ALABAMA SUPPLEMENTS TO THE

NATIONAL ENGINEERING FIELD HANDBOOK

CHAPTER 6. STRUCTURES

Contents

TABLES

FIGURES

GENERAL

Computer Programs for Structure Design

The following computer programs are available for use in designing hydraulic structures. These may be used to supplement, or in lieu of, many of the charts and tables in Chapter 6:

PROGRAM	FUNCTION	SOURCE
WINPOND	Can be used to size pipes and establish hydraulic elevation of ponds, sediment basins, storm water detention basins, pipe grade control structures.	NRCS
WIN TR-55	Determine runoff curve numbers, peak discharge from drainage areas, perform simple channel and structure flood routings.	NRCS
EFH2	Determine runoff curve numbers and peak discharge from drainage areas.	NRCS
Hydraulics Formula	Contains solutions to various hydraulic equations frequently encountered on soil and water conservation activities. Includes solutions for pipe drops, culverts, trapezoidal sections, dry hydrants, and other structures.	NRCS
CIRDIS	An Excel spreadsheet for computing flow through pipe drop systems. It calculates weir flow at the riser crest, orifice flow at the riser crest and barrel entrance, and full pipe flow. The limiting flow is displayed for each increment of elevation selected.	NRCS, Alabama
Watering System Design	An Excel spreadsheet used to determine pump horsepower and pipe requirements for livestock watering systems.	NRCS - Alabama
Rock_ChuteXP	An Excel spreadsheet used to determine stable rock size for riprap chutes and rock lined waterways.	NRCS - Alabama
Riser Base Floatation Design	An Excel spreadsheet used to determine concrete ballast volume required to provide floatation resistance for a pond riser.	NRCS - Alabama
Scour Hole Radius	An Excel spreadsheet used to determine the extent of scour protection needed at the entrance to a pipe or gate opening.	NRCS - Alabama
Stream Crossing	An Excel spreadsheet used to determine a minimum stable rock size and compute quantities for a riprap stream crossing.	NRCS - Alabama

DROP INLET SPILLWAY

Pipe Drop Inlet Hydraulic Design

There are several computer programs available for use in determining hydraulic capacity of drop inlets. These programs provide accurate analysis and convenient printed documentation for design records. Three programs that may be used are WinPond, Hydraulics Formula, and CIRDIS. See the Structure Design Computer Programs summary for a description of the programs.

Note that flow through a drop inlet may be controlled at different locations within the inlet. (See Figure 6-27). The Excel spreadsheet, CIRDIS, may be used to determine the flow control location as head increases over the crest of a drop inlet. Flow control by the orifice at the riser or inlet crest should be avoided for more efficient operation of the inlet and to avoid vibrations associated with slug flow. This may require use of a larger drop inlet or riser pipe.

Drop inlet spillways are often used to control discharges from sediment basins and storm water detention basins. WIN TR-55 may be used to route a storm through a sediment basin with a drop inlet. However, WIN TR-55 is limited in that it only computes full pipe flow starting at the riser crest. Therefore, any flood storage that may be available below the riser crest is unaccounted for, usually resulting in higher elevations for the bypass and top of embankment. Using WINPOND, the structure routing may be started at an elevation lower than the riser crest (as with a perforated riser and dry pool). This is accomplished by utilizing the **"user-inlet"** option under the **"principal spillway"** tab. Using this option allows the user to enter a user defined stage discharge curve. Using WINPOND in this manner may result in lower routed elevations for the bypass and top of embankment.

STRUCTURE DESIGN

Concrete and riprap lined flumes

Concrete or riprap lined flumes are used in concentrated flow channels where velocities exceed allowable velocities for the soil and/or vegetation. Typical applications include ditch linings, steep slopes at outlets of grassed waterways, the center section of grassed waterways, gully stabilization structures, and similar structures. Concrete and riprap lined flumes should be designed in accordance with criteria contained in Conservation Practice Standard, Lined Waterway or Outlet, Code 468. Flume capacity and velocities should be determined using Manning's Formula and a roughness coefficient from Table AL6-1.

