Drainage	Chapter INLETS & STORM SEWERS Subject General

DR 701-1 STORM SEWER DEFINITION

KYTC defines a storm sewer as two or more inlets, manholes or junction boxes connected by a series of pipes.

DR 701-2 FUNCTION & DESIGN PROCESS

The function of a storm sewer system is to collect storm runoff, convey the water to an outlet point and discharge the flow in an environmentally acceptable manner. The design is, at a minimum, a four step process with some iteration until a final design is achieved.

1. Determine the location of inlets into the storm sewer. This involves spacing the inlets at locations that will limit the spread and provide access for maintaining the system. Based on roadway geometrics and traffic safety requirements, more inlets may be needed. Determine where existing systems or inlets will tie into the proposed and where the system outfall points will be.
2. Calculate the inflow into the system. This involves determining the peak runoffs of drainage areas draining toward the inlets and checking if the spread and interception capacity are acceptable. If not, additional inlets may be required or inlet locations may have to be adjusted to meet drainage requirements.
3. Determine the size of the storm sewer pipe required to convey the runoff for the design event and whether the system design criteria are met.
4. Evaluate the impacts of the discharge at the outfall on adjacent property owners and downstream receiving waters. Determine if energy dissipation or channel lining is required to protect the outlet from excessive erosion. Determine if the design meets the Post Construction BMP requirements from local agencies, such as MS4s, or the Division of Water.

DR 701-3 JUNCTIONS

The designer shall provide inlets, junction boxes, or manholes at every break in horizontal or vertical alignment. This arrangement allows access to the ends of all sections of pipe in the system to clear potential obstructions. Refer to DR 703 "Manholes and Junctions" for additional information.

DR 701-4 POST CONSTRUCTION BMP'S

For information on post construction BMP's refer to DR 202.

DR 701-5 SANITARY SEWERS

A sanitary sewer system carries domestic, industrial, and/or commercial wastewater. Projects affecting sanitary sewers will usually relocate existing sewers and not require the hydraulic design of a system. Relocation or adjustment of sanitary sewers is normally handled as a utility item.

Allowable material requirements are different for storm sewers due to the physical and chemical differences between wastewater and stormwater runoff. Sanitary or combined sewer pipe materials should be governed by local guidelines. Division of Water criteria may also apply to the design of these facilities.

DR 701-6 COMBINED SEWERS

A combined sewer system transports both storm runoff and wastewater. It is illegal to construct new combined storm sewer systems. Tying into these types of systems should be avoided due to the extra load on waste treatment facilities. The potential also exists for peak storm runoff flows allowing wastewater to bypass the treatment facilities during peak storm events (storm water overflows) and contaminating downstream receiving waters. Designers may have to deal with a combined system on projects where there are existing combined systems and the project requires extending onto or off the existing drainage storm system.

The capacities of these systems are usually determined by the storm runoff and the waste water normally determines pipe material requirements. It has been the policy of the cabinet to require the last storm sewer inlet prior to connection into a combined sewer system be constructed with a trap to contain gases and odors from the sanitary sewer system. Standard drawing RDX-020-04 "Trap for Box Inlets" of the current edition of 2008 is the detail for this trapped inlet. There may also be local and/or Division of Water guidelines pertaining to combined sewer systems.

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Drainage	Chapter INLETS & STORM SEWERS
	Subject Inlets

DR 702-1 INLET CLASSIFICATION

KYTC drainage inlets are classified as curb inlets, drop inlets, and special purpose inlets. Curb inlets are further classified as curb opening, grated, or combination inlets. Drop inlets are primarily used in ditches, depressed medians, and as yard drains. Special purpose inlets are those such as bridge deck drains (scuppers), spring boxes, slotted drains and outlet structures for detention or retention ponds.

DR 702-2 STANDARD INLETS

Drainage inlets are designed for a multitude of situations as indicated in the Standard Drawings. The Standard Drawings provide flexibility by allowing minor modifications to the inlet based on the situation. Most curb inlets can be used with any curb shape and pipe chambers are designed to fit a variety of combinations of pipe sizes. Slopes of drop inlets may be flattened and aprons may be eliminated or added.

In all instances where structural limits for a proposed installation exceed the Standard Drawings, the designer shall provide a separate detail sheet for the plans depicting the modifications and sufficiently detailing the non-standard structure so that the contractor can bid the item. The modifications in structural aspects of the inlet shall be reviewed and approved by the Division of Structural Design prior to use on the project.

