flooding of the road in those situations when the first grating is blocked. On the other hand, outlets including more than three gratings may not prove economical due to the space they require and the size of the flow collecting structure under the outlet. For these cases a weir outlet is recommended - see Chapter 5.

3.10 In this geometry the side slope on the road side is extended below the invert level of the channel to produce a ponding effect over the gratings which increases the efficiency of the outlet. A gradual transition between the channel and the outlet is essential to direct the flow smoothly towards the gratings.

3.11 Local cross-falls should not be steeper than 1:4 and the spacing between gratings should not be less than 1.25G where G is the width of the gratings. The size of the gratings is determined by:

$$G/y_1 \geq 4.5 \qquad (5)$$

Trapezoidal channels

3.12 The in-line outlet geometries recommended for trapezoidal channels are shown in Figures B7 and B9. The width of the gratings is determined by:

$$G/y_1 = 3.0 \qquad (6)$$

3.13 The length of H is given by Equation (4). The comments in Paragraph 3.9 regarding the number of gratings, the importance of a gradual transition and the local side slopes apply also to this case.

3.14 The off-line geometries recommended are shown in Figure B8 and B10. The width of the gratings is determined by:

$$G/y_1 \geq 4.0 \qquad (7)$$

3.15 The length H is given by Equation (4). As for the in-line outlet, the comments in Paragraph 3.9 are also applicable to this case.

Terminal outlets

3.16 The requirement that surface water channels should not have any sides steeper than 1:4 applies also to the geometry of terminal outlets. When not protected by a safety barrier, surface water channels must therefore terminate with a smooth transition, without abrupt changes in level or width. Examples of recommended terminal outlets are shown in dashed lines in Figures B5 to B10. The terminal ramps should be built at a certain minimum distance from the grating furthest downstream. This reduces the probability of blockage of the gratings by debris since some of the debris will tend to accumulate in the area between the gratings and the terminal ramp. For in-line and off-line outlets in triangular channels, this distance should equal the grating width. For in-line and off-line outlets in trapezoidal channels, the recommended distances are given in terms of the grating width, G, and are shown in Figures B7 to B10.

4. HYDRAULIC DESIGN OF OUTLETS

General procedure

4.1 The design procedure involves choosing the type of outlet (in-line, off-line or weir outlet) and the number of gratings needed to achieve the required performance. The geometry of each type of outlet is predetermined as described in Paragraphs 3.4 to 3.16 and illustrated in Figures B5 to B10. The size of the gratings is related to the size of the channel in accordance with Equations (3) to (7).

4.2 The performance of an outlet should be determined for channel-full conditions (corresponding to the design flow depth y_1) but checks of the performance for surcharged flow conditions may also be carried out.

4.3 For intermediate outlets, design curves are presented which give the number of gratings needed to achieve the required performance of the outlet (Figures B11 to B22). For terminal outlets the number of gratings is obtained from Tables A1 and A2. The flow conditions are represented by a non-dimensional number so that the design procedure is valid for all sizes of channel having the same cross-sectional shape (triangular or trapezoidal).

4.4 The in-line and off-line designs are suitable only for channels with small to moderate longitudinal slopes. In steep channels (typically >1:50) the design procedure to adopt is described in Chapter 5.

Intermediate outlets

4.5 The hydraulic design of intermediate outlets is based on a number of curves (Figures B11 to B22) developed for channel-full and surcharged conditions. These curves show the variation of the efficiency of each outlet with the flow conditions.

4.6 In the curves, the flow conditions are represented by a non-dimensional number: F_d for channel-full and F_s for surcharged channel.

4.7 For triangular channels:

$$F_d = \frac{28.6 Q_d}{B_d^{2.5}} \qquad (8)$$

and

$$F_s = \frac{24.6 Q_s}{B_s^{2.5}} \qquad (9)$$

where

Q_d is the approach flow (in m^3/s) corresponding to channel-full conditions (ie flow depth y_1)

Q_s is the approach flow (in m^3/s) corresponding to surcharged conditions (ie flow depth y_s)

B_d is the surface width of the flow (in m) for channel-full conditions

B_s is the surface width of the flow (in m) in a surcharged channel neglecting the width of surcharge on the hard strip or hard shoulder - see Figures B1 and B2.

For the estimation of Q_d and Q_s refer to Chapter 2.

4.8 For trapezoidal channels with cross-falls of 1:4.5:

$$F_d = \frac{25.6\ Q_d}{B_d^{2.5}} \qquad (10)$$

and

$$F_s = \frac{22.2\ Q_s}{B_s^{2.5}} \qquad (11)$$

4.9 For trapezoidal channels with cross-falls of 1:5:

$$F_d = \frac{29.8\ Q_d}{B_d^{2.5}} \qquad (12)$$

and

$$F_s = \frac{25.5\ Q_s}{B_s^{2.5}} \qquad (13)$$

4.10 In Equations (5), (8), (10) and (12) the numerical constants are chosen so that critical flow under channel-full conditions corresponds to a value of $F_d = 1$. Equations (9), (11) and (13) are similarly defined so that $F_s = 1$ approximately represents critical flow for the two-stage channels formed under surcharged conditions.

4.11 Values of efficiency are plotted on the vertical axis of the design curves. The efficiency of an outlet is defined as the ratio of the flow intercepted by the outlet, Q_i, to the total flow approaching it:

$$\eta_d = Q_i/Q_d \qquad \textbf{(14)}$$

$$\eta_s = Q_i/Q_s \qquad \textbf{(15)}$$

where η_d and η_s refer to channel-full and surcharged conditions, respectively.

4.12 Although efficiencies of 100% may be desirable, the resulting outlets may be large and costly; more economic designs can often be achieved by allowing a certain amount of flow to by-pass intermediate outlets. However, it is recommended that intermediate outlets operating under channel-full conditions should not be designed for efficiencies less than 80%.

4.13 The design charts for triangular channels (Figures B11 to B14) include curves for one, two and three gratings or pairs of gratings. The design charts for trapezoidal channels (Figures B15 to B22) include curves for only two and three gratings because use of more than one grating is recommended for high capacity channels. The curves shown dashed were obtained by extrapolating the results of the laboratory tests using a conservative approach.

4.14 The designer should use the value of Q_d calculated as described in Section 3 to determine F_d defined by Equations (8), (10) and (12). Having decided which type of outlet to adopt (in-line or off-line outlet), the number of gratings necessary to achieve the required efficiency is then read off the curves. Alternatively, the designer can check whether a particular outlet geometry or number of gratings is adequate for the approach flow.

4.15 It is recommended that outlets should normally be designed for channel-full conditions (ie, the 1-year return period event) but the designer may wish to check the performance for surcharged flow conditions. Figures B12, B14, B16, B18, B20 and B22, which correspond to a width of surcharging of 1m, should then be used.

4.16 For triangular channels, the minimum width of grating, G, required for an outlet is determined by Equations (3) or (5); the length, H, should not be less than G (see Equation (4)). The designer should choose a size of commercially available grating that is not smaller than the calculated values of G and H and that provides a waterway area of opening between bars that is not less than required in Paragraph 2.3. For trapezoidal channels, the grating dimensions are given by Equations (4), (6) and (7).

Terminal outlets

4.17 The efficiency of a terminal outlet is generally higher than that of a similar intermediate outlet because of the effect of the end ramp. Also, a terminal outlet needs to be designed for an efficiency close to 100%, because any water by-passing the outlet may flow on to the verge or back on to the road.

4.18 For the design of terminal outlets, the first step is to calculate values of F_d and F_s as described in Paragraph 4.6. The value of F_d should then be compared with the limiting values given in Table A1 (for triangular channels) or Tables A2 and A3 (for the trapezoidal channels). The type of outlet selected should have a limiting value of F_d that is not less than the calculated value. As for the case of intermediate outlets, a check may be carried out for surcharged conditions using the calculated values of F_s.

4.19 The values presented in Tables A1, A2 and A3 for terminal outlets correspond to efficiencies of 97.5%. The small amount of by-passing that is permitted is considered acceptable for rare storm events.

Grating design

4.20 As mentioned in Paragraph 3.2, the design curves were based on tests carried out with gratings having a diagonal bar pattern. Comparing the performance of gratings equivalent in terms of overall size and waterway area, longitudinal bars are more efficient than diagonal bars, which in turn are more efficient than transverse bars.

4.21 Longitudinal bar patterns can potentially cause safety problems for two main reasons: 1) bicycle tyres may get trapped in the slots between the bars; and 2) longitudinal bars provide a lower skidding resistance than diagonal bars. These safety considerations do not apply in cases where surface water channels are built behind safety fences. The value of efficiency for the longitudinal bars will be higher than given by the relevant design curve for diagonal bars. If η_D is the efficiency corresponding to a diagonal bar pattern, the efficiency η_L corresponding to a longitudinal bar is approximately given by :

$$\eta_L = 0.5 + 0.5\, \eta_D \qquad (16)$$

4.22 The use of gratings with bars transverse to the direction of the flow has been found to reduce the outlet efficiency considerably and is therefore not covered by this document.

5. WEIR OUTLET

5.1 The flow-collecting efficiency of an outlet decreases as the steepness of the surface water channel and the velocity of the flow within it are increased. When the types of grated outlet illustrated in Figures B5 to B10 are not able to provide the necessary level of performance (minimum efficiencies of 80% for intermediate outlets and 97.5% for terminal outlets), an alternative layout termed a weir outlet should be used. In this type of outlet, the water is gradually directed away from the carriageway and discharged over a side weir into a collecting channel in the verge. In order to prevent wheels of vehicles dropping into the channel, a safety fence will normally need to be installed along the carriageway-side of the collecting channel. The recommended layout of the weir outlet is shown in Figures B23 and B24.

5.2 In order to allow the high-velocity flow in the surface water channel to be turned towards the side weir without spilling out on to the carriageway, it is necessary for the channel to be flowing only partly full immediately upstream of the outlet. It is recommended that this condition should be achieved by locally widening the surface water channel in a transition section upstream of the outlet (see Figure B24); with this design the overall depth and cross-falls of the channel are kept constant and the width increased sufficiently to reduce the design flow depth approaching the outlet to two-thirds of the overall channel depth.

5.3 The total length, L_w, of the weir outlet is made up of a straight length, L_s, parallel to the edge of the carriageway and a length, L_a, at an angle θ to the carriageway (see Figure B24). L_s is equal to B_t, the surcharged width of the channel at the downstream end of the transition, so that:

$$\frac{L_w}{B_t} = 1 + \frac{1}{\tan\,\theta} \qquad (17)$$

5.4 The values of the ratio L_w/B_t and θ are obtained from Figure B25 and are dependent on the non-dimensional number, F_d, in Equation (8) which is calculated for design flow conditions in the upstream surface water channel. As shown in Figure B24, the straight and angled portions of the weir outlet should be joined by a curved side transition with its upstream end at the mid-point of the length L_s.

Triangular channels

5.5 The procedure for designing weir outlets for triangular surface water channels is explained in the flow chart of Figure B26. In the transition section upstream of the outlet (see Figure B24), the cross-falls and overall depth remain constant but the triangular shape is transformed to a trapezoidal cross-section in order to reduce the flow depth approaching the weir outlet. The length, L_t, of the transition and the base width, B_b, at the downstream end are as follows:

1:5 cross-falls:- $L_t = 25\ y_1$ **(18)**

$B_b = 5\ y_1$ **(19)**

where y_1 is the design flow depth in the surface water channel upstream of the transition (see Figure B1).

Trapezoidal channels with cross-falls of 1:4.5

5.6 The procedure for designing weir outlets for trapezoidal surface water channels with side slopes of 1:4.5 is explained in the flow chart of Figure B27. In the transition section upstream of the outlet, the cross-falls and overall depth remain constant but the base width is increased (from a value of $2y_1$ at the upstream end) in order to reduce the flow depth approaching the weir outlet. The length, L_t, of the transition and the base width, B_b, at the downstream end are as follows:

1:4.5 cross-falls:- $L_t = 25\ y_1$ **(20)**

$B_b = 7\ y_1$ **(21)**

where y_1 is the design flow depth in the surface water channel upstream of the transition (see Figure B2).

Trapezoidal channels with cross-falls of 1:5

5.7 The procedure for designing weir outlets for trapezoidal surface water channels with side-slopes of 1:5 is explained in the flow chart of Figure B28. In the transition section upstream of the outlet, the cross-falls and overall depth remain constant but the base width is increased (from a value of $2y_1$ at the upstream end) in order to reduce the flow depth approaching the weir outlet. The length, L_t, of the transition and the base width, B_b, at the downstream end are as follows:

1:5 cross-falls:- $L_t = 30\ y_1$ **(22)**

$B_b = 8\ y_1$ **(23)**

where y_1 is the design flow depth in the surface water channel upstream of the transition (see Figure B2).

6. GENERAL RECOMMENDATIONS ON DESIGN OF OUTFALL STRUCTURES

6.1 An outfall conveys water from one or more outlets in a surface water channel to a suitable discharge point. The design of an outfall may vary considerably depending on the general topography and nature of the ground, the layout of the road scheme and whether the water is discharged to a watercourse, a soakaway or a below-ground piped system.

6.2 A chamber or gully pot should be located below or immediately adjacent to each outlet to collect sediment carried with the flow from the surface water channel. Standard circular gully pots have a limited hydraulic capacity and it is recommended that they should not be used for flow rates exceeding 5 l/s unless their suitability has been determined by test.

6.3 The plan shape of the chamber will be determined by the layout of the gratings forming the outlet. The invert of the outgoing pipe from the chamber should be set a minimum of 300mm above the bottom of the chamber to retain an adequate volume of sediment.

6.4 The invert level of the outgoing pipe should be chosen so that the water level in the chamber does not rise high enough to prevent flow discharging freely from the surface water channel into the outlet. For design, it is recommended that the water level in the chamber should be at least 150mm below the underside of the gratings when the outlet is receiving flow from the channel under surcharged conditions. The height Z (in m), of the water surface in the chamber above the invert of the outgoing pipe can be estimated from the equation:

$$Z = \frac{D}{2} + 0.23\,\frac{Q^2}{D^4} \qquad (24)$$

where D is the diameter of the pipe (in m) and Q is the flow rate (in m^3/s) in the chamber corresponding to surcharged conditions in the surface water channel. The gradient and diameter of the outgoing pipe should be determined from standard flow tables or resistance equation so that the pipe is just flowing full under surcharged conditions.

6.5 Provided the chamber below the outlet is designed to trap sediment, the outgoing pipe from the chamber may be connected directly to a collector pipe by means of a 45° Y junction without the need for a manhole at the junction position.

6.6 If a weir outlet is used (see Chapter 5), the collecting channel into which flow drops from the weir should be deep enough to allow the outlet to discharge freely when the surface water channel is flowing under surcharged conditions. The design flow depth, J (in m), can be estimated from the equation:

$$J = 4.82\,(E^4 Q^4 / A^5) \qquad (25)$$

where E is the top width of flow (in m) and Q is the design rate of flow (in m^3/s). The overall depth of the channel is obtained by adding 0.15m to the value of J. The top width of the channel should not be less than 0.5m.

6.7 It is recommended that the collecting channel below a weir outlet should discharge into a chamber with a removable cover in order to still the flow and allow sediment to be collected. The sizes of the chamber and the outgoing pipe should be determined in accordance with the general recommendations in Paragraphs 6.3 to 6.6.

7. SPACING OF OUTLETS WITH BY-PASSING

7.1 When by-pass flow is allowed in the design of an intermediate outlet, ie when efficiencies lower than 100% are adopted, the design of the channel downstream of the outlet is no longer directly covered by HA 37. In this case the spacing of the outlets needs to be reduced in order to allow for the additional flow by-passing the upstream outlet. As an interim measure, it is recommended that the distance L between outlets, as determined in HA 37, should be reduced to ηL, where η is the adopted design efficiency of the upstream outlet.

8. OVERALL DESIGN OF SURFACE WATER CHANNEL SYSTEMS

8.1 In order to obtain the most cost-effective solution for a drainage system using surface water channels, the designer should consider the total cost of the channels and outlets together. In some cases, a design based on the longest possible spacings between outlets may not be the optimum solution. Shorter spacings will require more outlets but these may be smaller and cheaper; also, the shorter distance between outlets will allow use of smaller sizes of surface water channel. The effect on the total cost of allowing different amounts of by-passing at intermediate outlets should also be considered. For each option the relationship between channel size and required outlet spacing should be determined from HA 37, and the effect of allowing by-passing at intermediate outlets should be estimated according to Chapter 7.

9. WORKED EXAMPLES

9.1 Example 1

Design an intermediate in-line outlet in a triangular surface water channel having the following characteristics:

cross-falls	1:5
design flow depth	0.120m
longitudinal channel gradient	1:200 =0.005
Manning's roughness coefficient (average condition)	0.013

Adopt an efficiency of 100% for the outlets and a carriageway cross-fall of 1:40.

The flow in the channel is calculated from Equation (1) but first it is necessary to calculate the hydraulic radius R using Equation (2):

$$R = \frac{A}{P} = \frac{(1.2 \times 0.12)/2}{2(0.120^2+0.6^2)^{0.5}} = \frac{0.072}{1.224} = 0.0588\text{m}$$

The channel-full flow Q_d is then given by:

$$Q_d = \frac{0.072 \times 0.0588^{2/3} \times 0.005^{½}}{0.013} = 0.0592\text{m}^3/\text{s}$$

The flow Q_s for surcharging of 1m width of the hard-strip or hard-shoulder is determined from Figure B3. For B_d = 1.2m, Q_s/Q_d = 1.7 and therefore:

$$Q_s = 1.7 \times 0.0592 = 0.1006\text{m}^3/\text{s}$$

Then calculate F_d using Equation (8):

$$F_d = \frac{28.6 \times 0.0592}{1.2^{2.5}} = 1.07$$

Calculate also F_s using Equation (9). It is first necessary to calculate B_s. For a carriageway cross-fall of 1:40, 1m of surcharging corresponds to 0.025m of water depth above the channel-full depth, ie a total depth of 0.145m.