Table AL6-1. Manning's "n" for flume linings.

Lining	**"n" Value**
Concrete	
Trowel finish	0.012 - 0.014
Float finish	0.013 - 0.017
Shot Crete	0.016 - 0.022
Flagstone	0.020 - 0.025
1/ Riprap - (Angular Rock)	$n = 0.047 (D_{50} S)^{0.147}$

1/ Applies on slopes between 2 and 40% with a rock mantel thickness of 2 x D_{50} where:
D_{50} = median rock diameter (in.),
S = lined section slope (ft./ft) $(.02 \leq S \leq .4)$

The Hydraulics Formula program may be used to determine flow characteristics of concrete flumes. Flow capacity, velocity, and stable rock sizes for riprap flumes should be determined using procedures in the publication Design of Rock Chutes, Robinson, K.M., C.E. Rice, and K.C. Kadavy. 1988. Transactions of ASAE, Vol. 41(3):621-626.

The computer program Rock_Chute XP contains the design formulas from Design of Rock Chutes.

Concrete flumes should not be used in situations where ground water seeps to the surface. High ground water can create buoyant forces beneath the flume and may cause soil to pipe from beneath the flume through the contraction/expansion joints.

Energy dissipation is needed at the outlet of flumes. This is especially true where the flume ends at an abrupt change from a steep gradient to a flatter gradient. For small concrete flumes this can often be accomplished by sloping the outlet section (last 20 feet) into the ground at a slope of about 4:1. This will force the development of a scour hole below the elevation of the outlet ditch bottom and will serve as an energy dissipater. Riprap flumes may often be terminated by gradually flattening the gradient until the velocities are less than the allowable velocities for the outlet conditions. Large capacity flumes should be carefully analyzed to avoid problems due to outlet erosion, changes in alignment, and hydraulic jumps.

STRUCTURE DESIGN

Gabion Structures

General

Gabions are compartmented rectangular containers made of galvanized steel wire mesh and filled with stone. Compartments, or cells, are formed by factory-inserted wire netting diaphragms or partitions. These partitions add strength to the container and help retain its shape during the filling operation. They also provide assurance that the rock fill will remain evenly distributed, under high velocities or settlement. Gabion baskets are manufactured of galvanized wire and may be PVC coated. For installations in acid soils, polluted or salt water, or high sediment loads, PVC coated gabions should be used.

Gabions have a number of advantages over other types of construction materials, particularly for installations on unstable foundations. The primary advantage is flexibility. Gabions can tolerate differential settlement without separation of the structure. Practically no hydrostatic head can build up behind gabions due to their high permeability. Another advantage is the ability to withstand high velocities. The confining wire holds the rock in place and allows the use of smaller rock and thinner layers than would be required if the rock were loose.

Gabions are commonly available in the standard sizes listed in Table AL6-2. Structures should be designed to utilize standard gabion dimensions.

Table AL6-2. Standard Sizes and Stone Capacity for Gabion Baskets.

Length (ft.)	Width (ft.)	Height (ft.)	Stone Capacity (cu. yds.)
6	3	3	2.0
9	3	3	3.0
12	3	3	4.0
6	3	1’ 6”	1.0
9	3	1’ 6”	1.5
12	3	1’ 6”	2.0
6	3	1	0.7
9	3	1	1.0
12	3	1	1.3
9	6	0’ 9”	1.5
12	6	0’ 9”	2.0

Assembly and Installation

For easy handling and shipping, gabions are supplied folded into a flat position. They are readily assembled by unfolding and by simply wiring the edges together and the diaphragms to the sides. Adjoining gabions are wired together at their edges. Empty gabions, stacked on filled gabions, are connected with lacing wire to the filled gabions at front and back. After the gabion is filled, the top is folded shut and wired to the ends, sides, and diaphragms. Where practical, several gabions should be wired together and stretched before filling to reveal weak areas of lacing.