The following considerations should be noted in regards to KYTC inlets, manholes, and junction boxes shown in the Standard Drawings:

- KYTC inlets depicted in the standard drawings are designed to have a maximum depth of 15 feet. KYTC junction boxes, drop boxes and manholes have limitations of eight (8) to nine (9) feet in the Standard Drawings. A Type B Manhole has structural design and out to 60 feet of fill height in the Standard Drawings.

- All KYTC inlets, junctions, and manholes (except for Drop Box Inlet Type 12) are bid per each individual structure regardless of chamber size or riser height. Type 12 inlets are bid by linear feet.

- Inlet pipe chambers should be designed such that the outside limits of a proposed pipe will fit entirely inside the chamber. See DR 705-6 “Outside Pipe Dimensions and Pipe Chambers” for further discussion.

- KYTC inlets, manholes, and junction boxes are constructed according to Section 710 of “Standard Specifications for Road and Bridge Construction.”

DR 702-3 GENERAL PLACEMENT GUIDELINES

The following general rules apply to inlet placement:

- An inlet is required at the uppermost point in a gutter section where gutter capacity criteria is violated. This point is established by moving the inlet (and thus changing the drainage area) until the tributary flow does not violate spread or depth criteria. Successive inlets are spaced by locating the point where the sum of the bypassing flow and the flow from the additional contributing area is less than or equal to the gutter capacity as calculated by spread or depth criteria.

- To prevent pedestrian or vehicular hazards, inlets are normally used at intersections to prevent flow from crossing intersecting streets. It is desirable to intercept 100 percent of the flow along a street before it is released into an intersecting street or an intersection. Inlets in intersections should be placed on straight curb sections near the point where the curb line starts its radius to meet the curb from the adjacent street, unless there is a sag point in the radius.

- Inlets are required in areas just upstream of where the street cross slope changes and causes the water to flow across to the pavement and not in the gutterline. The purpose of these inlets is to reduce the traffic hazard from street cross flow. Sheet flow across the pavement at these locations is particularly susceptible to icing.

- Inlets should be located at any point where side drainage enters streets and may overload gutter capacity. Where possible, these side drainage inlets should be located to intercept side drainage before it enters the street.

- Inlets shall be placed at all sag points in gutters, medians, and channels.

- Flanking inlets should be placed at major sag points where significant ponding may occur, and no other outlet exists except through the system.

- Inlets are used upstream of bridges to prevent pavement drainage from flowing onto the bridge decks and downstream of bridges to intercept drainage from the bridge.

- As a matter of general practice, inlets should not be located within driveway areas.

- Inlet structures can serve as access holes in storm sewer systems and should be used in lieu of manholes or junction boxes where the benefit of extra stormwater interception is achieved at minimal additional cost.

- Inlets should be placed immediately upstream of median breaks, and entrance/exit gore ramps.
- Inlets should be placed immediately upstream of crosswalks.
- Avoid adding curb inlets in intersection radiuses where high truck traffic can be expected, due to how easily they can be damaged. The larger curb lengths can be problematic to construct in the radius. Curb Box Type F inlets are especially vulnerable to damage from trucks.
- A goal in highway Drainage design should be to emulate natural drainage and existing drainage patterns, insofar as practical.

DR 702-4 COMPOSITE GUTTER SECTIONS

In most instances the standard design is to match the gutter cross slope and the pavement cross slope. Although this design is usually sufficient, composite gutters may be used to increase the capacity of gutters and inlets. Composite gutters are created by sloping the gutter line at a steeper grade than the adjoining pavement (i.e., 2% pavement cross slope with 4% gutter cross slope) Using a composite gutter section concentrates more flow in the gutter line thereby reducing the spread of water on the pavement and increasing the capacity of the inlets. The use of composite gutters with greater than 2% algebraic difference between gutter cross slopes and road cross slopes should be discouraged due to break over grade limits and problems that will develop with pavement overlays.

DR 702-5 CURB BOX INLETS

Curb inlets are usually located in the curb line or incorporated into the design of a raised median and may be one of several configurations. Most of these inlets consist of two or three units for construction purposes which include a bottom phase, a riser section (when needed), and a top phase. The bottom phase is also known as the pipe chamber.

Curb opening inlets have a depressed slot (referred to as a curb opening or throat) constructed through the curb for water to pass into an inlet pipe chamber. Access to the pipe chamber is through a manhole lid on top of the inlet located behind the curb line.

Combination inlets may consist of a curb opening with a grate in the gutter or a slotted drain pipe with a grate in the gutter. The grate is removable to provide access to the pipe chamber. The following sections describe each inlet type.