Therefore

$$B_s = 5\ (0.120 + 0.145) = 1.325\text{m}$$

$$F_s = \frac{24.6 \times 0.1006}{1.325^{2.5}} = 1.22$$

Figures B11 and B12 are appropriate for the design of in-line intermediate outlets in triangular channels.

The designer should begin by considering channel-full conditions, which are described by Figure B11. Adopting an efficiency of 100%, Figure B11 shows the need for two pairs of gratings installed on the sloping sides of the channel. Figure B12 shows that two pairs of gratings are also satisfactory for surcharged conditions.

The size of the gratings (G is width and H is length) is calculated as described in Paragraphs 3.6 and 3.7:

$$4.5 \leq G/0.120 \leq 5.1$$

$$\text{and } H \geq G$$

Taking the smallest dimensions allowed gives

$$G = 0.120 \times 4.5 = 0.540\text{m}$$

$$H = G = 0.540\text{m}$$

The designer should therefore choose from commercially available gratings, gratings with width and length not smaller than 540mm. The total waterway area of the slots should not be less than $0.44G^2$ or 0.128m^2 (Paragraph 3.2).

As shown in Figure B5, the longitudinal distance between the two pairs of gratings should be at least equal to 1.7 x 0.540 = 0.918m if a grating of width 0.540m is chosen.

9.2 Example 2

Design a terminal off-line outlet in a triangular surface water channel with the same characteristics as in Example 1.

The flow in the channel for channel-full conditions Q_d was calculated to be $0.0592\text{m}^3/\text{s}$ and for surcharged conditions Q_s was found to be 0.1006m³/s. The values of F_d and F_s were, respectively, 1.07 and 1.22.

Table A1 should be consulted for the design of terminal outlets in triangular channels. Checking first for channel-full conditions it can be seen that for an off-line outlet, one single grating would be able to intercept the flow satisfactorily (F_d = 1.2 in Table A1 is bigger than the calculated F_d = 1.07). However, when checking for surcharged conditions, Table A1 indicates the need for a minimum of two gratings (F_s = 1.0 in the table is smaller than the calculated F_s = 1.22). The designer is, in this case, recommended to adopt two gratings not only to account for floods of higher return period but also for the possibility of partial blockage of the gratings by debris.

The size of the gratings is the same as in the previous example. The longitudinal distance between the two gratings should be at least equal to 1.25 x 0.540 = 0.675m. The total length of the outlet including one upstream transition of 2.02m should be equal to or greater than 4.9m (see Figure B6 for details of the geometry).

9.3 Example 3

Design an intermediate off-line outlet in a trapezoidal surface water channel having the following characteristics:

cross-falls	1:5
design flow depth	0.150m
base width	0.300m
longitudinal channel gradient	1/500 =0.0020
Manning's roughness coefficient (average condition)	0.013

Adopt an efficiency for the outlets of 85% and a carriageway cross-fall of 1:40.

The flow in the channel is calculated from Equation (1) but first it is necessary to calculate the hydraulic radius R using Equation (2):

$$R = \frac{A}{P} = \frac{\frac{1}{2}(0.30 + 1.80) \times 0.15}{0.3 + 0.2\,(0.15^2 + 0.75^2)^{1/2}}$$

$$= \frac{0.1575}{1.830} = 0.0861 \text{ m}$$

The channel-full flow is then given by:

$$Q_d = \frac{0.1575 \times 0.0861^{2/3} \times 0.002^{1/2}}{0.013} = 0.106 \text{ m}^3/\text{s}$$

The flow Q_s for surcharging of 1m width of the hard-strip or hard-shoulder is determined from Figure B4. For B_d = 1.8m, Q_s/Q_d = 1.5 and therefore:

$$Q_s = 1.5 \times 0.106 = 0.159 \text{ m}^3/\text{s}$$

Then calculate F_d using Equation (12):

$$F_d = \frac{29.8 \times 0.106}{1.8^{2.5}} = 0.73$$

Assuming 0.025m of surcharging above the channel-full depth of 0.150m, the surcharged width of the channel is:

$$B_s = 0.30 + 5\,(0.150 + 0.175) = 1.925\text{m}$$

The corresponding value of F_s is found from Equation (13):

$$F_s = \frac{25.5 \times 0.159}{1.925^{2.5}} = 0.79$$

Figures B21 and B22 are appropriate for the design of off-line outlets in trapezoidal channels with cross-falls of 1:5. For channel-full conditions, Figure B21 shows that for F_d = 0.73 a minimum of two gratings is required to achieve a collection efficiency of 85%. Checking for surcharged conditions using Figure B22, it can be seen that for F_s = 0.79 two gratings are also satisfactory and just satisfy the efficiency criterion of 85%.

The dimensions of the gratings are calculated as described in Paragraph 3.14:

$$G \geq 4.0 \times 0.150 = 0.600 \text{ m}$$

$$H \geq 0.600 \text{ m}$$

The total waterway area of the slots should not be less than $0.44G^2$ or 0.158m² (Paragraph 3.2). The layout of the outlet is similar to the one shown in Figure B10 but with only two gratings. The minimum overall length of the outlet is 6.0G or 3.60m including two 0.96m long transitions.

9.4 Example 4

Design a suitable terminal outlet for a triangular surface water channel having the following characteristics :

cross-falls	1:5
design flow depth	0.120m
longitudinal channel gradient	1:25
	= 0.04
Manning's roughness coefficient (average condition)	0.013

The flow in the channel is calculated using equation (1) as in Example 1 :

$A = 0.072m^2$
$R = 0.0588m$

$$Q_d = \frac{0.072 \times 0.0588^{2/3} \times 0.04^{1/2}}{0.013} = 0.168m^3/s$$

The value of F_d is calculated using equation (8) :

$$F_d = \frac{28.6 \times 0.168}{1.2^{2.5}} = 3.05$$

From Table A1 (and the flow chart in Figure B26) it can be seen that, because $F_d > 2.30$, neither an in-line or an off-line outlet is adequate and therefore a weir outlet is required. Following the procedure in Figure B26, the first step is the design of the transition section upstream of the weir outlet. Using Equation (18), the required length of the transition is:

$L_t = 25 \times 0.120 = 3.000m$

Over this distance, the triangular profile of the surface water channel is transformed to a trapezoidal shape with the same depth and cross-falls but with a base width given by Equation (19) of:

$B_b = 5 \times 0.120 = 0.600m$

Assuming 0.025m of surcharging above the channel-full depth of 0.120m, the surcharged width at the downstream end of the transition is:

$B_t = 5 \times 0.120 + 0.600 + 5 \times 0.145$
$= 1.925m$

The dimensions of the weir outlet are determined from Figure B25. For a value of $F_d = 3.05$, this gives:

$L_w = 4.15 \times 1.925 = 8.0m$

$\theta = 17.6°$

The straight and angled portions of the weir have the following lengths:

$L_s = B_t \approx 2.0m$

$L_a = L_w - L_s = 8.0 - 2.0 = 6.0m$

10. GLOSSARY OF SYMBOLS

A	Cross-sectional area of the flow
B_b	Base width of trapezoidal channel
B_d	Surface width of flow for channel-full conditions
B_s	Surface width of flow in surcharged channel neglecting the width of surcharge on hard-strip or hard-shoulder
B_t	Value of B_s at downstream end of transition for weir outlet
D	Pipe diameter
E	Top width of flow in collecting channel
e	Distance between lower edges of pairs of in-line gratings in triangular channels
F_o	Non-dimensional number for channel-full
F_s	Non-dimensional number for flow in surcharged channel
G	Width of gratings
H	Length of gratings
J	Design flow depth in collecting channel
L	Distance between outlets
L_a	Length of angled part of weir outlet
L_w	Total length of weir outlet
L_s	Length of straight part of weir outlet parallel to carriageway
L_t	Length of transition for weir outlet
n	Manning roughness coefficient
P	Wetted perimeter of channel
Q	Flow rate
Q_d	Approach flow for channel-full conditions
Q_i	Flow intercepted by outlet
Q_s	Approach flow for surcharged conditions
R	Hydraulic radius of channel
S	Longitudinal gradient

S_e Value of equivalent longitudinal slope

y_1 Depth of the channel from the invert centreline to the lower edge of the carriageway (equal to design flow depth)

y_2 Depth of the channel from the invert centreline to the upper edge of the carriageway

y_3 Overall depth of channel from the invert centreline to the allowable level of surcharge

Z Head of water above pipe invert

η Efficiency

η_d Efficiency of outlet for channel-full conditions

η_D Efficiency of outlet for gratings with diagonal bar pattern

η_L Efficiency of outlet for gratings with longitudinal bar pattern

η_s Efficiency of outlet for surcharged conditions

θ Angle of weir outlet

11. REFERENCES

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1. HA 37. "Hydraulic Design of Road-Edge Surface Water Channels". (DMRB 4.2.1)

2. Amendment No. 1 to HA 37. (DMRB 4.2.1)

Manual of Contract Documents for Highway Works (MCHW)

3. Highway Construction Details. (MCHW3)

4. "Surface Water Channels and Outfalls: Recommendations on Design", HR Wallingford (1996), Report SR 406

12. ENQUIRIES

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

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TABLES

Table A1 Triangular channels: Limiting values of F_d and F_s for terminal outlets

Type of Outlet	No of Gratings (or Pairs of Gratings) 1	2	3
In-Line Outlet:			
Channel full (F_d)	0.95	2.0	2.3
Surcharged (F_s)	0.80	1.8	2.1
Off-Line Outlet:			
Channel full (F_d)	1.2	1.4	2.0
Surcharged (F_s)	1.0	1.3	1.7

Table A2 Trapezoidal channel with cross-falls of 1:4.5: Limiting values of F_d and F_s for terminal outlets

Type of Outlet	No of Gratings 2	3
In-Line Outlet:		
Channel full (F_d)	0.55	0.85
Surcharged (F_s)	0.40	0.70
Off-Line Outlet:		
Channel full (F_d)	1.0	1.3
Surcharged (F_s)	0.9	1.2

Table A3 Trapezoidal channel with cross-falls of 1:5: Limiting values of F_d and F_s for terminal outlets

Type of Outlet	No of Gratings 2	3
In-Line Outlet:		
Channel full (F_d)	0.45	0.65
Surcharged (F_s)	0.30	0.50
Off-Line Outlet:		
Channel full (F_d)	0.75	1.1
Surcharged (F_s)	0.65	1.0

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FIGURES

Figure B1 Cross-sectional shape of triangular channel

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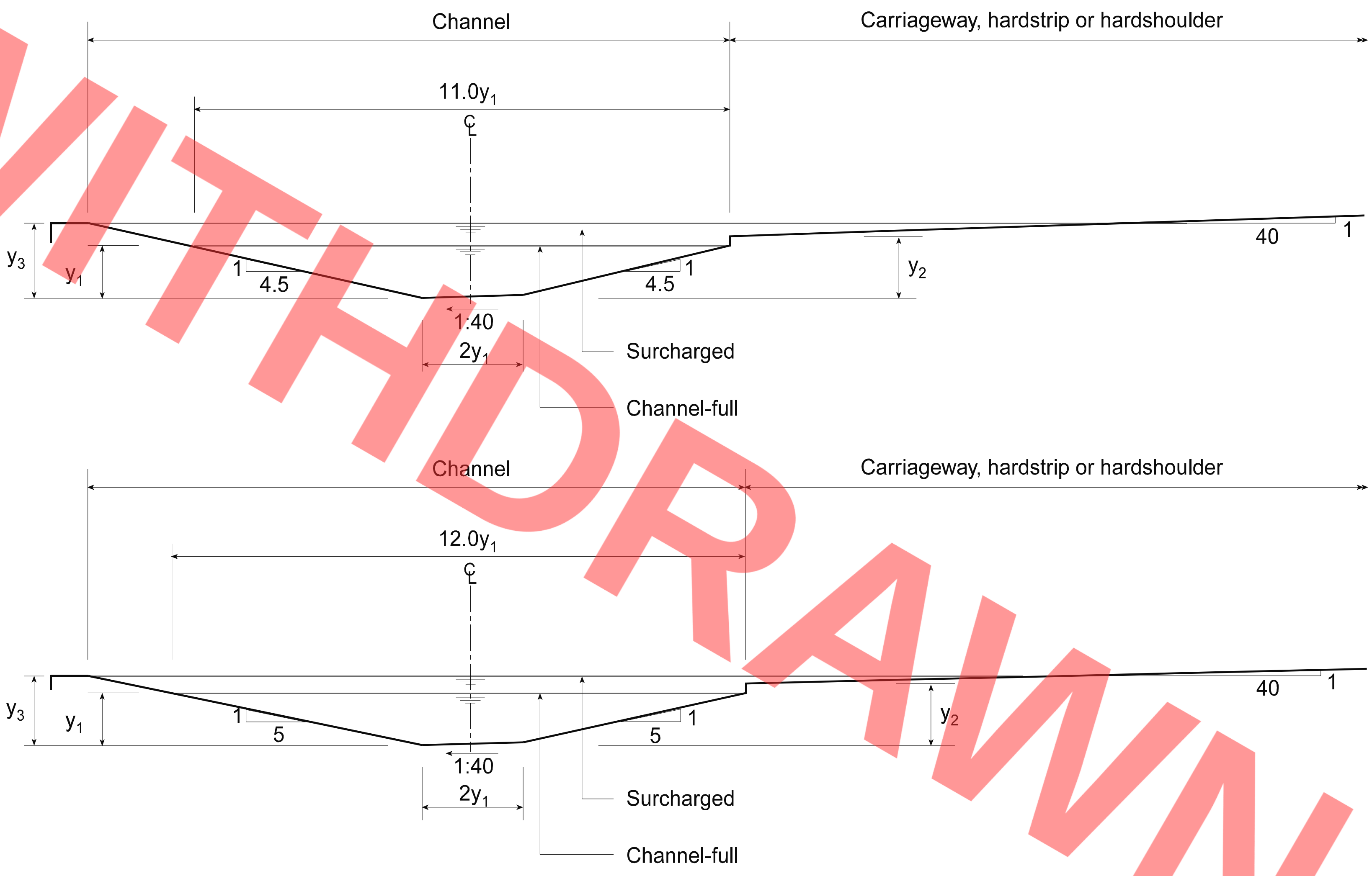
Figure B2 Cross-sectional shape of trapezoidal channels



[N.B. $y_3 = y_2$ in central reserve]

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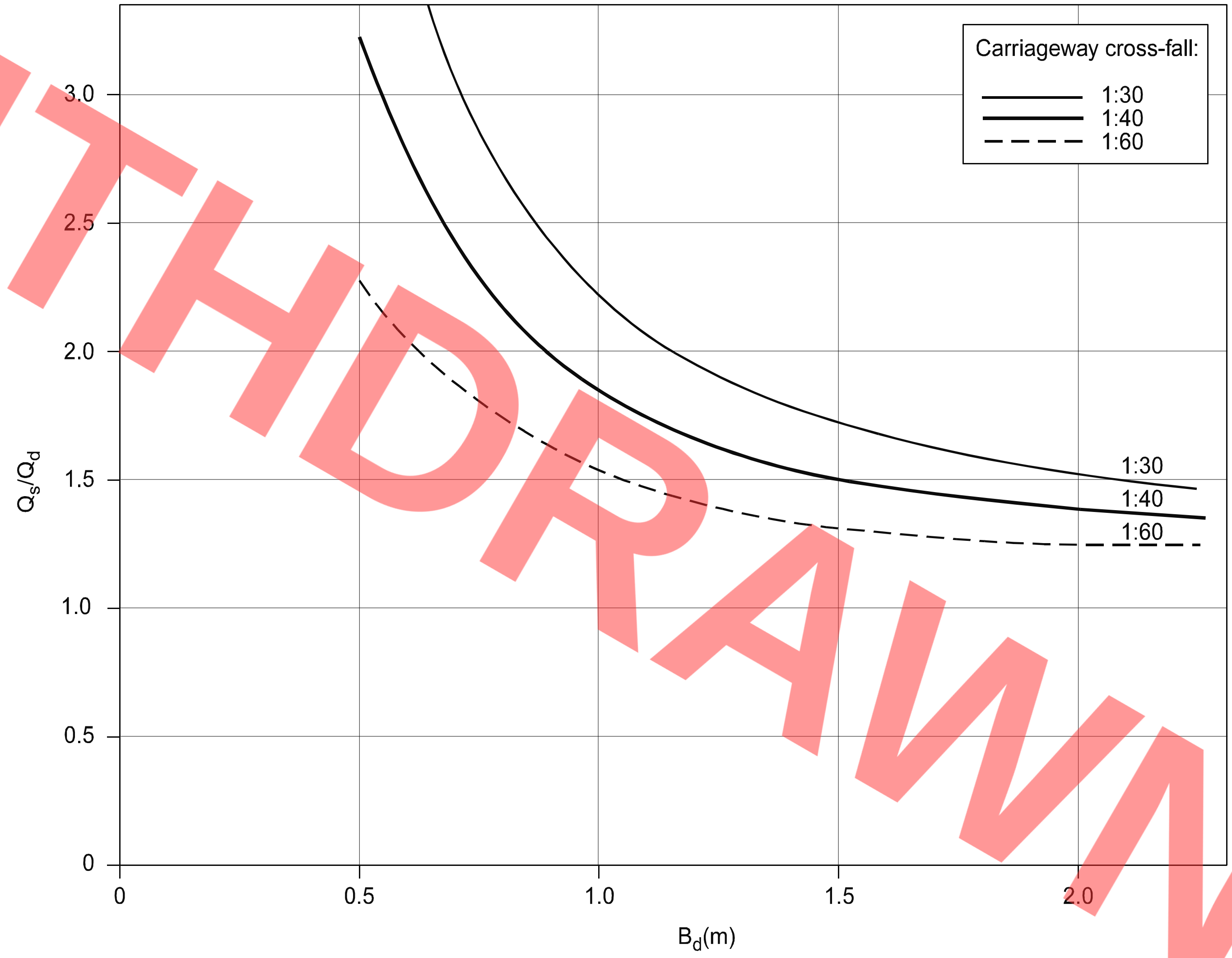
Figure B3 Relationship between surcharge and channel-full flows: Triangular Channels