Gabions may be filled by almost any type of earth handling equipment such as front-end loader, crane, or modified concrete bucket. Some hand stone adjustment during the filling operation is required to prevent undue voids. Exposed faces should be hand placed using selected stone. This will add to the appearance of the structure and prevent the gabions from bulging.

Gabion Lined Chutes

Due to the confining wire, gabion linings are able to withstand high velocities. The gabion thickness therefore is based on other considerations in addition to stable rock sizes. The lining thickness and allowable velocities within the gabion lining will depend on the underlying soil type and the rock size used.

Flow paths are directed through the rock layer and if velocities are high enough, may cause erosion of the underlying soil. Therefore, easily eroded soils will require thicker linings and lower velocities. Highly plastic clays and gravels can withstand higher velocities thereby requiring thinner gabion linings. It is recommended that a rock size be used that will allow at least two overlapping layers of rock in the gabion. The rock should have enough small stones to fill the voids, however, the percentage smaller than the wire mesh opening should be no more than about 5 to 10 percent.

Table AL6-3 will serve as a general guide for determining the required gabion thickness for maximum velocities and different soil types. It follows the recommendations of the manufacturer based on experience and observation of gabion installations. Designs with velocities exceeding those in Table AL6-3 should be used with caution. Excessive velocities may move the rock within the basket and/or erode the soil from under the basket.

Table AL6-3. Minimum Thickness and Allowable Velocity for Gabion Baskets

Soil Type	Gabion Thickness (in.)	Allowable Velocity (fps)
Erosion Resistant Moderate to highly plastic clay	9	15
	12	15
Easily Eroded [1/] Silt, fine sand, low plastic clay, clayey or silty sand	9	12
	12	15

[1/] Easily eroded soils should always have geotextile or gravel filter layers beneath the gabion basket.

Where high ground water conditions exist or soils are easily eroded a filter layer or geotextile should be used to prevent erosion of the soil through the rock. Sand and gravel filter layers or geotextile will also allow gabion thicknesses to be reduced to the minimum thickness. Where gabion lined waterways are on steep slopes and subject to high velocities, geotextile may not be adequate to prevent movement of the soil beneath the gabion. Where these conditions exist gravel, or geotextile and gravel, along with other design features may be required to prevent soil movement beneath the lining.

Lined waterways should meet the criteria of Conservation Practice Standard, Lined Waterway or Outlet, Code 468, where applicable. Good engineering judgment must be used where specific guides are not given. Consideration should be given to the long-term conditions of the structure and the relation this may have to the capacity, velocity, and stability.

Hydraulic computations are generally the same as for any other rock lined channel. Manning's equation is used to determine the hydraulic capacity of a gabion lined channel. Figure AL6-1 relates Manning "n" to the predominate rock size used in filling the gabions. Computer programs such as NRCS Hydraulics Formula may be used to determine flow capacity and velocity of trapezoidal and parabolic sections.

EXAMPLE 1:

Given: A road ditch in CL soils. The 10-year, 24-hour peak runoff is 60 cfs. Average ditch slope is 5%.

Find: Gabion lined waterway size and gabion thickness.

Solution: From Table AL6-3, the allowable velocity for low plastic clays is 12 fps, with a gabion thickness of 9 inches. Geotextile is required.

Try a parabolic section with depth of 1 foot and a top width of 12 feet.

Since the thickness is 9 in., use a rock size with a median size of 4 in. which will give two layers of rock. From Figure AL6-1, “n” = 0.028.

Using the parabolic section tab in the Hydraulics Formula program, the capacity is 71.56 cfs and the velocity if 8.95 fps.

The actual velocity of 8.95 fps is less than the allowable of 12 fps and the actual capacity of 71.56 cfs is greater than the required 60 cfs, therefore, the trial section is adequate.