CURB BOX INLET TYPE A

Curb Box Inlet, Type A is designed with a top phase (which includes a manhole access) and a bottom phase. The top phase shall match adjoining curbs. The bottom phase consists of a riser and a pipe chamber that accommodates a maximum circular pipe size of 48 inches.

The inlet shown on the plans is a minimum size based upon the size of the pipes connected to the chamber. The designer has the option of increasing the bottom phase inlet size for purposes of standardization, simplicity of design, to accept multiple pipes, or due to adverse angles of pipes entering the pipe chamber.

This inlet has a two-inch minimum drawdown and throat lengths of five, ten, fifteen, and twenty feet. A ten-foot throat length is recommended for most situations, while the other lengths are recommended for cases where site conditions restrict the throat length or longer throats are required for 100% interception.

This inlet is noted on the plans, pipe sheets, and drainage summary as “Curb Box Inlet Type A,” followed by two numbers and a box height. The first number is the bottom phase size and the second number is the top phase size. Refer to Standard Drawing 410 “Box Inlet Pipe Chamber” and to the “Bottom Phase Numbers for Curb Box Inlet A” chart below for selection of the first number. Refer to Standard Drawing RDB-272 “Curb Box Inlet Type A (Top Phase Tables)” for selection of the second number.

An example of a construction note for a Curb Box Inlet, Type A is “CONSTRUCT CBI A-16,2(H=6.31’).” The “2” denotes that the CBI is on grade and has a throat length of ten feet. The “16” denotes the bottom phase vault dimensions. The depth to the pipe invert is 6.31 feet below the 2” drawdown.

Refer to Standard Drawing RDB-270 “Curb Box Inlet Type A (Detail drawing)” for details on Box Inlet Type A.

Table 702-1
Bottom Phase Numbers for Curb Box Inlet A
Pipe Located on "X" Side of Inlet (Parallel to Centerline)

	Dia.	0	12"	15"	18"	21"	24"	27"	30"	33"	36"	42"	48"
Pipe Located On “Y” Side of Inlet	**0**	-	2	4	6	10	15	19	25	32	40	50	62
	12"	2	2	4	6	10	15	19	25	32	40	50	62
	15"	4	4	4	6	10	15	19	25	32	40	50	62
	18"	6	6	6	6	10	15	19	25	32	40	50	62
	21"	11	11	11	11	11	16	20	26	33	41	51	63
	24"	16	16	16	16	16	16	20	26	33	41	51	63
	27"	21	21	21	21	21	21	21	27	34	42	52	64
	30"	24	24	24	24	24	24	24	28	35	43	53	65
	33"	31	31	31	31	31	31	31	35	35	43	53	65
	36"	38	38	38	38	38	38	38	39	39	44	54	66
	42"	47	47	47	47	47	47	47	48	48	49	55	67
	48"	58	58	58	58	58	58	58	59	59	60	61	68

CURB BOX INLET TYPE B

Curb Box Inlet, Type B is a combination inlet that has a very narrow top phase width. The main difference between this inlet and the Type A inlet is that this inlet does not have the manhole access. The Curb Box Inlet, Type B also has its pipe chamber shifted towards the centerline. This inlet is used for bridge end drainage and in urban areas where a narrow inlet is needed because of existing utilities and limited right of way behind the inlet. Another location where this inlet may be useful is in storage lanes of narrow raised medians.

This inlet is noted on the plans, pipe sheets and drainage summary as a Curb Box Inlet, Type B, followed by two numbers and a box height. The first number is the bottom phase size and the second number is the top phase size.

Refer to Standard Drawing RDB-410 “Box Inlet Pipe Chamber” and to the following chart for the first number. Refer to Standard Drawing RDB-282 “Curb Box Inlet Type B (Top Phase Tables)” for the second number.

Inlet sizes shown on the plans are the minimums for pipe size selection. As with Curb Box Inlet, Type A, the designer has the option of increasing the bottom phase inlet size for purposes of standardization, simplicity of design, to accept multiple pipes, or due to adverse angles of pipes entering the pipe chamber.

Refer to Standard Drawing RDB-280 “Curb Box Inlet Type B (Detail Drawing)” for details on Box Inlet Type B.