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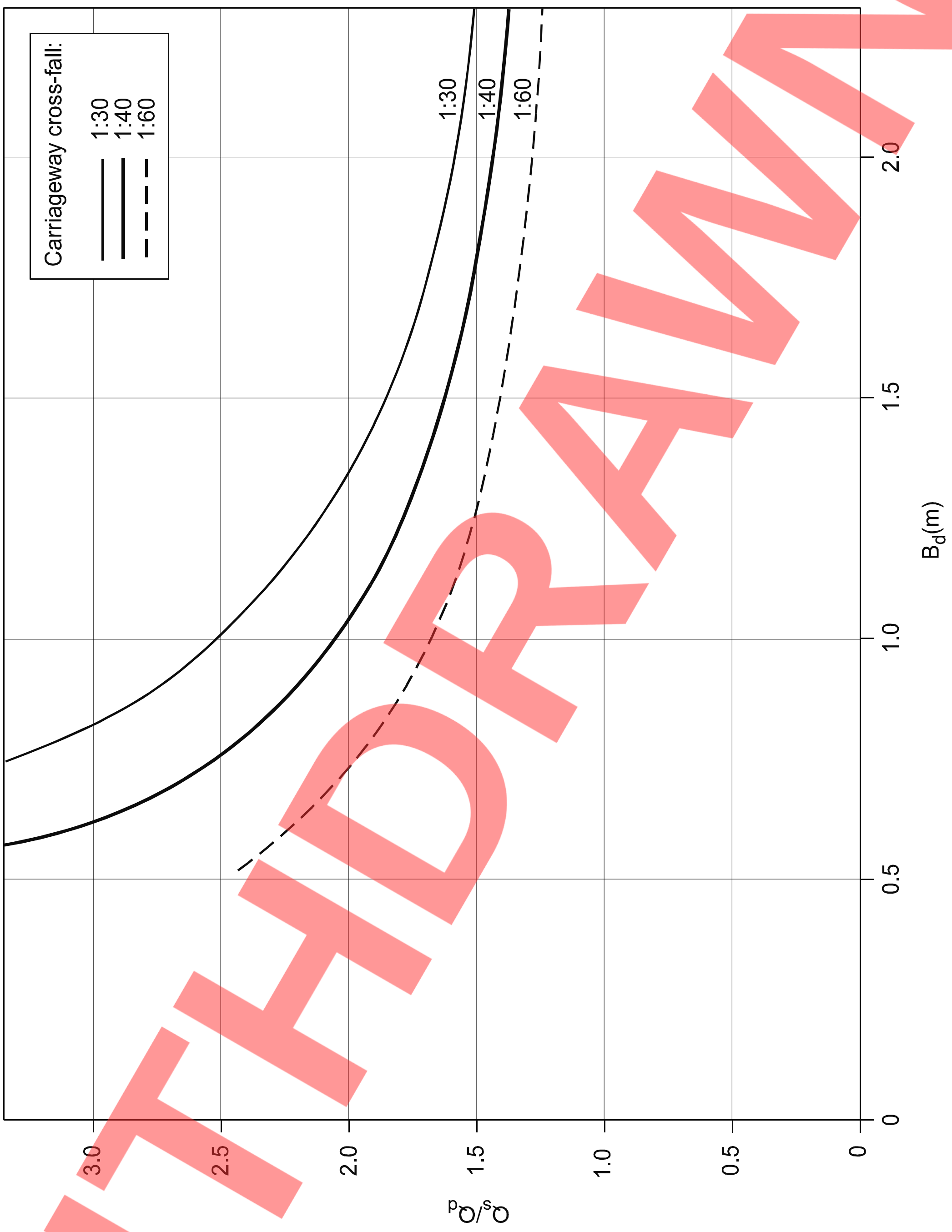

Figure B4 Relationship between surcharged and channel-full flows: Trapezoidal channels

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Figure B5 Triangular channel In-line outlet

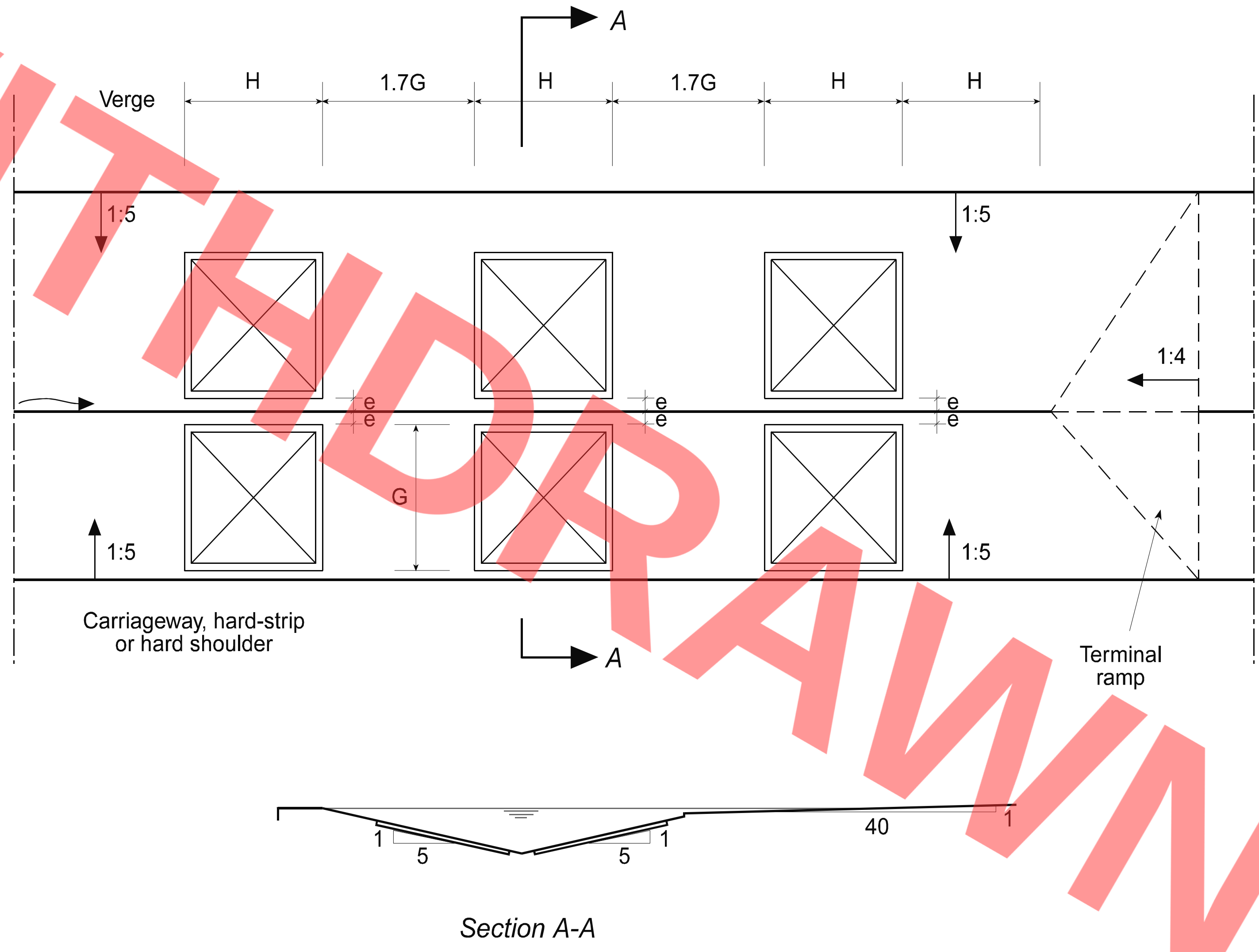

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Figure B6 Triangular Channel Off-line outlet

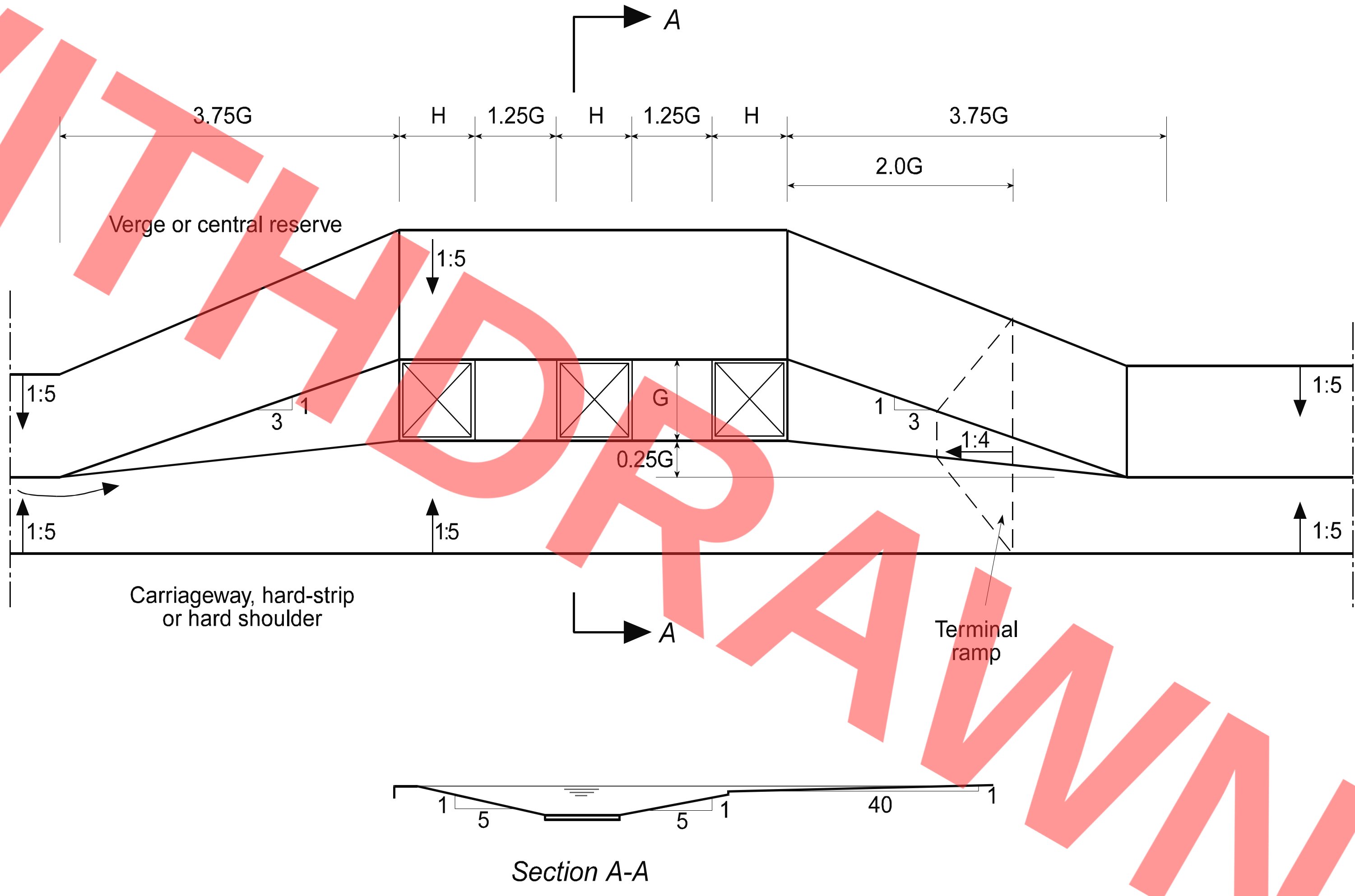

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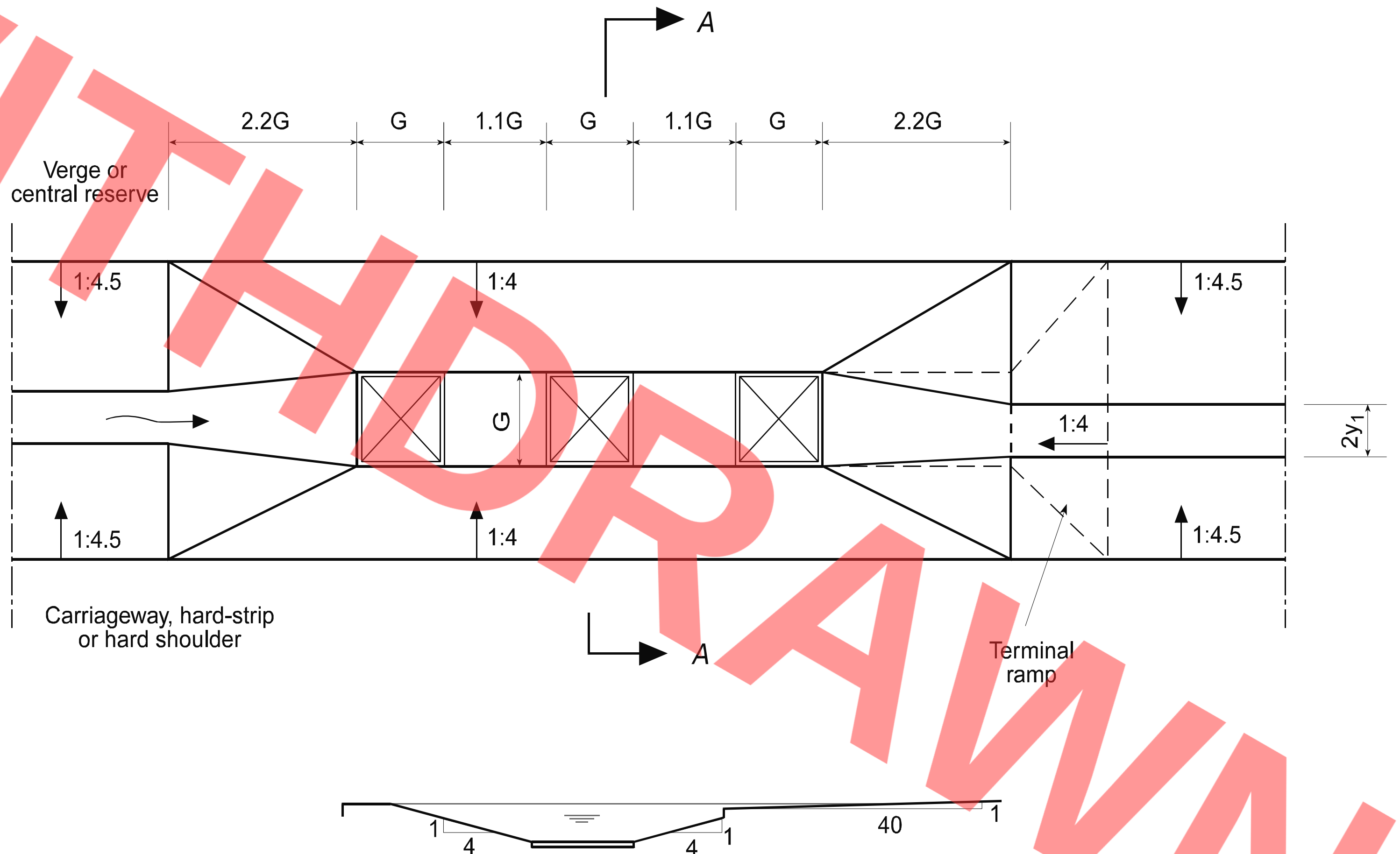
**Figure B7 Trapezoidal channel with cross-falls of 1:4.5
In-line outlet**