EXAMPLE 2:

Given: A gully with a head cut in fine silty sands. The 10-year, 24-hour peak runoff is 100 cfs. Ground water seeps from the gully sides.

Find: Determine the required dimensions for a gabion lined waterway and the gabion thickness.

Solution: Since the soils are easily eroded and ground water keeps areas of the surface saturated, use geotextile underneath the gabion to prevent erosion of soil from underneath the gabion.

Try a gabion thickness of 12 inches. Use a median stone size of 5 in. to provide 2 layers of rock. From Figure AL6-1, “n” = 0.029.

Try a trapezoidal section with a bottom width of 6 feet, 3:1 side slopes and a gradient of 10%. Assume a flow depth of 1.5 feet. The top width is then 15 feet. Using the trapezoidal section tab of the Hydraulics Formula program, the resulting capacity is 258 cfs and the velocity of 16.4 fps.

Since the capacity is much greater than required, try a depth of 1 ft. in the same trapezoidal section.

The top width is 12 ft. for the flow surface in the 6 ft. bottom width channel. The resulting flow capacity is 118.2 cfs with a velocity of 13.14 fps. Therefore, a 1 foot flow depth is adequate. A slightly flatter gradient would decrease the velocity to 12 fps or less and would allow the use of 9 inch thick gabions.

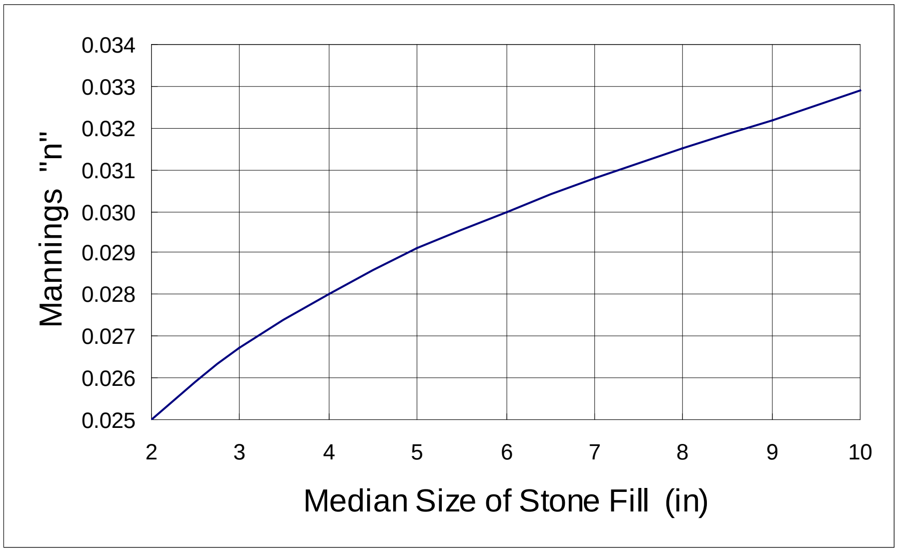


Figure AL6-1. Variation of Manning's "n" with size of stone fill.

Gabion Straight Drop Spillway

Gabion drops used as grade stabilization structures will conform to the requirements of Conservation Practice Standard, Grade Control Structures, Code 410. Criteria relating required capacity to drainage area and drop heights are contained in CPS 410. The drops should also conform to any other standard applicable to the purpose for which the drop is being used.

The two primary concerns in designing drops are the capacity and stability of the structure. A minimum capacity will be dictated by the applicable conservation practice standard. The design storm may be a relatively frequent, low volume flow. Consideration should be given to conditions occurring when less frequent storms occur. Freeboard or bypass areas should be provided where possible to give protection for flows larger than the design flow. Where specific criteria are not provided, good engineering judgment should be used in the design.