Table 702-2
Bottom Phase Numbers for Curb Box Inlet B
Pipe Located on "X" Side of Inlet (Parallel to Centerline)

	Dia.	0	12"	15"	18"	21"	24"	27"	30"	33"	36"	42"	48"
Pipe Located On “Y” Side of Inlet	0	-	1	3	5	8	13	19	25	32	40	50	62
	12"	1	1	3	5	8	13	19	25	32	40	50	62
	15"	3	3	3	5	8	13	19	25	32	40	50	62
	18"	5	5	5	5	8	13	19	25	32	40	50	62
	21"	7	7	7	7	9	14	20	26	33	41	51	63
	24"	12	12	12	12	14	14	20	26	33	41	51	63
	27"	17	17	17	17	18	18	21	27	34	42	52	64
	30"	22	22	22	22	23	23	24	28	35	43	53	65
	33"	29	29	29	29	30	30	31	35	35	43	53	65
	36"	36	36	36	36	37	37	38	39	39	44	54	66
	42"	45	45	45	45	46	46	47	48	48	49	55	67
	48"	56	56	56	56	57	57	58	59	59	60	61	68

CURB BOX INLET TYPE F
This curb box inlet is used primarily for situations where very little capacity is needed or lack of space prevents use of larger inlets. A typical application would be in the parking zone of a rest area or at a side street approach where little runoff or truck traffic is expected. Note: This inlet is designed for use with a standard curb shape.

Refer to Standard Drawing RDB-320 “Standard Curb Box Inlet, Type F.”

MEDIAN BARRIER BOX INLET

This inlet provides a collection point for surface runoff where a median barrier is constructed. The pipe chamber is accessed through the grate. The inlet may be constructed where it will intercept flow from either side or both sides of the median barrier. Note in the case of a double sided barrier inlet, this will require checking for acceptable spread on both sides of the inlet. The inlet is noted on the plans, pipe sheets and drainage summary as Median Barrier Box Inlet, followed by a number (n1), a letter (a1), an optional letter (a2), and a number (n2). These designations are defined as follows:

- **n1**—top width of wall (9”, 12”, or 14”)
- **a1**—“A” for sag condition; “B” for grade condition
- **a2**—“1” if opening is on only one side; “2” if opening is on both sides of wall
- **n2**—“b” if bottom phase only; “t” if top phase only; blank for complete inlet

A typical construction note may read “Construct CMBBI Type 12A2.”

Refer to Standard Drawings RDB-230, RDB-231, RDB-240, and RDB-241 for CMBBI details.

DR 702-6 DROP BOX INLETS

GENERAL

These inlets consist of an opening in the top of a pipe chamber covered by one or more grates. Several grate designs are used, based on the purpose of the inlet. Grated inlets do not have a slot or throat through the curb. They have a pipe chamber, with or without a riser section, and use a variety of grate configurations to cover the access to the pipe chamber. These inlets may be located in gutterlines, channels, medians, parking lots and other areas where curbs are present. The back portion of the inlet is usually formed to match an adjacent curb.

The interception capacity and efficiency of a grate inlet depends on the amount of water flowing over the grate, the size and configuration of the grate and the velocity of flow in the ditch, median, or gutter. Exhibit DR-700-1 “Physical Attributes of KYTC Grated Inlets” contains a detailed listing of physical properties of KYTC grates.

Drop box inlets are placed in ditch lines to ensure that ditch flow capacity is not exceeded. They also are used at required points of interception, such as in a sag or other ponding locations. Drop box inlets are used in lieu of headwalls where traffic safety is a consideration. Ditch inlets are recommended whenever a clear zone is provided.

Note: Grates for Drop Box Inlet Types 1 & 3, 2 & 4, and 5 & 6 are interchangeable. Replacement of the grate should be considered when an existing facility is proposed to be reconstructed and the safety design parameters have changed.

DROP BOX INLET TYPE 1
This inlet accommodates pipe diameters of 15, 18, and 24 inches. It is to be used on rural projects where traversal by a pedestrian or bicyclist is not anticipated. Refer to Standard Drawing RDB-001 “Drop Box Inlet Type 1.”

DROP BOX INLET TYPE 2
This inlet accommodates pipe diameters of 30 and 36 inches. It is to be used on the same type projects recommended for a Drop Box Inlet, Type 1. Refer to Standard Drawing RDB-002 “Drop Box Inlet Type 2.”

DROP BOX INLET TYPE 3
This inlet accommodates pipe diameters of 15, 18, and 24 inches and is similar to a Drop Box Inlet, Type 1 except for the grate which is bicycle and pedestrian safe. It is to be used on projects where traversal by a pedestrian or bicyclist is anticipated. Generally, this type of inlet should be employed in urban locations and in rural areas where a bike or pedestrian safe inlet is needed. Refer to Standard Drawing RDB-003 “Drop Box Inlet Type 3.”

DROP BOX INLET TYPE 4
This inlet accommodates pipe diameters of 30 and 36 inches and is designed similar to a Drop Box Inlet, Type 2 except the grate of the inlet is bicycle and pedestrian safe. It is to be used on the same type of projects recommended for a Drop Box Inlet, Type 3. Refer to Standard Drawing RDB-004 “Drop Box Inlet Type 4.”