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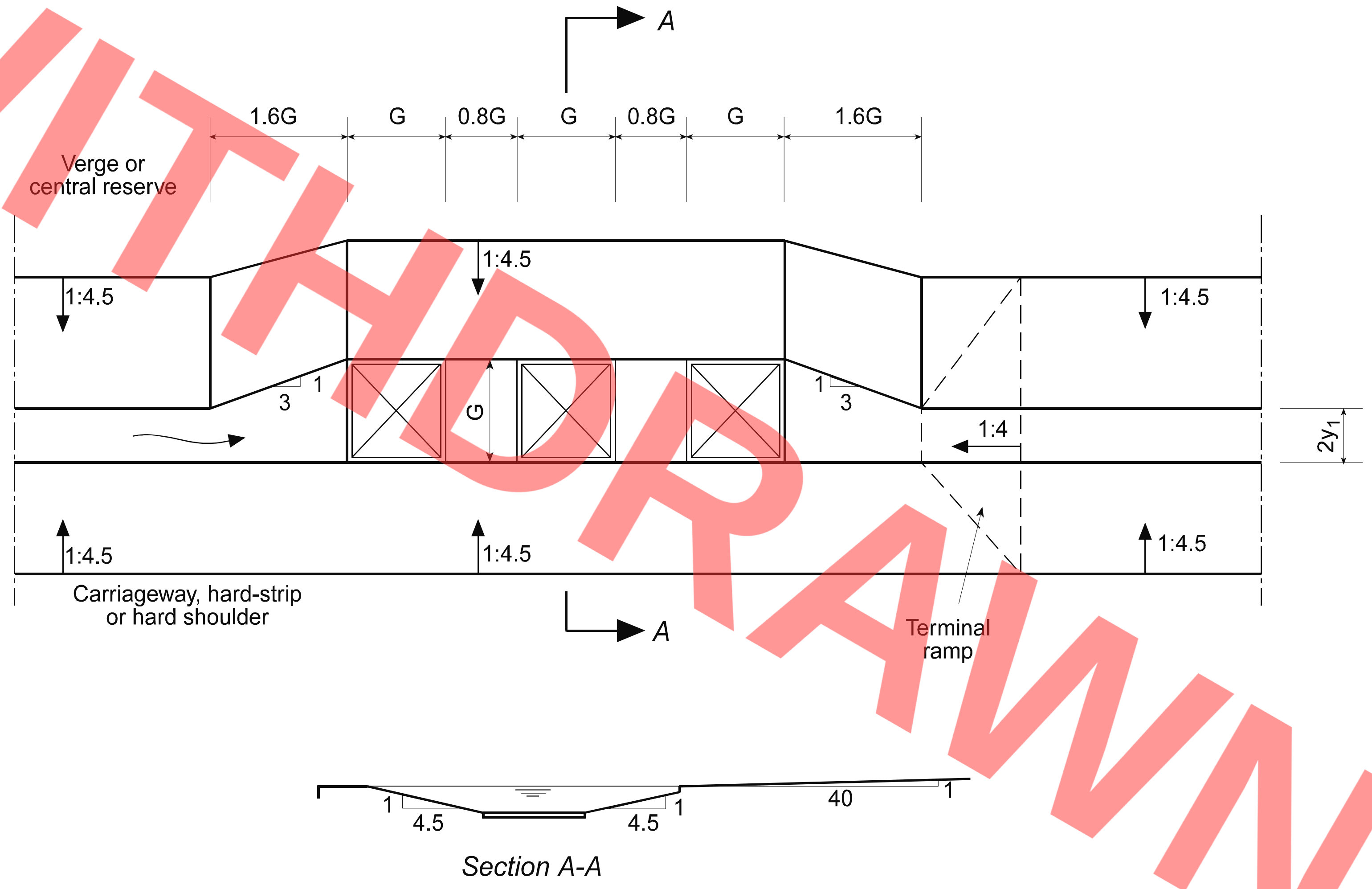

Figure B8 Trapezoidal channel with cross-falls of 1:4.5 - Off-line outlet

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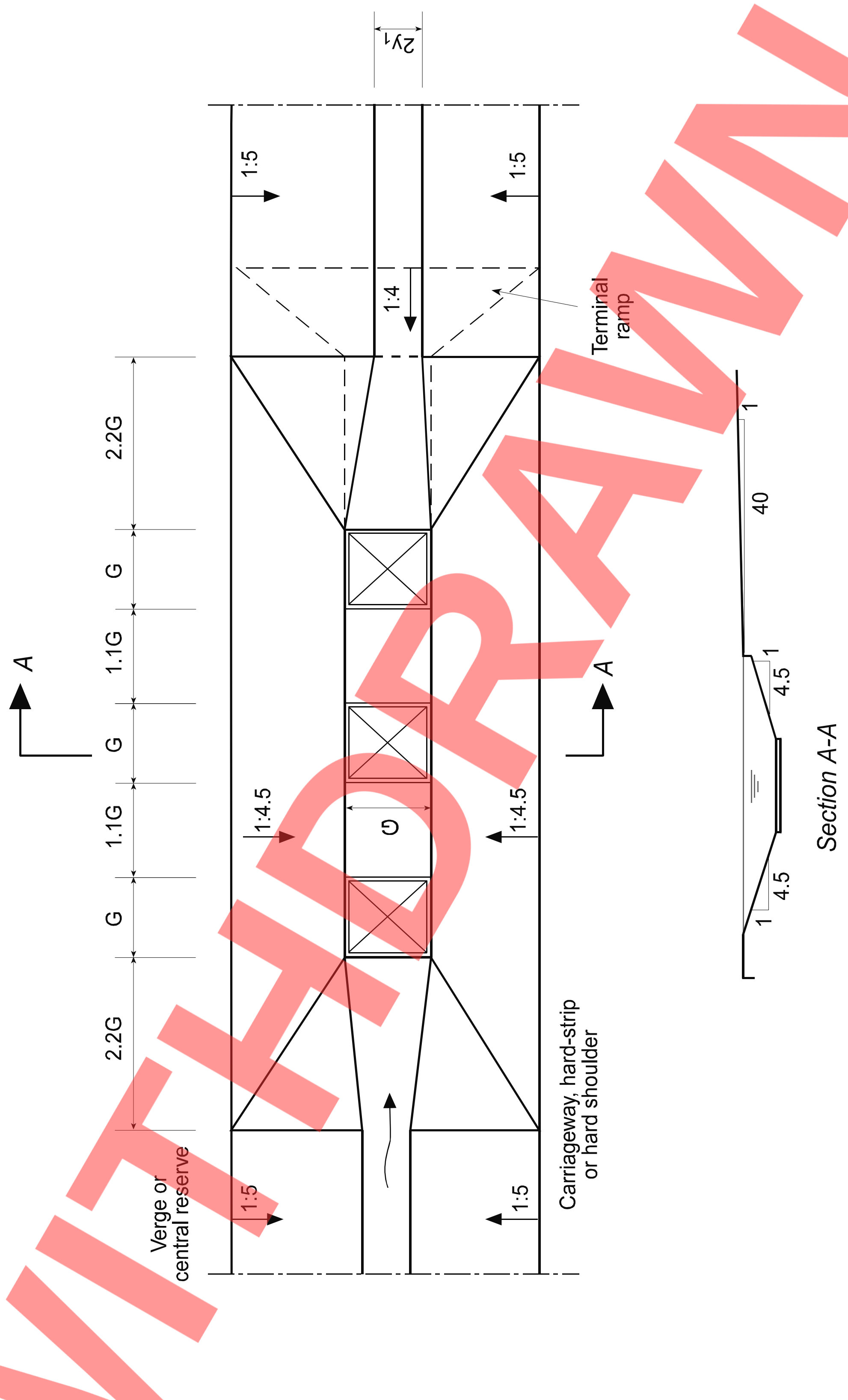

Figure B9 Trapezoidal channel with cross-falls of 1:5 In-line outlet

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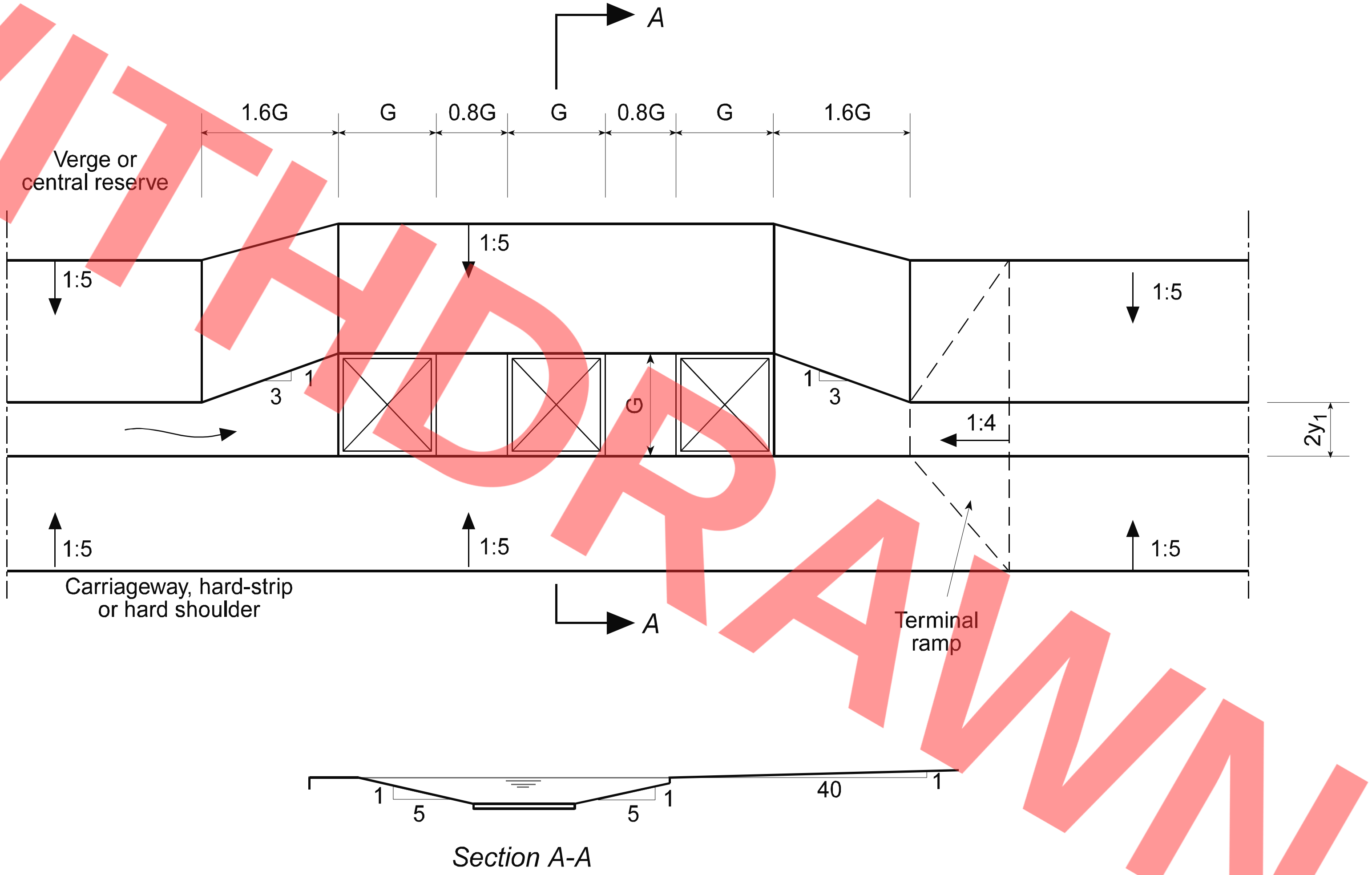

Figure B10 Trapezoidal channel with cross-falls of 1:5 - Off-line outlet

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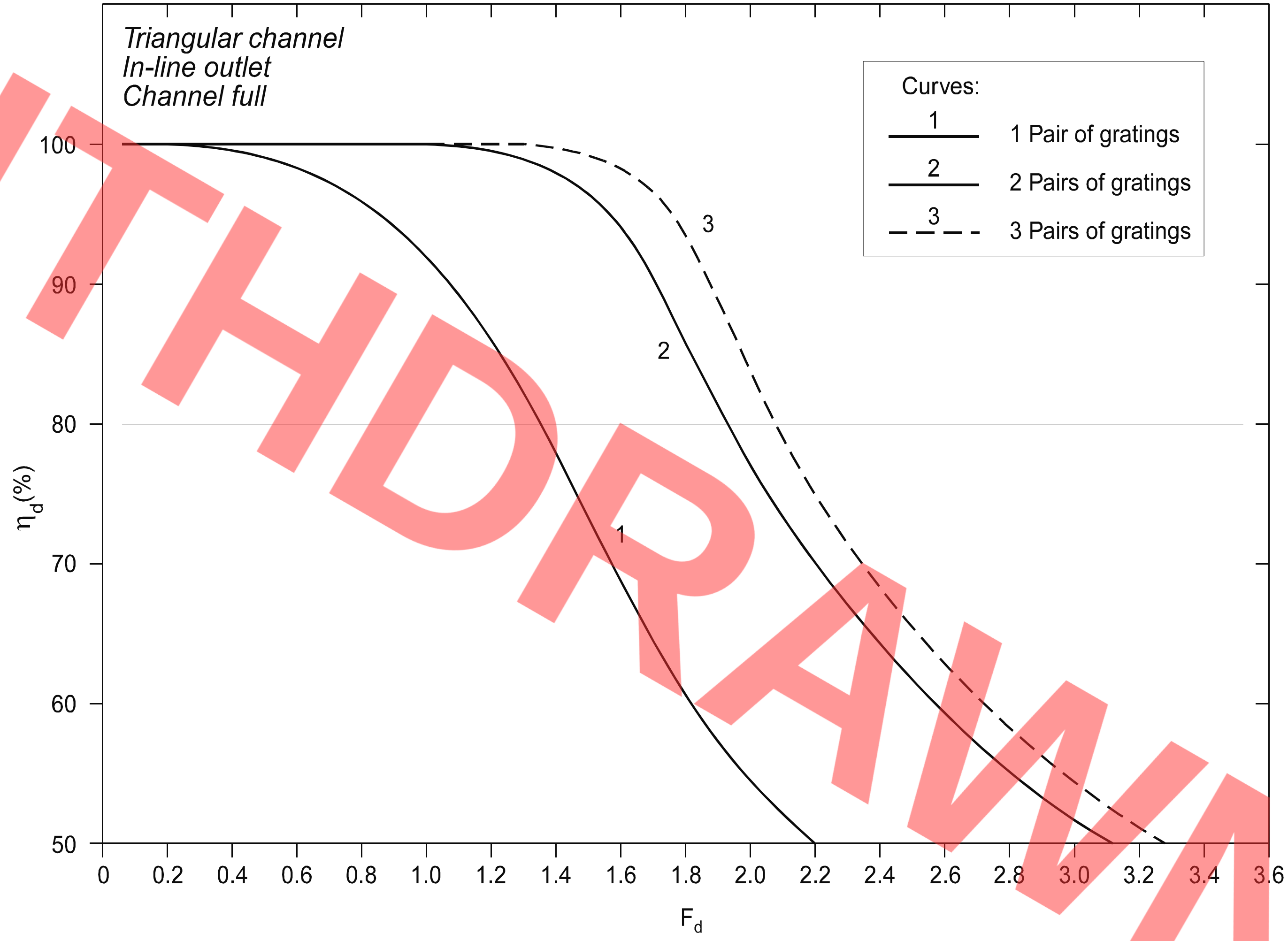