Most drop structures may be sized by procedures in the National Engineering Handbook (NEH) Section 11. Table AL6-4 lists dimensions for a range of small drops which have been sized using Section 11. Small drops may be selected from Table AL6-4 provided all the stated conditions are met. Larger drops or those not meeting the stated conditions should be individually designed.

Note that Table AL6-4 is developed for the minimum tail water conditions. In most gully or waterway applications, the bottom of the drop basin will have to be lowered below the downstream grade in order to achieve the minimum tail water depth. Where tail water conditions greater than the minimum occur, a longer basin length (L_B) will be required and design graphs in NEH Section 11 should be used.

Table AL6-4. Sizing small drop structures.					
SELECTED DROP DIMENSIONS *					
H	F	L_B	t_{min}	SW	s
0 - 1.0	1-5	5	1.2	1.8	-
1.0 - 1.5	2-5	8	1.7	2.6	0.50
1.5-2.5	2-5	10	2.9	4.4	0.75
2.5-3.0	3-5	12	3.5	5.2	0.75
3.0-3.5	3-5	15	4.1	6.1	1.00

* All dimensions are in feet.

CONDITIONS FOR WHICH TABLE AL6-4 IS VALID:

(1) $0.1 \leq h/F \leq 1.43$

(2) Tailwater depth, t, equals but does not exceed t_{min}.

(3) Dimensions are defined on Figure AL6-3.