DROP BOX INLET TYPE 5
This inlet accommodates pipe diameters of 15, 18, 24, and 30 inches and is to be used in a depressed median on projects where pedestrian or bicycle traffic is not anticipated. The inlet grate is considered a non-safety grate. The inlet type designation varies with median cross slope as shown in the following table:

Table 702-3
Drop Box Inlet Type 5 Description

TYPE	MEDIAN CROSS SLOPE
5A	12H:1V
5B	6H:1V
5C	5H:1V
5D	4H:1V
5E	3H:1V
5F	As specified by Engineer

Refer to Standard Drawing RDB-005 “Drop Box Inlet, Type 5A, 5B, 5C, 5D, 5E, and 5F.”

DROP BOX INLET TYPE 6
This inlet accommodates pipe diameters of 15, 18, 24, and 30 inches and is to be used in the depressed median on projects where pedestrian or bicycle traffic is anticipated. The inlet grate is designated as a safety grate. The inlet type designation varies with the median cross slope as shown in the Table 702-3

"Drop Box Inlet Type 5 Description." Refer to Standard Drawing RDB-006 "Drop Box Inlet, Type 6A, 6B, 6C, 6D, 6E, and 6F."

DROP BOX INLET TYPE 7
This inlet is intended for large pipe sizes. It accommodates pipe diameters of 42, 48, 54, and 60 inches. Refer to Standard Drawing RDB-007 "Drop Box Inlet, Type 7."

DROP BOX INLET TYPE 10
This inlet is primarily designed for use as a valley gutter with a paved ditch. It is designed to accommodate a pipe diameter of 15 or 18 inches. Refer to Standard Drawing RDB-010 "Drop Box Inlet, Type 10."

DROP BOX INLET TYPE 11
This inlet is primarily designed for use at interior locations of parking lots. It is designed to accommodate a maximum pipe diameter of 24 inches. Refer to Standard Drawing RDB-011 "Drop Box Inlet, Type 11."

DROP BOX INLET TYPE 12
This inlet is primarily designed to intercept sheet flow from driveways and approaches. The length of the inlet will normally be the width of any driveway or approach; a minimum length of six feet is required. It is recommended that this inlet be sized in increments of two feet where the grates will bolted to the frame and six feet where the grates will be unbolted.

The assumption is made that the inlet will intercept 100% of the small amount of water that flows across it. The normal minimum depth is eight inches with a minimum slope of 4% that will provide 5.8 cubic feet per second capacity. If additional capacity is needed, the box depth can be increased. Refer to Standard Drawing RDB-012 "Drop Box Inlet, Type 12 or 12A." Type 12A denotes that the grate is bolted to the frame.

DROP BOX INLET TYPE 13
This type of inlet is primarily designed for use with raised medians and is constructed in two phases. The curb portion shall be constructed to match the adjoining curb. This drop box inlet is used along the outside gutter of urban streets where the local depression or compound section used in a Curb Box Inlet Type A is not desirable. It is also useful in curb returns where the Curb Box Inlets are not desirable.

This inlet is not very useful in large open areas such as parking lots due to the configuration of the vane grate. This grate, however, is highly efficient in curbed locations. Refer to Standard Drawing RDB-013 "Drop Box Inlet Type 13."

DROP BOX INLET TYPE 14 & 15
These two inlets are primarily used as yard drains. Type 14 has a radial grate and is to be used in areas where yard maintenance is anticipated. Type 15 has a beehive grate and is to be used in nonresidential areas where low or no yard maintenance is anticipated and where clogging might occur. Refer to Standard Drawing RDB-020 for "Drop Box Inlet, Type 14 and 15."

DROP BOX INLET TYPE 16
This is a combination inlet that uses a vane grate and a slotted drain pipe in the gutter. It is a modification of Drop Box Inlet Type 13. It has the same high-efficient grate as Type 13, but its interception efficiency is enhanced by the addition of various lengths of slotted drain. Refer to Standard Drawing RDB-030 for "Drop Box Inlet, Type 16."

DR 702-7 BRIDGE DECK INLETS

These inlets are located on bridges to intercept runoff captured by the bridge deck. Several designs include small rectangular grated scuppers, round pipes through the deck, and slots through the bridge rails.

See SD-501-7 of the Structural Design Manual and Standard Drawing BGX-015 "Bridge Drains" for typical KYTC bridge deck drains.