Figure B11 Design curves. Triangular channel - In-line outlet Channel full

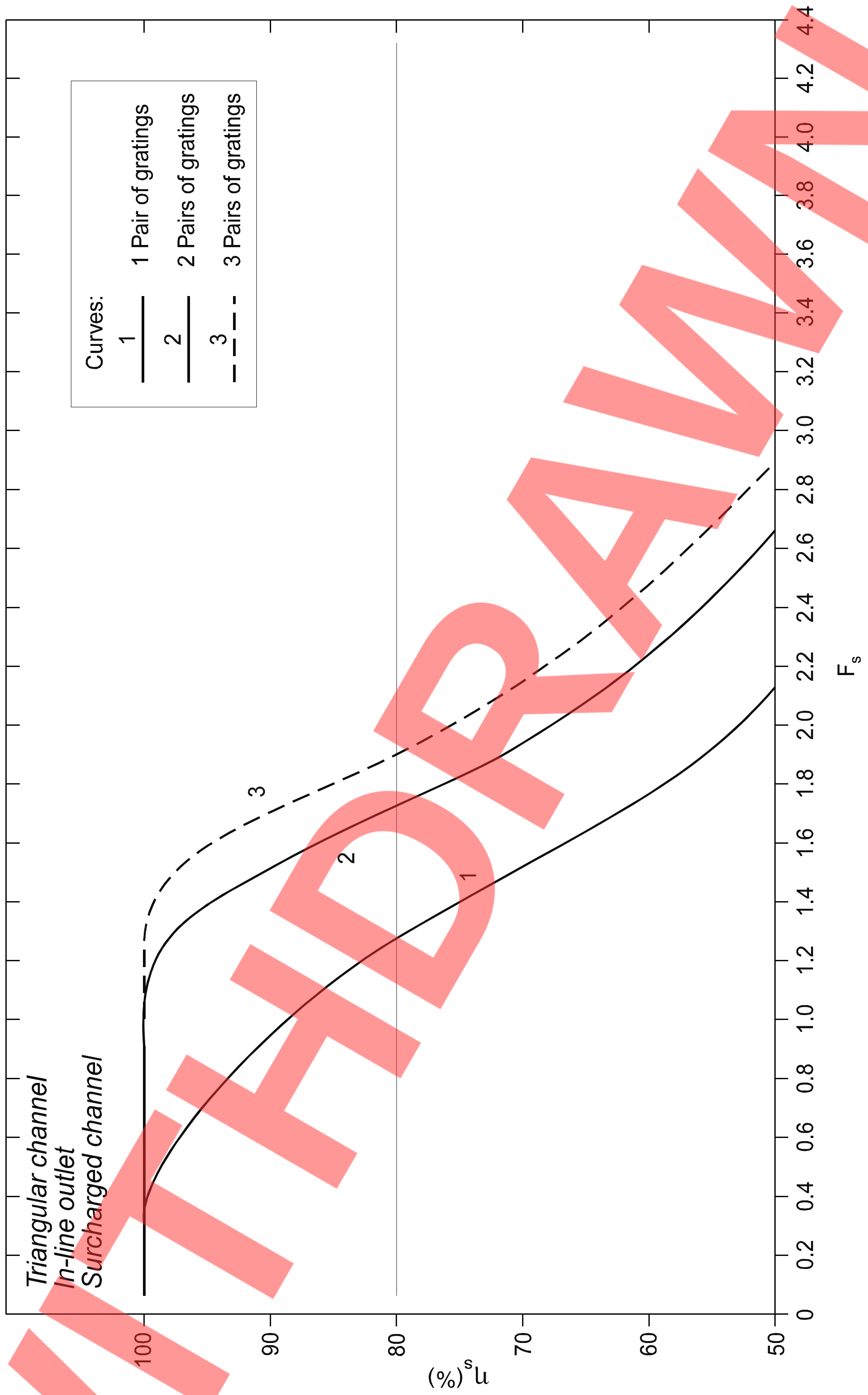

Figure B12 Design curves. Triangular channel - In-line outlet Surcharged channel

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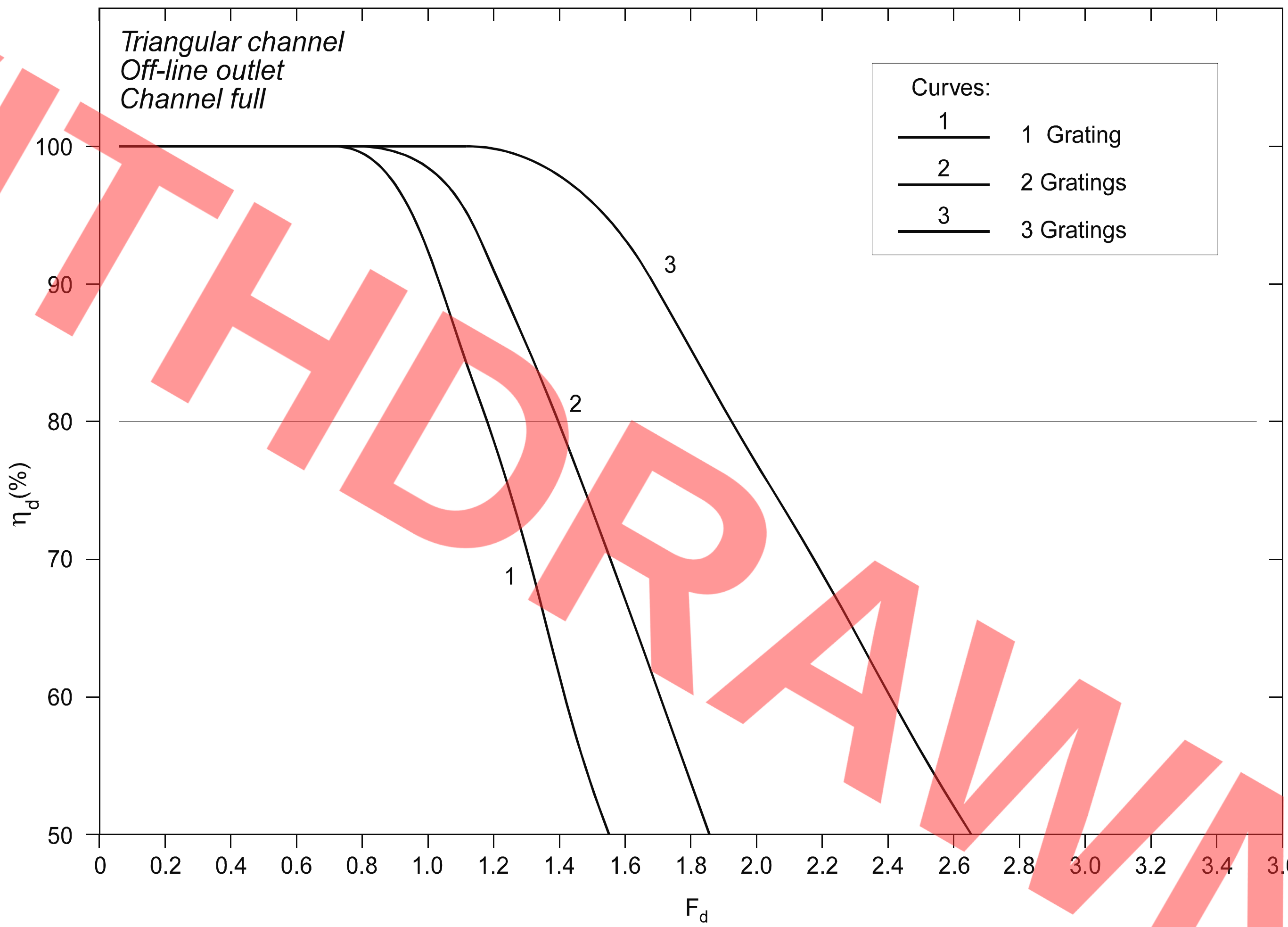

Figure B13 Design curves. Triangular channel - Off-line outlet Channel full

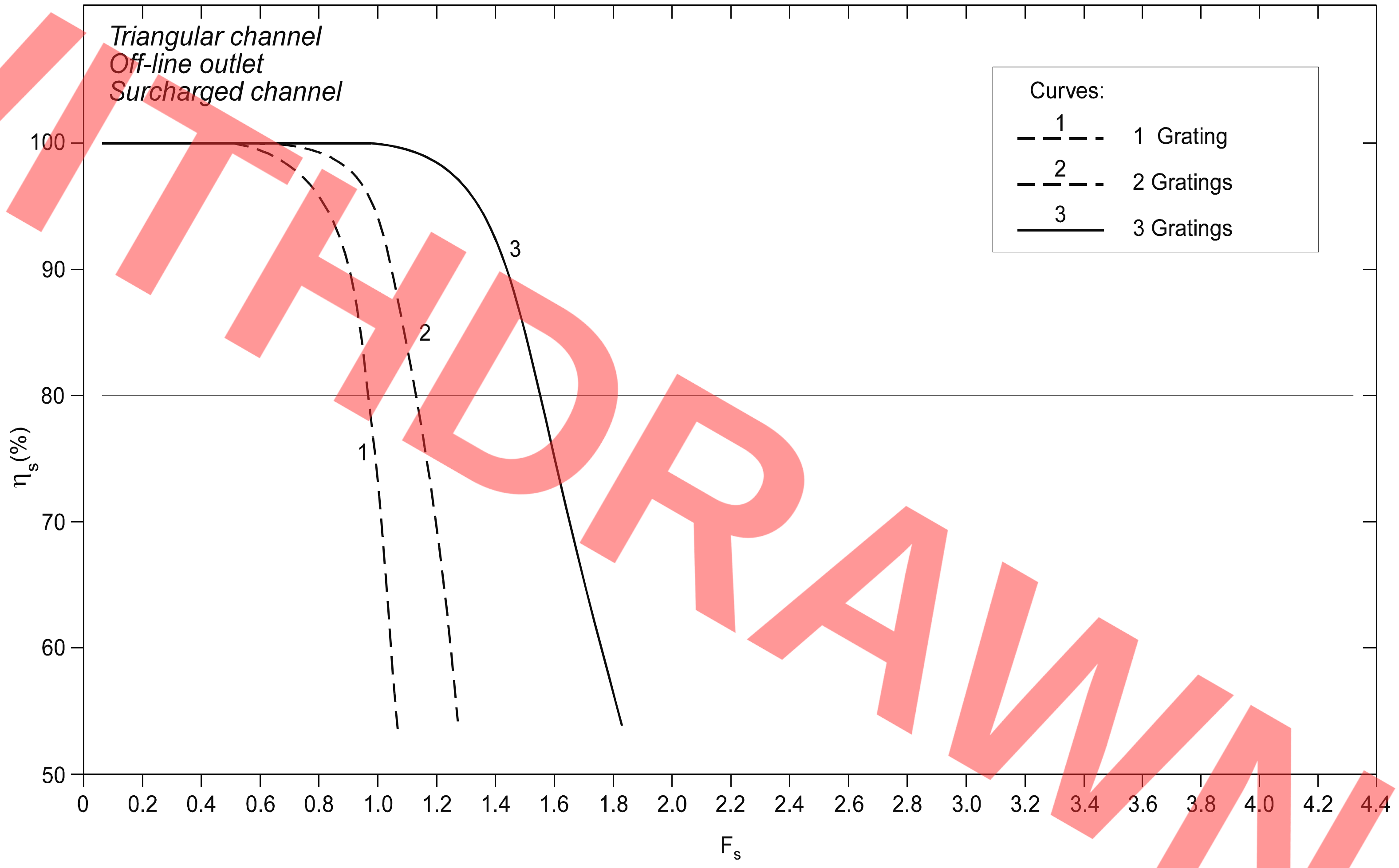

Figure B14 Design curves. Triangular channel - Off-line outlet Surcharged Channel

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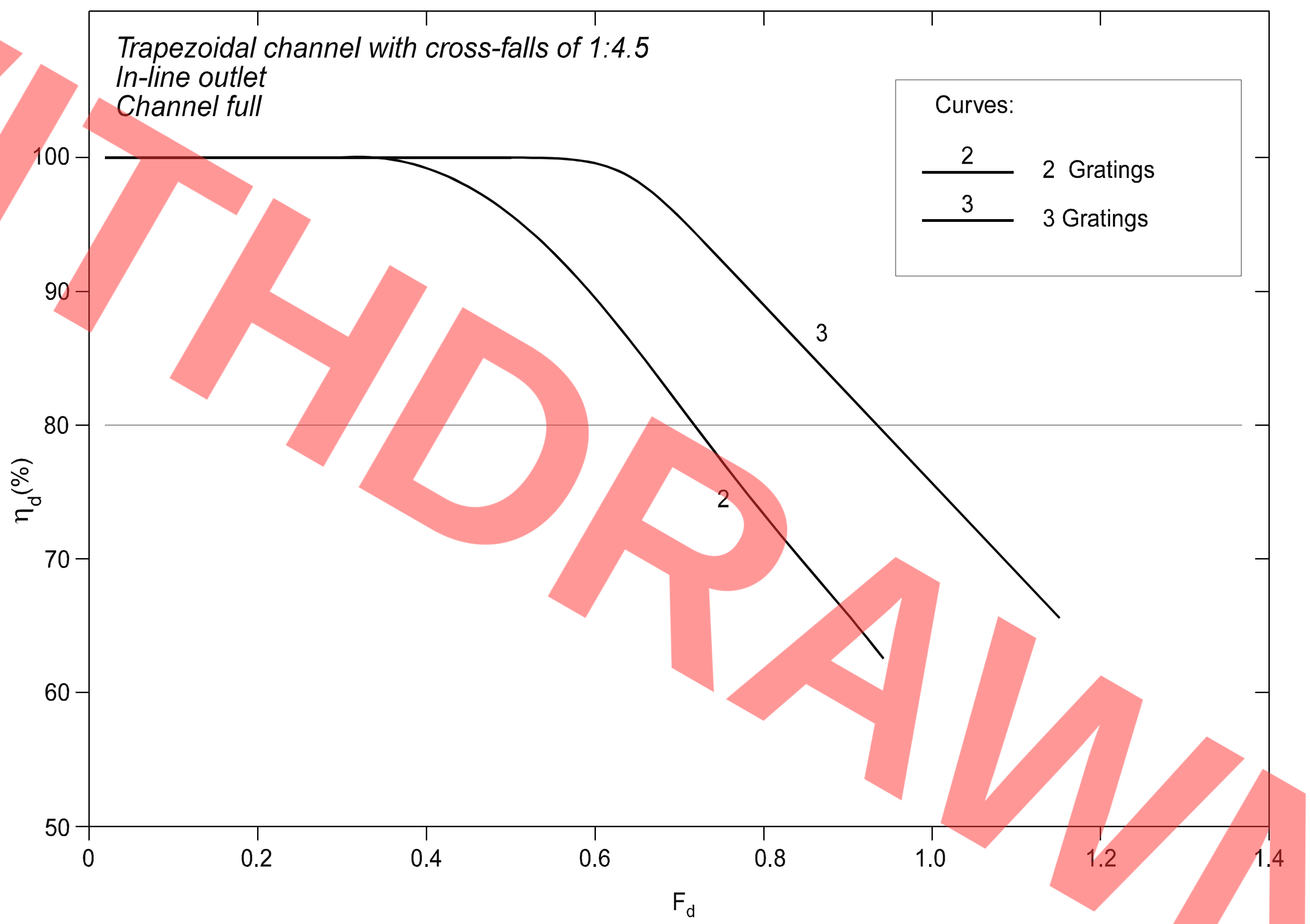


Figure B15 Design curves. Trapezoidal channel with cross-falls of 1:4.5 In-line outlet. Channel full

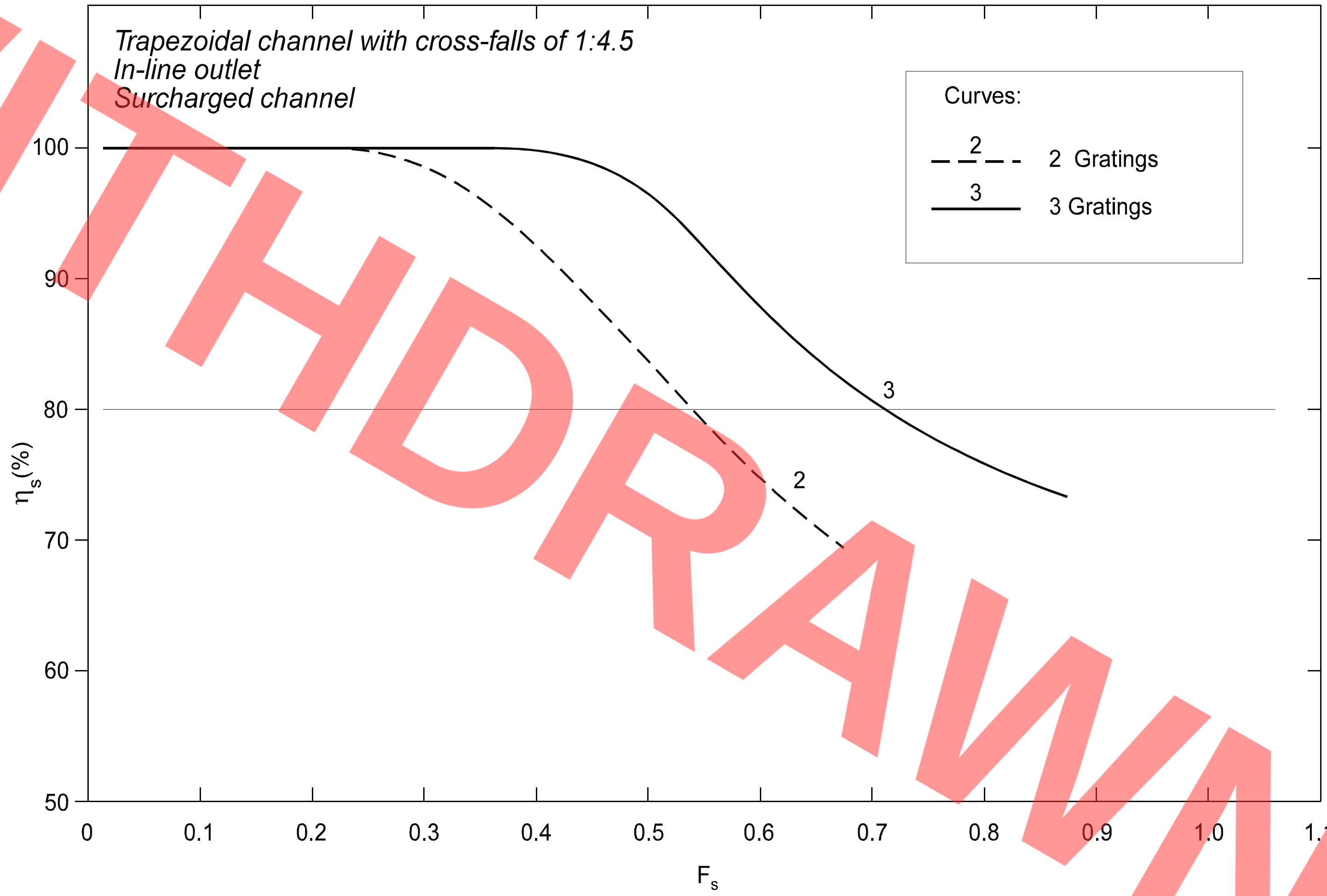
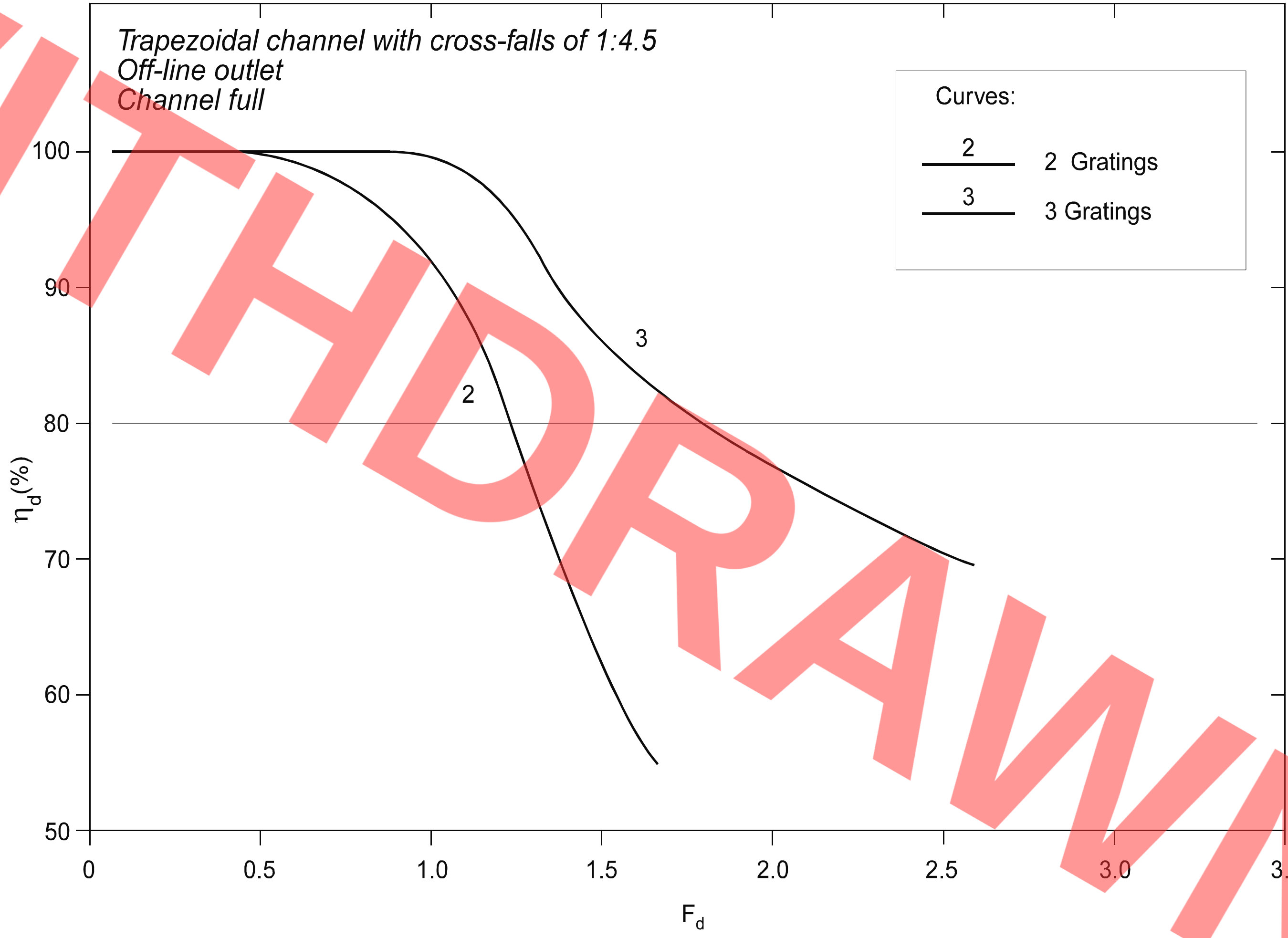