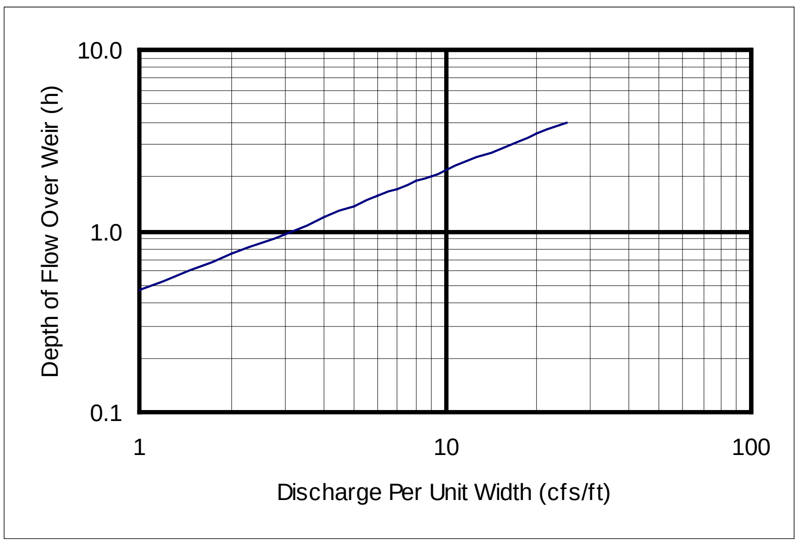
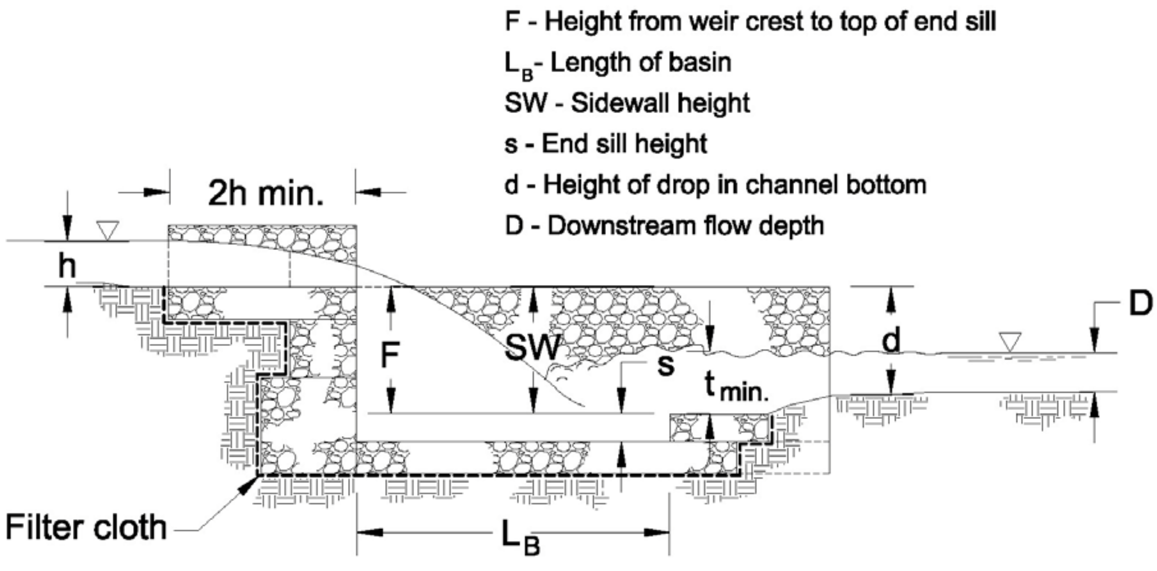
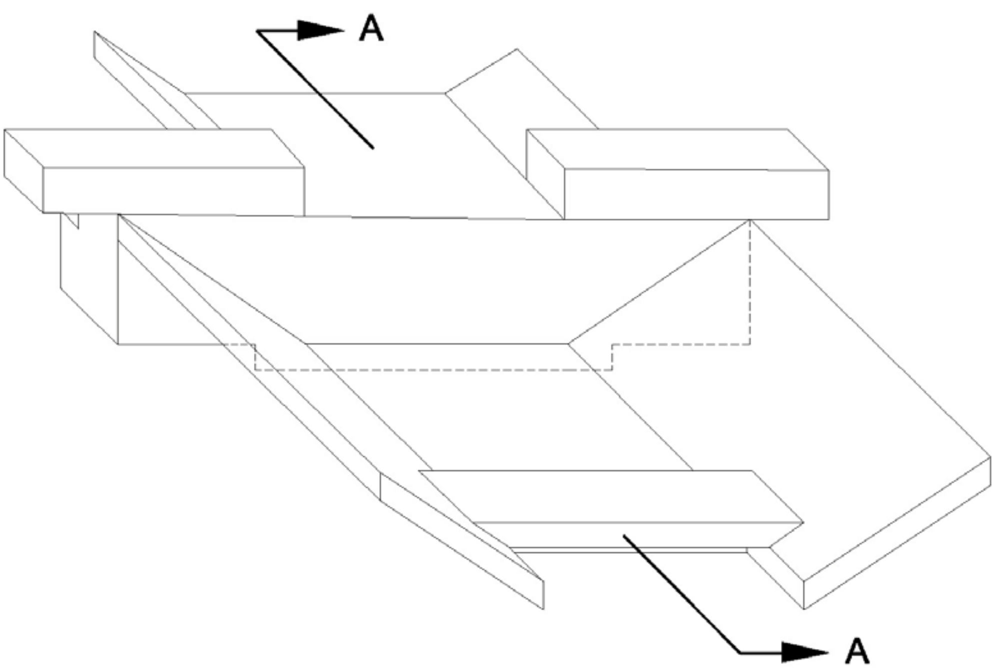


Figure AL6-2. Discharge per unit width for gabion drops.



SECTION A-A



ISOMETRIC VIEW

Figure AL6-3. Drawing of Typical Gabion Drop Structure.

Low drops may be used to reduce the gradient in steep water courses having relatively shallow depths of flow. The spacing between structures and the drop heights should be established to provide a stable grade between structures. The following formula may be used to estimate the required spacing between drops.

$$S = \frac{100d}{g_1 - g_2}$$

Where g1 is the original gradient of the water course in percent without drops, g2 is the planned gradient of the stream between drops in percent, and d is the drop in the channel bottom at the structure in feet. The value of g2 is chosen so that the flow velocity will be low enough to prevent erosion.