Bridge deck drainage is essential to traffic safety and bridge maintenance. Standing water will ice over on bridge decks faster than on roadways, creating a hazard to traffic. This hazard and the corrosive action of deicing agents on the bridge structure are the two most important reasons for quick and efficient removal of water from bridge decks.

Bridge decks are most effectively drained where the gradient is sufficient to convey water off the deck. Depending on the gradient, cross slope, and design spread, the number of inlets can be decreased on the bridge deck if roadway drainage is intercepted upgrade of the bridge.

The principles of inlet interception on bridge decks are the same as for roadway inlets. However, requirements for deck drainage systems differ in the following respects from roadway drainage systems:

- Total or near total interception is desirable upstream of expansion joints in order to prevent unnecessary flow from entering into these joints, resulting in deterioration of the structure.

- Bridge deck underdrain systems used to pipe water under a bridge are highly susceptible to clogging.

- Bent spacing often determine inlet spacing.

- Inlet sizes are often constrained by structural considerations.

As a general rule of thumb, bridge decks with an area of over 2,000 square feet require deck drains. Grated scuppers are spaced using grated curb inlet spacing equations. Slots through bridge rails are spaced using curb opening inlet spacing equations.

If the allowable spread of water on the bridge deck is not exceeded, the designer may elect to use bridge end drainage inlets only. Bridge end drainage inlets also may be used in conjunction with bridge deck drains if structural constraints prohibit placing an adequate number of drains on the bridge. Refer to the Standard Drawings in the RBB and RBC Series for bridge end drainage details.

DR 702-8 SLOTTED DRAIN PIPES

Slotted drain pipe is usually located in areas associated with curbs. It consists of a circular corrugated metal culvert with a riser welded along the top of the pipe that extends up to a grate that intercepts sheet flow and/or reduces ponding of surface runoff. The riser assembly is tall enough to allow the pipe to be located at or near the subgrade level.

Slotted drain pipes are an alternative form of pavement drainage when clogging is not an issue and they have a variety of applications. They can be used on curbed or uncurbed sections and offer little interference to traffic. They can also be used to add capacity to existing systems to deal with increased runoff due to widening.

Slotted drain pipe installations do not require the use of drop boxes. There are instances where site conditions, increased costs caused by inlet construction, and/or best engineering practices may dictate the use of slotted pipe alone. Likewise, a drop box inlet with a section of slotted pipe can be used as a combination inlet.

Slotted drain pipes are sized and spaced in the same manner as curb opening inlets, functioning as if they are weirs with flow entering from the side. One linear foot of slotted drain pipe is assumed hydraulically equivalent to one linear foot of curb opening. The interception capacity is dependent upon the flow depth, inlet length, and total flow. Refer to Standard Drawing RDB-030 “Drop Box Inlet Type 16”.

DR 702-9 SPECIAL PURPOSE INLETS

TRAPPED INLETS

A trap for an inlet functions similar to P traps used in residential drainage systems. These traps shall be constructed on the last storm inlet before connecting to a sanitary or combined sewer system. Refer to Standard Drawing RDX-020 “Trap for Box Inlets.” Refer to Standard Drawing RDM-050 for an illustration of a Trapped Manhole.

SPRING BOX INLET TYPE A

This inlet is to be used to protect springs that would be covered by a highway fill of ten feet or more. The inlets are also intended to be used when constructing on top of a sinkhole. Refer to Standard Drawing RDX-010 “Spring Box Inlet, Type A.”

SPRING BOX INLET TYPE B

This inlet is to be used to protect springs that would be covered by a highway fill of less than ten feet. The inlets are also intended to be used when constructing on top of a sinkhole. Refer to Standard Drawing RDX-011 “Spring Box Inlet, Type B.”

DR 702-10 MSE / Retaining Walls/ Barrier Wall & Drainage Inlets

Inlets placed against Mechanically Stabilized Earth walls (MSE) or other retaining walls can present structural and/or drainage issues. When roadways are elevated on these walls, there is most often a barrier wall setting top of the retaining or MSE wall as well. Figure 702-1 shows an inlet next to an MSE/barrier wall combination.

When it is necessary to place drainage inlets and pipes in close proximity to a retaining or MSE wall, the following issues should be considered.

- The location of pipe chambers for the inlets may be limited by the MSE, retaining or barrier wall.

- Barrier walls on top of an MSE or other retaining wall may require moment slabs to act as a counterweight for the barrier wall. This will generally apply when the pavement is bituminous. For concrete pavement the barrier wall can be directly tied to the pavement. Inlet chambers will likely require "block outs" of this moment slab when placed next to the barrier. This may limit spacing of the inlet structures to prevent excessive block out of the moment slab. However, since these walls are specially designed, different restrictions may apply depending on the site conditions.