Figure B16 Design curves. Trapezoidal channel with cross-falls of 1:4.5 In-line outlet. Surcharged channel

Figure B17 Design curves. Trapezoidal channel with cross-falls of 1:4.5 Off-line outlet. Channel full



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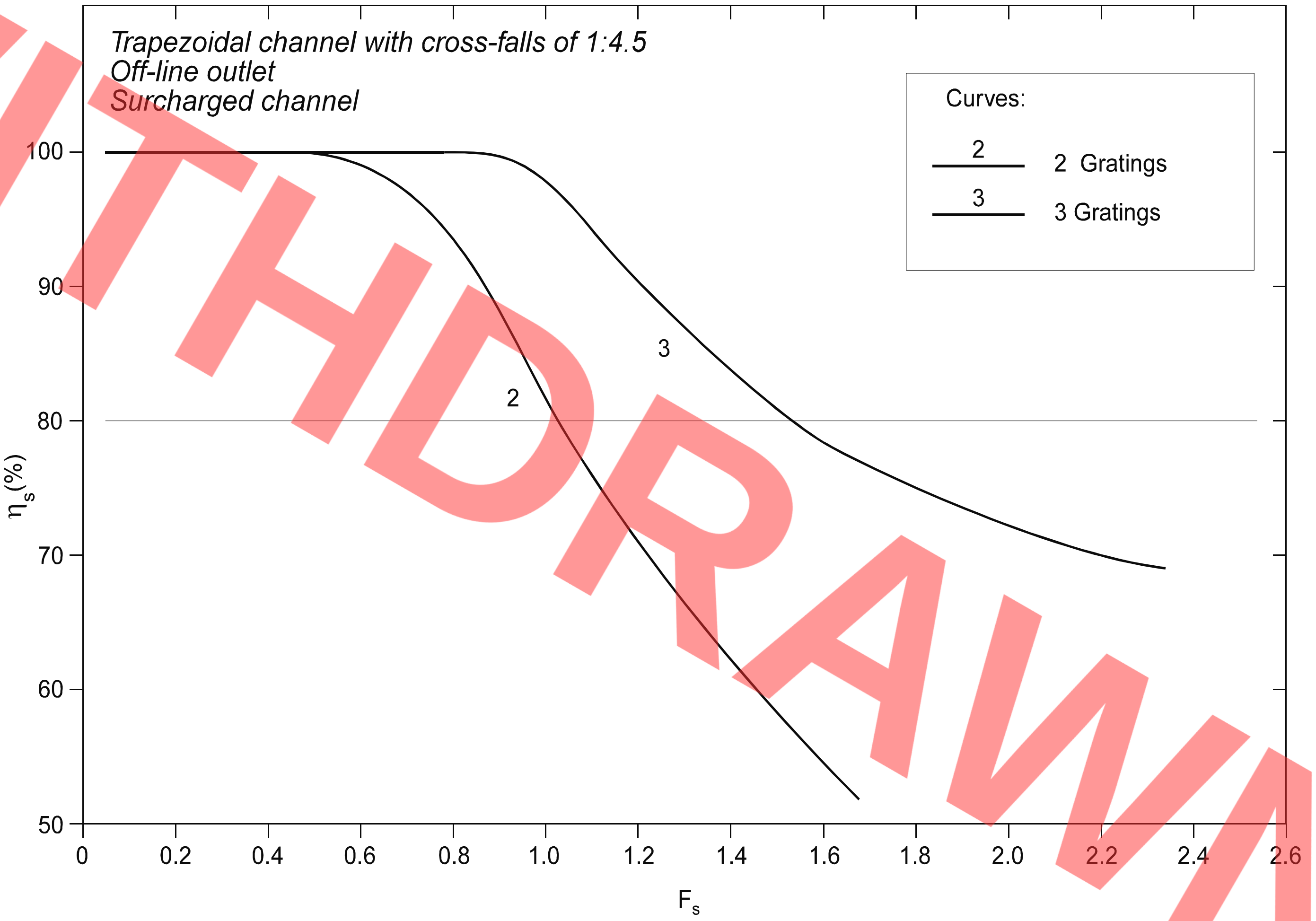

Figure B18 Design curves. Trapezoidal channel with cross-falls of 1:4.5 Off-line outlet. Surcharged channel

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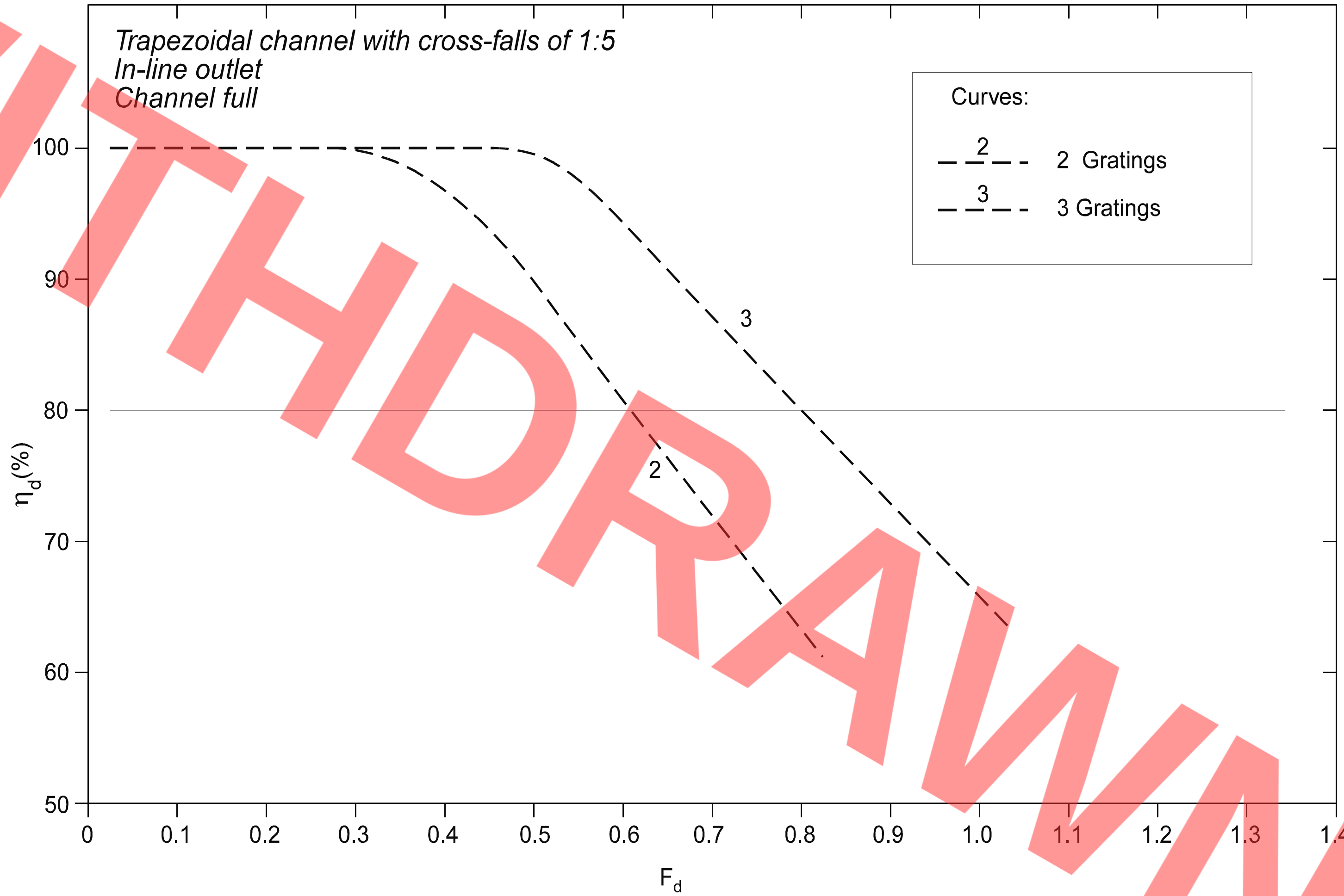

Figure B19 Design curves. Trapezoidal channel with cross-falls of 1:5 In-line outlet. Channel full

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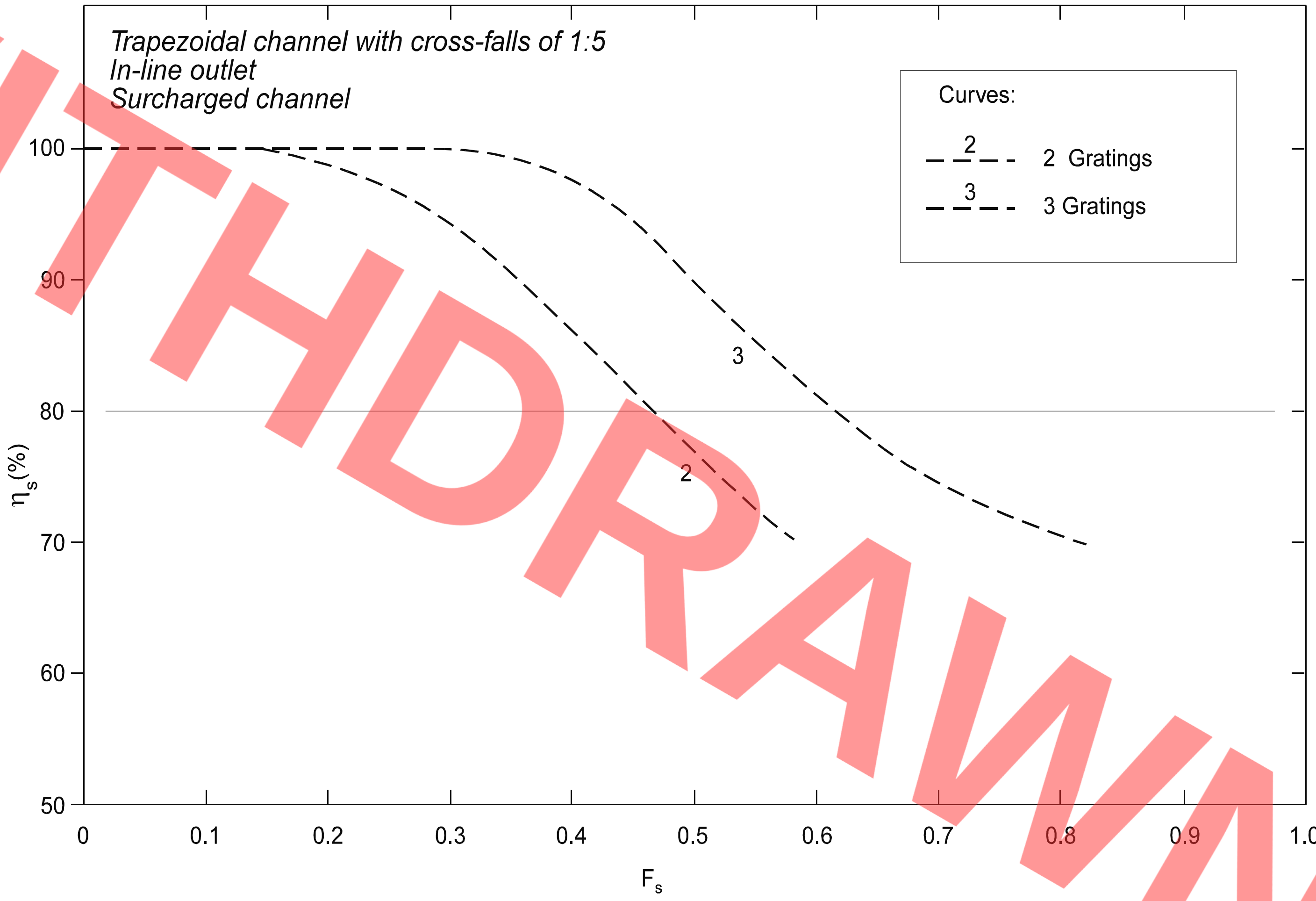

Figure B20 Design curves. Trapezoidal channel with cross-falls of 1:5 In-line outlet. Surcharged channel

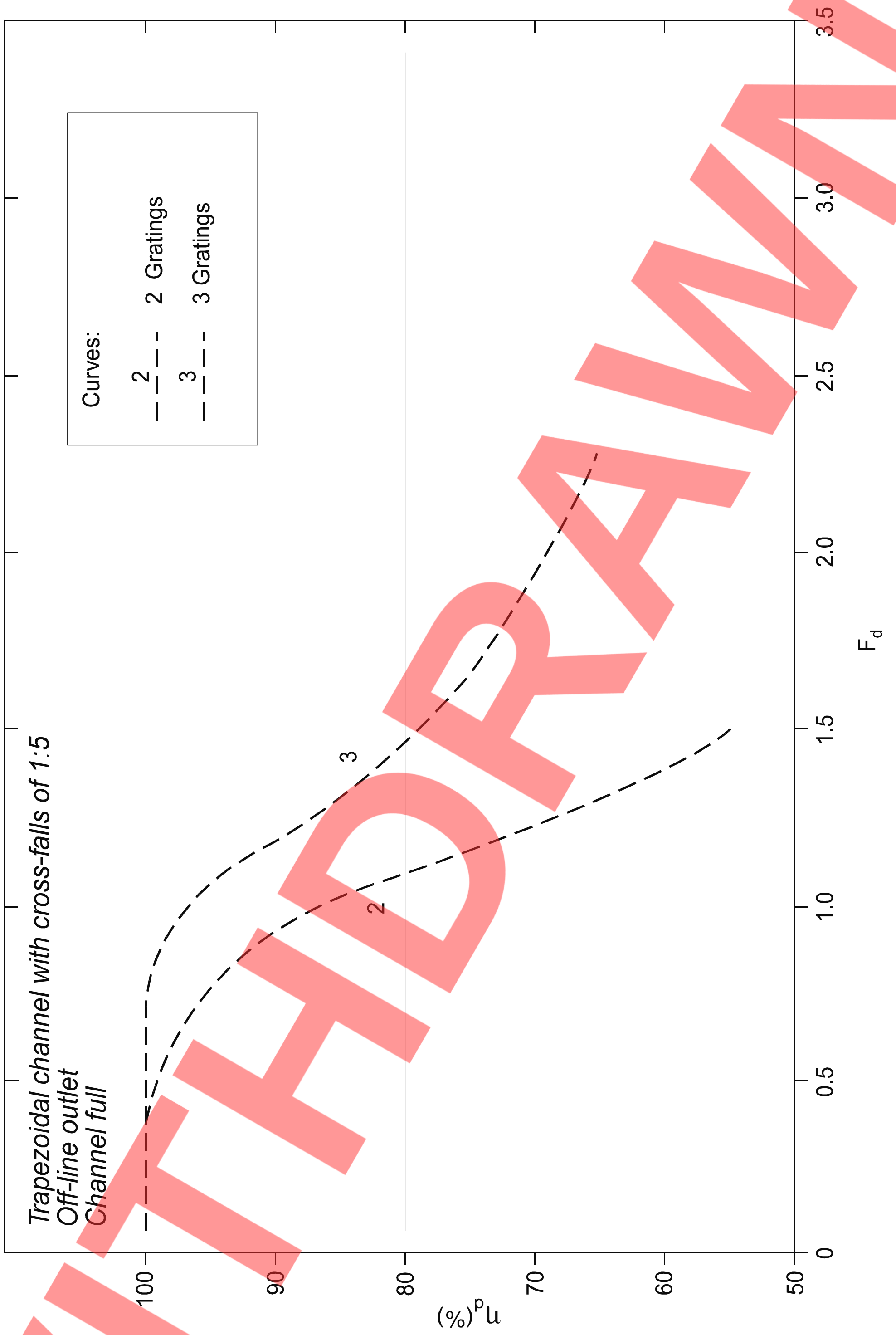

Figure B21 Design curves. Trapezoidal channel with cross-falls of 1:5 Off-line outlet. Channel full