Drops must be keyed into the banks to prevent erosion around the sides. The ends of the gabion headwall should extend a minimum of three feet into the banks. Gabion drops should be placed on and backed with geotextile to prevent migration of fines into and through the rock. It is critical that there be no gaps or holes through the geotextile.

Where a significant bed load of sands or gravels is present, the crest of the weir and drop floor should be capped with concrete to protect the wire from abrasion. The concrete should have joints at spacings of about six feet. Where significant settlement is anticipated, the concrete should be applied several months after the gabion is installed and settlement is complete.

EXAMPLE 3:

Given: A 10 ft. deep gully in silty sand. The existing grade is 4%. Drainage area is 40 acres. The 10-year, 24-hour peak runoff is 132 cfs and the 25-year peak is 161 cfs. Allowable velocity is 3 fps.

Find: Height of drop, spacing between drop structures and structure dimensions to create a stable grade.

Solution: <u>First determine the stable grade.</u>
Assuming the gully bottom can be shaped as a waterway and grassed, the design storm for a waterway is the 10-year, 24-hour rainfall (CPS 412).

From Chapter 7 of the National Engineering Field Handbook, select a waterway cross section and gradient to provide a maximum velocity of 3.0 fps.

For V = 3.0 fps, retardance “c” and Q = 132 cfs, the following parabolic waterway designs are available.

Grade (%)	**T (ft.)**	**D (ft.)**
0.25	22.8	2.89
0.50	33.7	1.97
0.75	40.9	1.62
1.00	47.4	1.42
1.50	63.2	1.14

Flatter grades will require a closer structure spacing for a given drop height, and may also require more shaping. The cost of the structures and the shaping should be balanced to provide the most economical system.

For this example, assume the gully size limits us to a width of about 35 feet. Select a waterway width of 33.7 ft., depth of 1.97 ft., and grade of 0.5%.

Determine spacing for 3, 4, and 5 foot drops.

$$S = \frac{100d}{g_1 - g_2}$$

$g_1 = 4\%$ $g_2 = 0.5\%$

d = 3, 4, or 5 feet.

d (ft)	S (ft)
3	86
4	114
5	143

Determine structure dimensions.

First determine the minimum discharge the structure must carry. From CPS 410, Table 410-2, the required capacity is the 10-year, 24-hour peak. Note that had the drainage area exceeded 250 acres the required discharge would have been 25-year, 24-hour peak which is greater than the design peak of the waterway.

The 10-year, 24-hour peak is 132 cfs. Add 15% to the 10-year peak for freeboard or add height over the crest for freeboard.

132 cfs x 1.15 = 152 cfs
152 cfs is the design flow which will provide the minimum freeboard.

Flow depth in the waterway for 152 cfs is approximately 2.1 feet (Estimated from exhibits in Chapter 7)

Use h = 2.1 ft.

Unit discharge, q = 9.5 cfs/ft. (Figure AL6-2)

Weir length = 152 ÷ 9.5 = 16.0 ft.

t_{min} = 2.9 ft. From (Table AL6-4, for h = 1.5 ft. - 2.5 ft.)

Try d = 5.0 ft. for maximum spacing

$F = d + t_{min} - D$ (Assume depth "D", downstream is same as "h" upstream)

F = 5.0 ft. + 2.9 ft. - 2.1 ft. = 5.8 ft.

This exceeds the F value in Table AL6-4, For h = 1.5 ft. - 2.5 ft.

Try d = 4.0 ft.

F = 4.0 ft. + 2.9 ft. - 2.1 ft. = 4.8 ft. ok

Select structure dimensions from Table AL6-4

F = 4.8 ft. L_B = 10 ft. tmin = 2.9 ft.,
S = 0.75 ft. SW = 4.4 ft.