- The inlet depicted in Figure 702-1 is not a standard KYTC inlet. All KYTC grated inlets have a solid back wall which causes the grate to span from inside wall to inside wall of the pipe chamber. This prevents the grate from accepting water that is flowing against the gutter line. One solution to this problem is to extended the grate to the gutter line and provide a notch out in the back wall as shown in Figure 702-1. Another solution (not shown) is to shift the pipe chamber to the outside so that the inside wall of the pipe chamber is directly under the gutter line. Both of these solutions will require a special designed inlet.

- If practical, avoid placing drainage boxes that interfere with the reinforcing or anchoring elements of MSE or anchored retaining walls. If it is necessary to place drainage boxes in the reinforcing or anchoring zone, limit the depth and width of the boxes to minimize the disruptions.

The following issues apply specifically to MSE wall:

- MSE walls are structurally dependent on reinforcing elements that run through the soil layers. These reinforcing elements are connected to the inside face of the wall. Inlets against MSE walls are an obstruction in the soil reinforcement layers. Any drainage structures placed next to MSE walls must be coordinated with the Geotechnical and/or Structural Engineers.

- In order to minimize obstructions to the reinforcing elements, runs of pipe parallel to MSE walls should be limited when the pipe is close to the wall.

Avoid this situation if possible and practical, particularly where pipe sizes are greater than 18 inches. If running the pipe parallel and close to the MSE wall is necessary, avoid slopes greater than 2% to prevent the pipe from interfering with multiple layers of reinforcement.

- One option to avoid interface with the reinforcing elements is to shift parallel runs of pipe away from the wall. If a parallel pipe intercepts a reinforcing layer, the reinforcement will have to deflect around the pipe at a small enough angles not to generate moment in the reinforcement or the connection at the wall (See Figure 702-2). In order to avoid this issue it is recommend that the reinforcing straps have deflections smaller than fifteen degrees. It is also recommended to maintain a 3 inch clearance form the outside edge of the pipe and the reinforcing strap. Table 702-4 gives recommended clear distances from the inside MSE panels to the pipe wall for runs of pipe parallel to MSE walls.

Table 702-4
Recommended Clear Distance of Pipe from Panels in MSE walls Based on RCP Dimensions

PIPE	Clear Distance	Outer Diameter
12”	2’ 8”	1’ 4”
15”	3’ 3”	1’ 7.5”
18”	3’ 9”	1’ 11”
21”	4’ 3”	2’ 2.5”
24”	4’ 6”	2’ 6”

- Pipes that outlet through an MSE Wall are less problematic as long as the skew to the wall is less than 20 degrees. Smaller pipe sizes can be grouted into place through the wall panel. A cast in place headwall may be required with large pipe sizes. Some MSE manufacturers have special headwalls that apply to these situations.

Refer to SD “Structural Design Manual” Exhibit 517 for a MSE wall schematic diagram. Exhibit 601 “Railing System Type III Slab Details” displays the “typical” barrier used on top of these MSE walls.

Contact the Drainage Branch for details on specially designed inlets that alleviate some of the above problems.