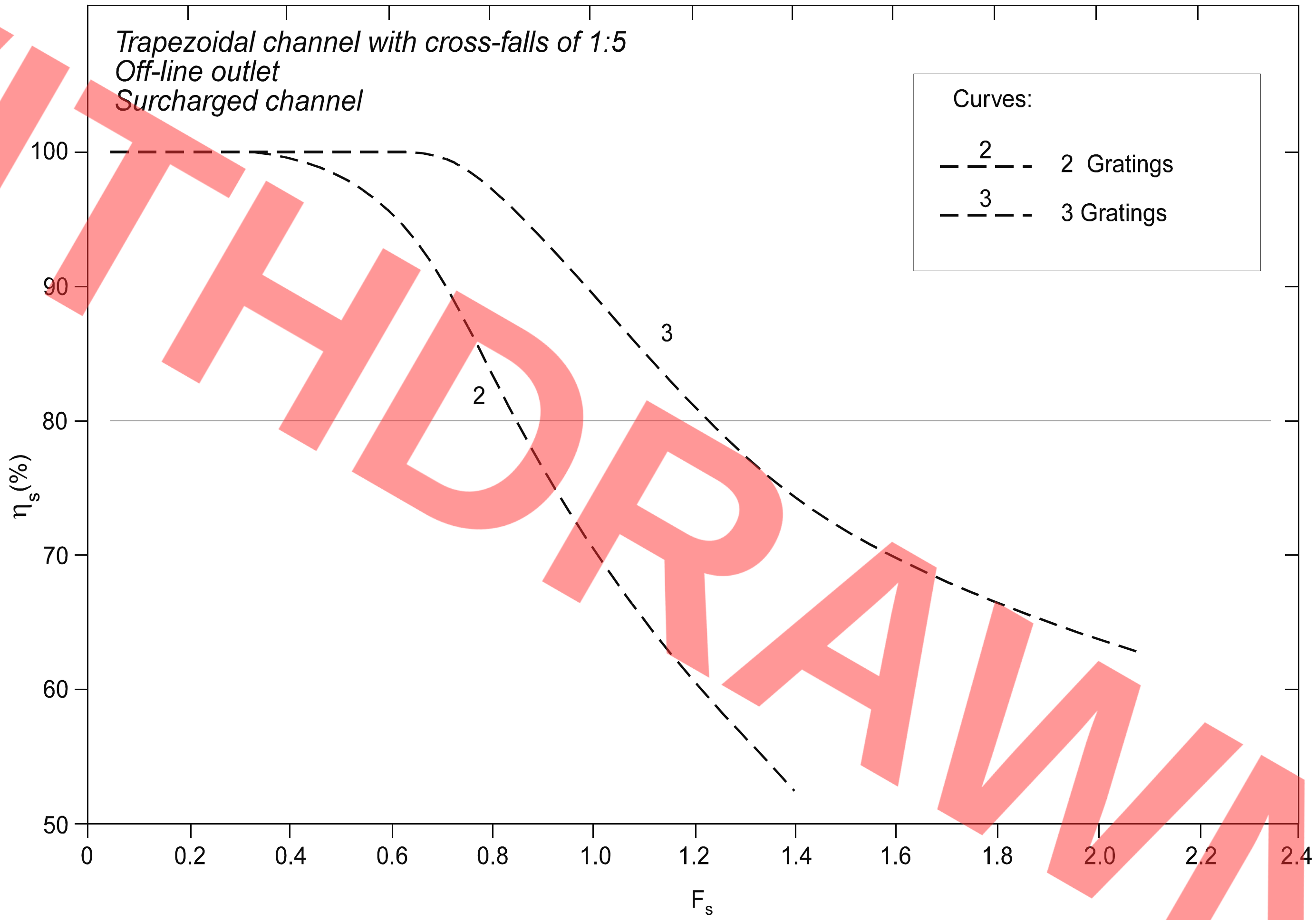

Figure B22 Design curves. Trapezoidal channel with cross-falls of 1:5 Off-line outlet. Surcharged channel

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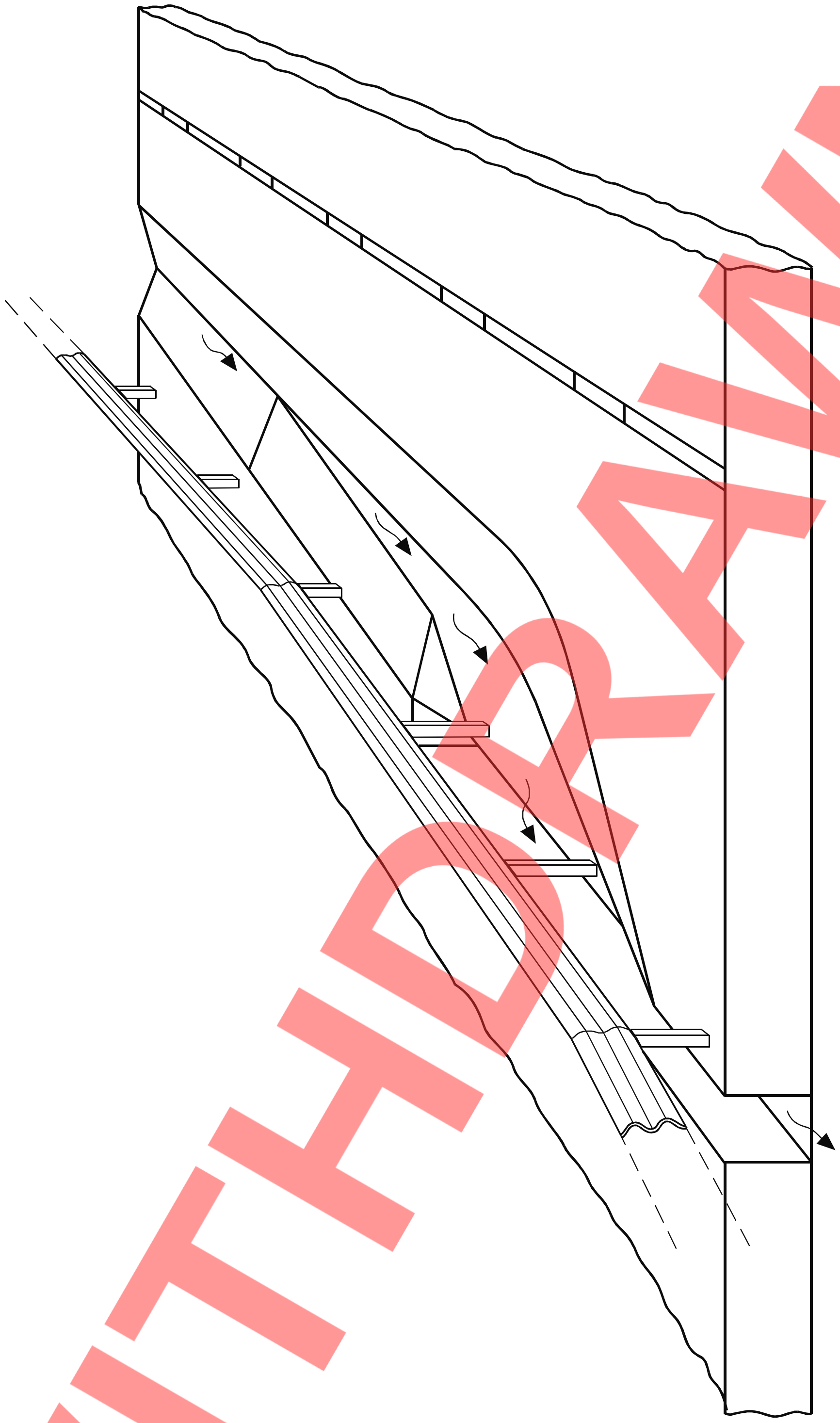
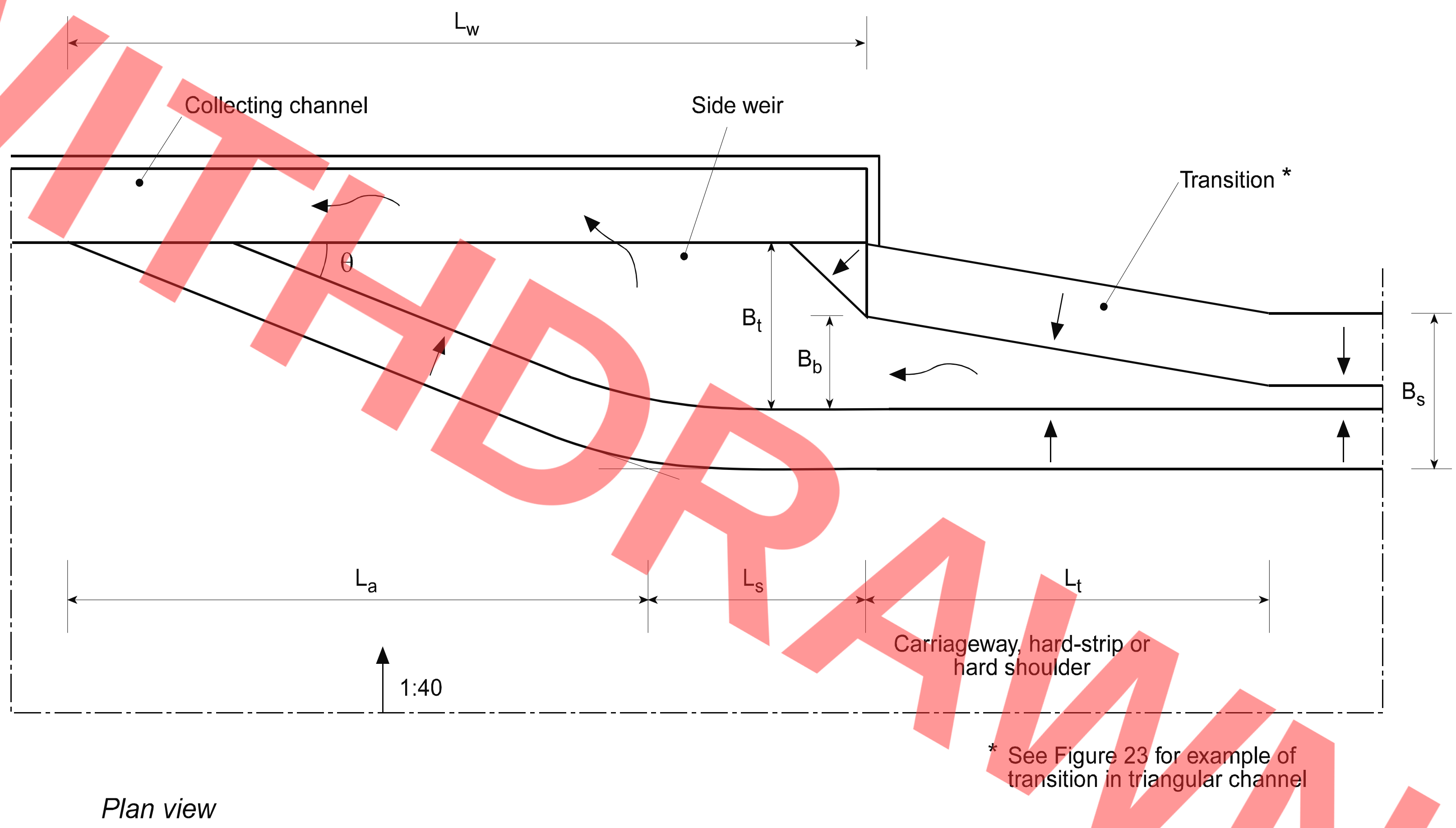


Figure B23 Isometric view of weir outlet indicating possible location of safety fence

Figure B24 Diagrammatic layout of weir outlet and upstream transition



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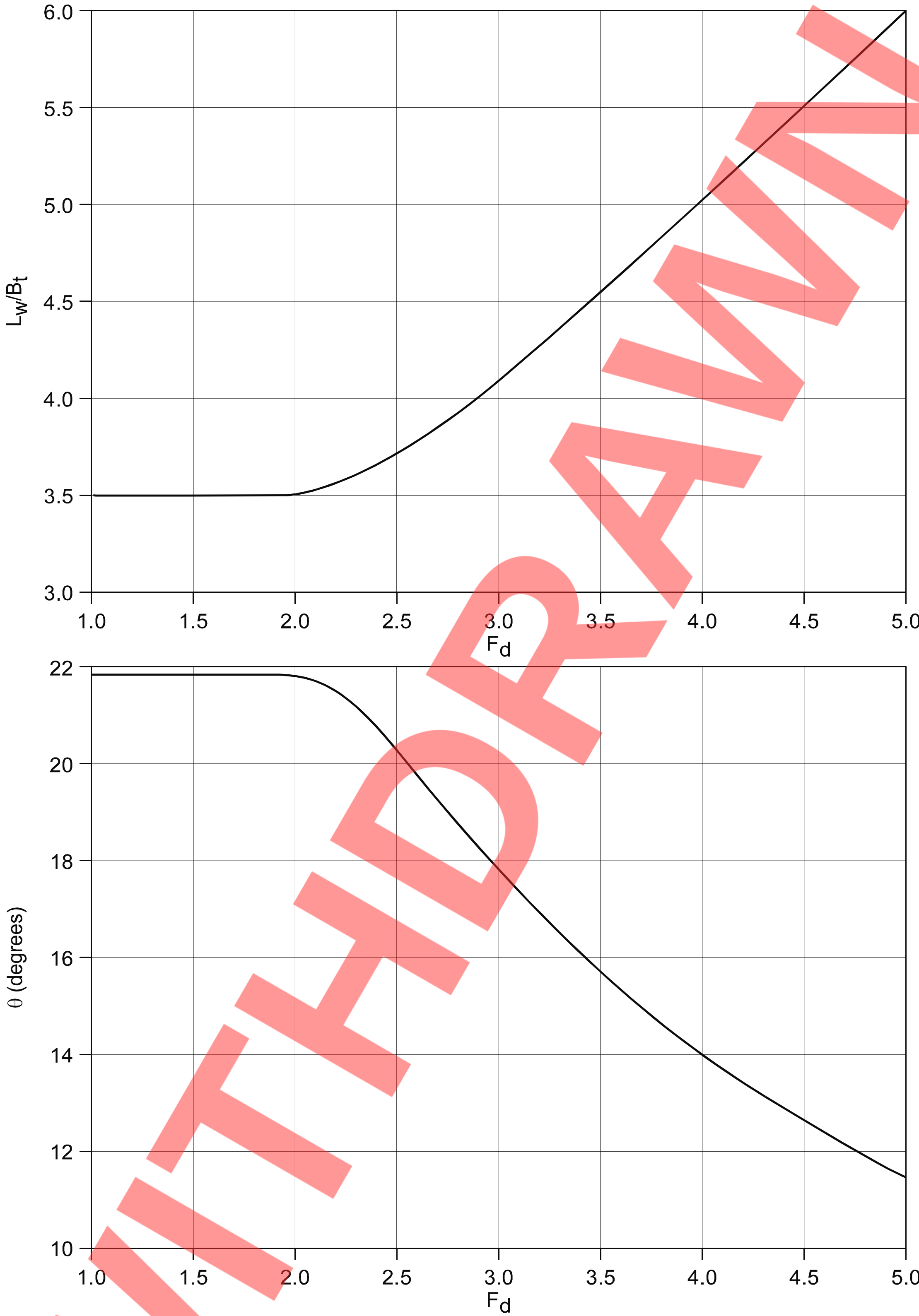

Figure B25 **Variations of geometry of weir outlet with flow conditions**

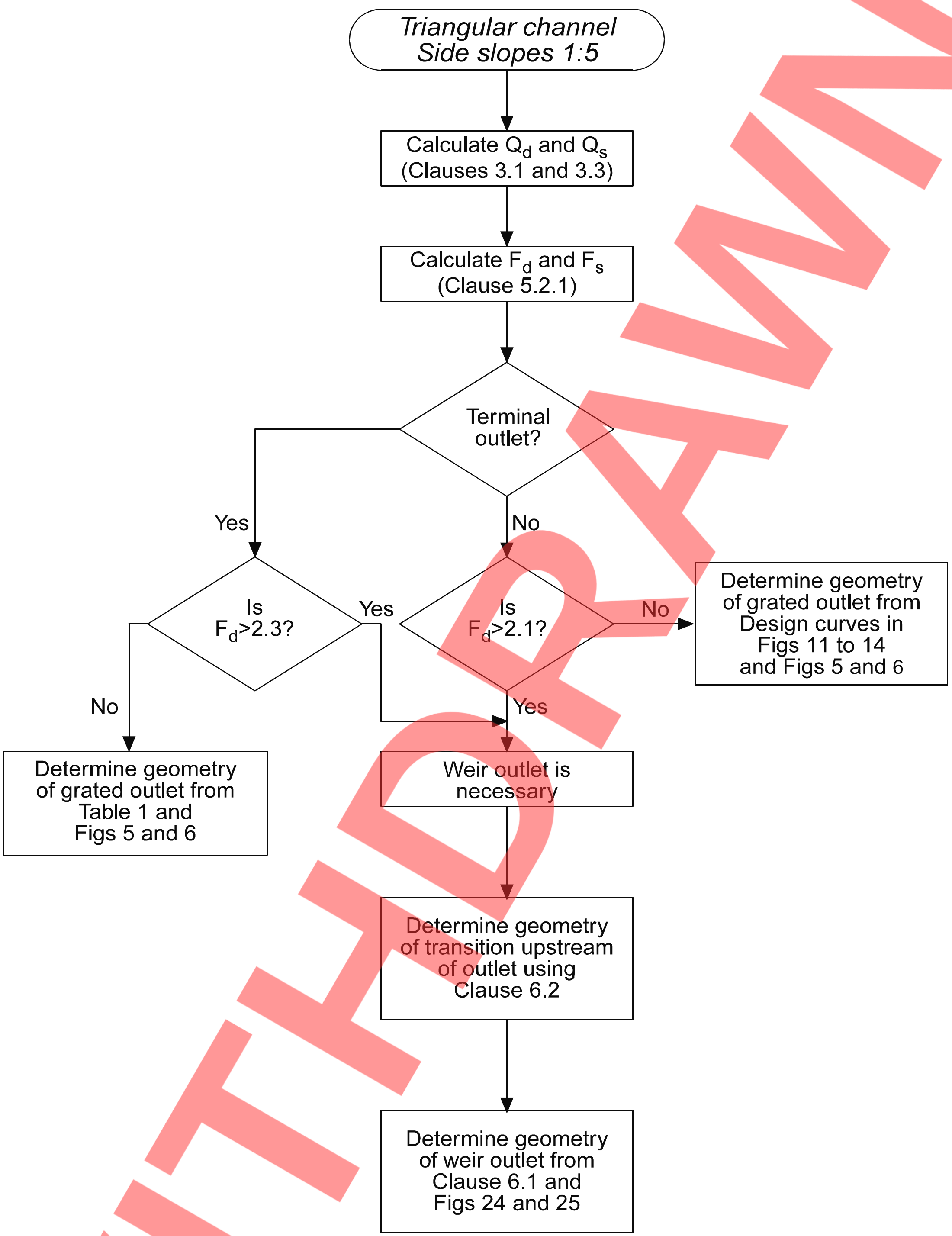

Figure B26 Flow chart for design of weir outlets in triangular channels

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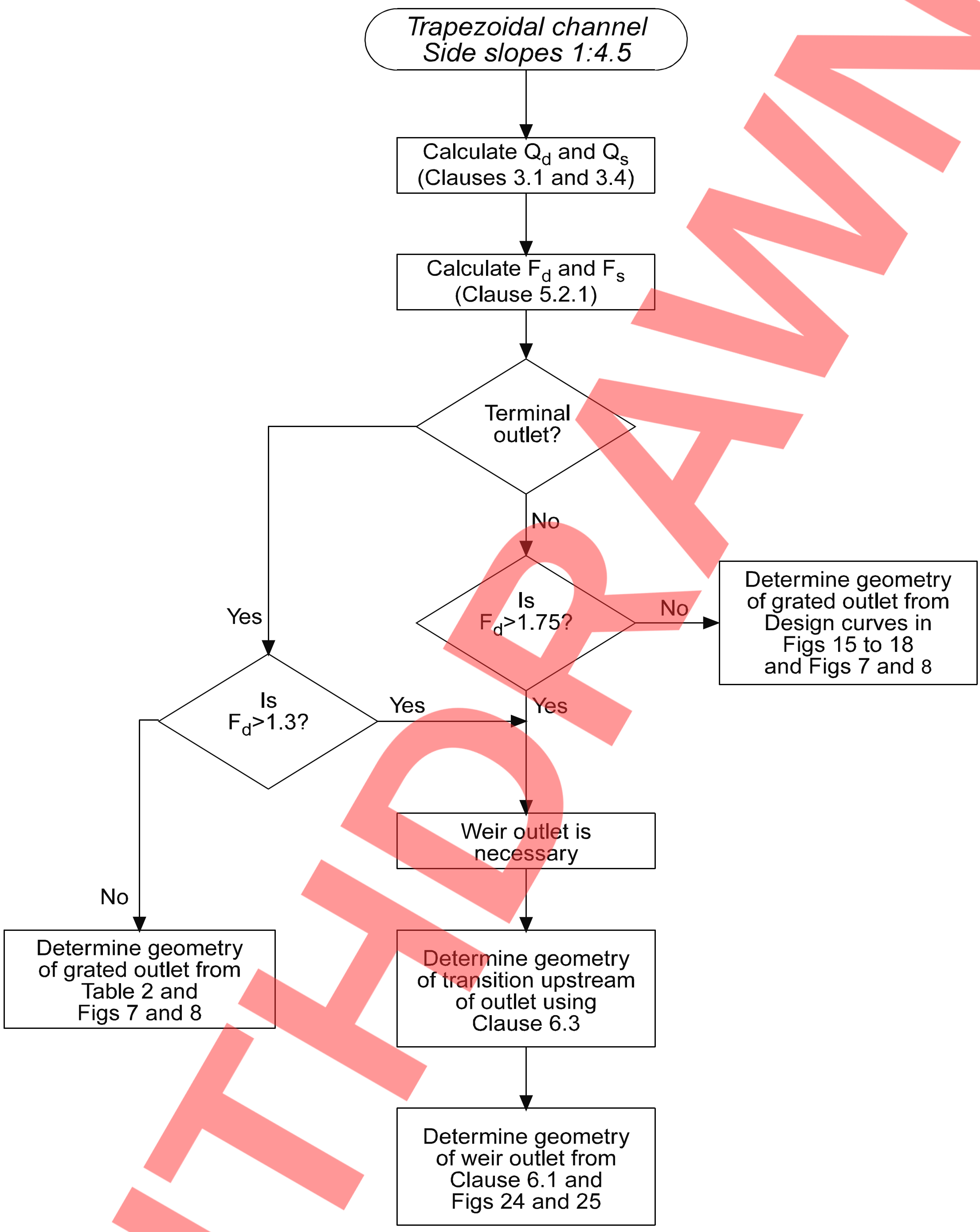

Figure B27 Flow chart for design of weir outlets in trapezoidal channels with cross-falls of 1:4.5

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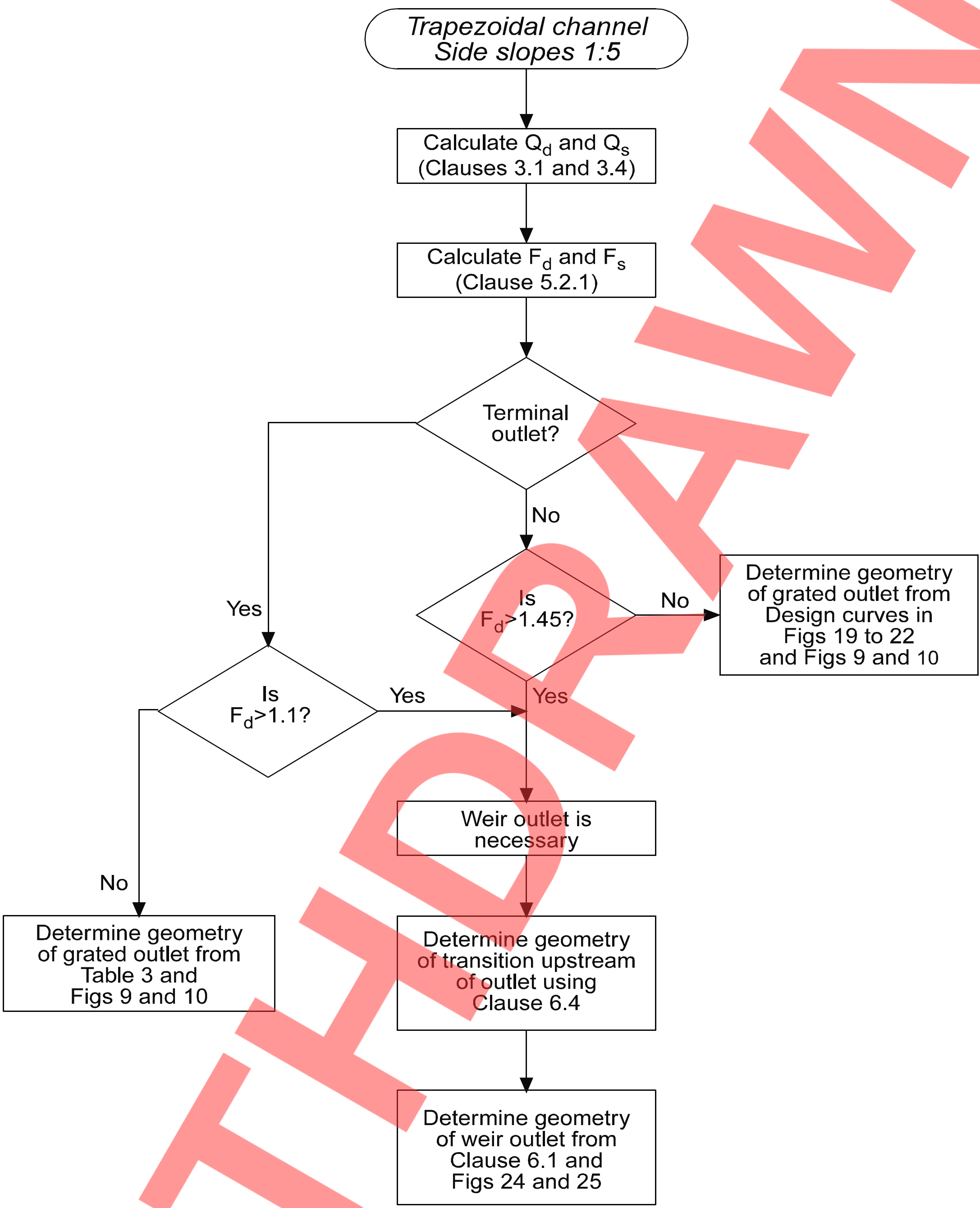

Figure B28 Flow chart for design of weir outlets in trapezoidal channels with cross-falls of 1:5

EXAMPLES

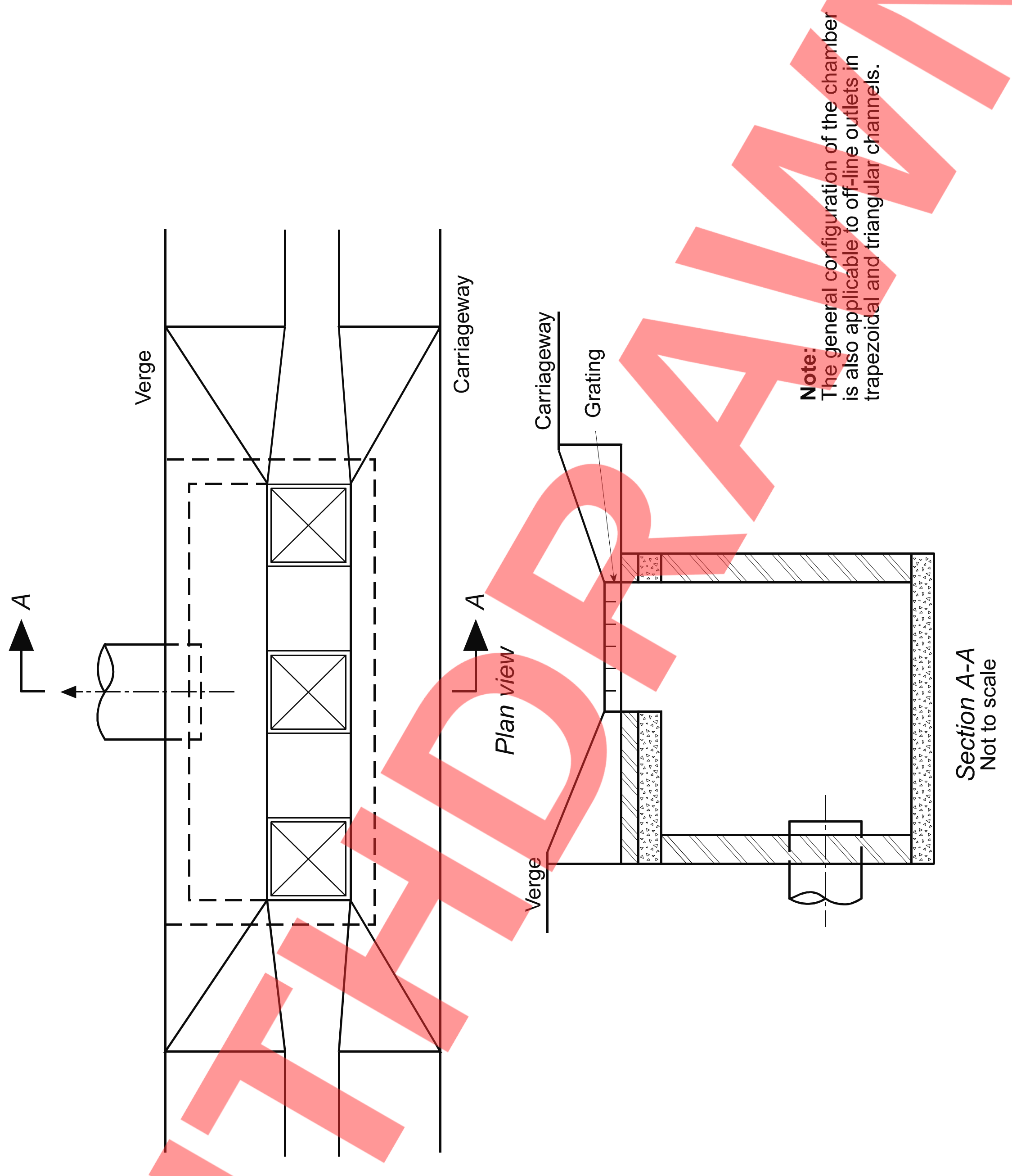

Figure C1 Example of collecting chamber for in-line outlet in trapezoidal channel

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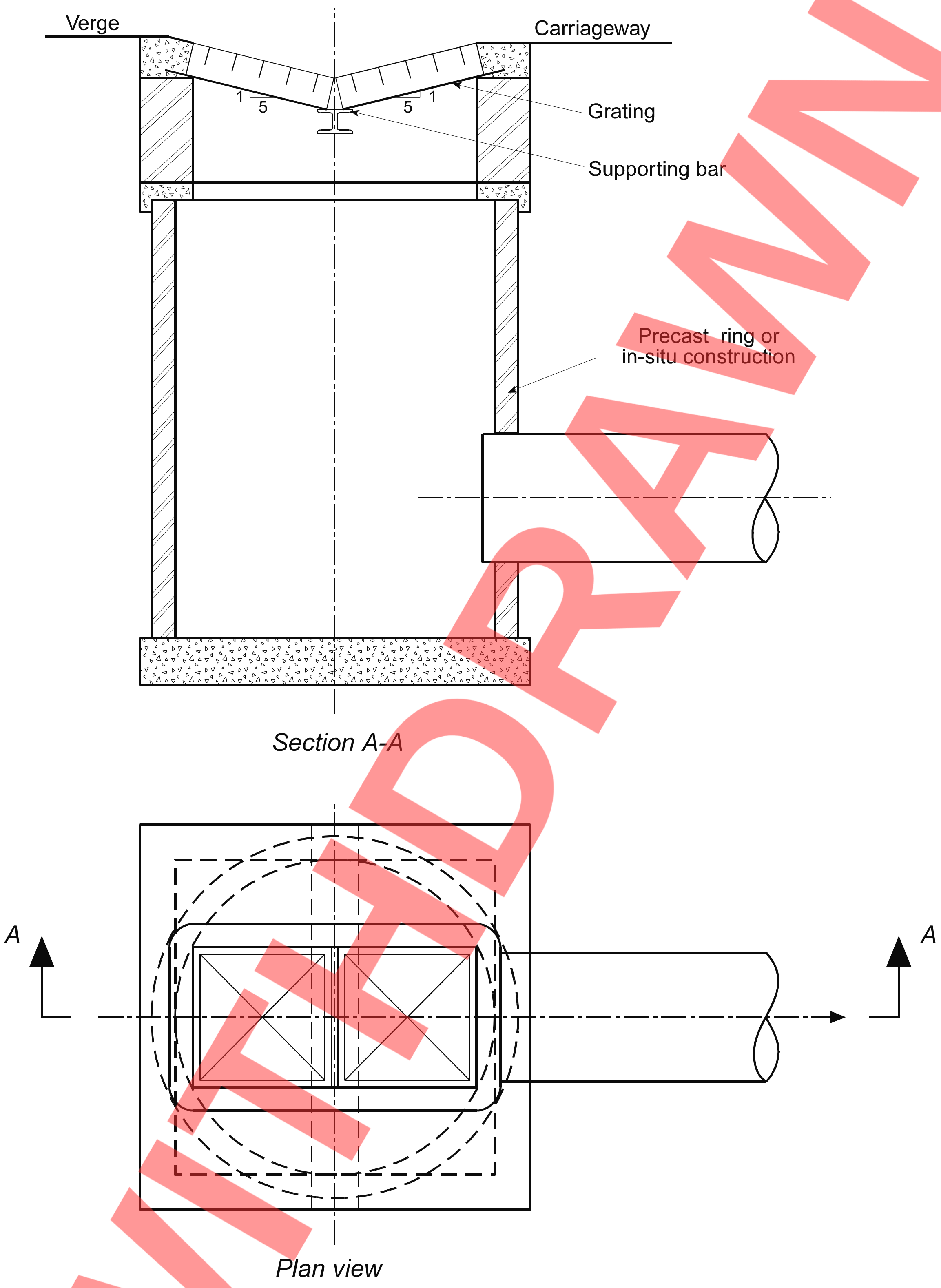

Figure C2 Example of collecting chamber for in-line outlet in triangular channel