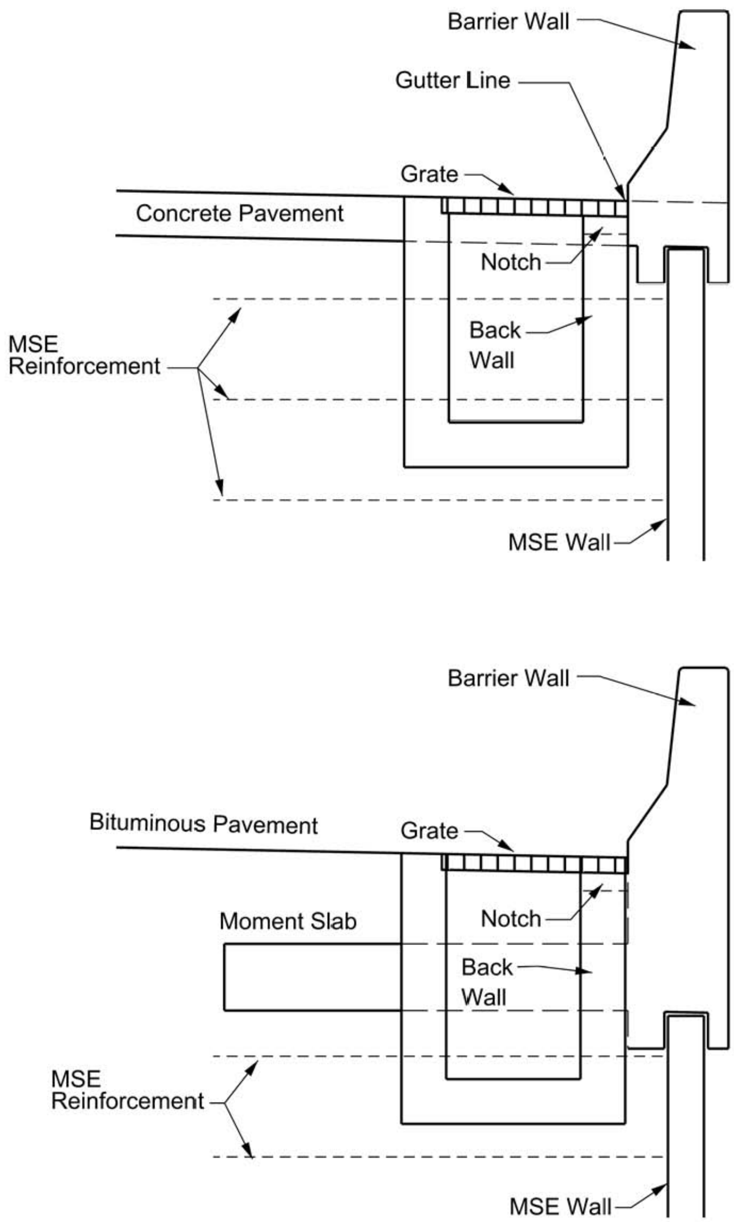

FIGURE 702-1 TYPICAL SECTION WITH INLET INSIDE MSE WALL

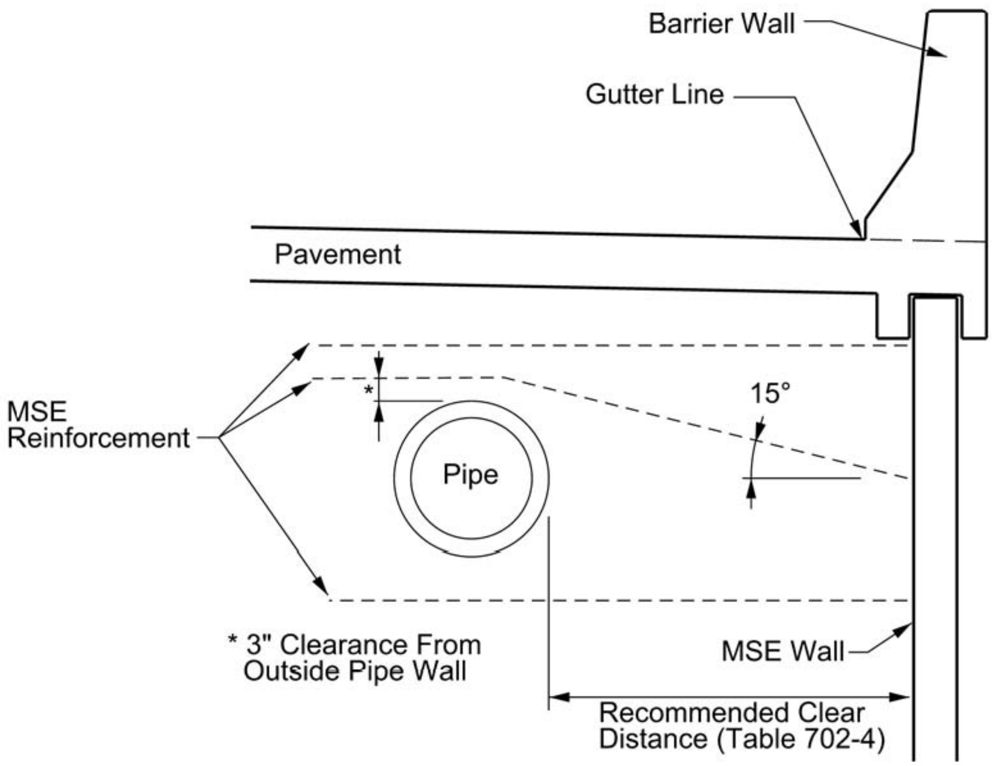

FIGURE 702-2
MSE REINFORCING STRAPS

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Drainage	Chapter INLETS & STORM SEWERS Subject Manholes & Junctions

DR 703-1 GENERAL

Manholes or junction boxes shall be provided at breaks in horizontal or vertical alignment where it is not feasible to construct an inlet. Another primary consideration in locating these structures is to provide access to the storm sewer for maintenance purposes. Refer to the access point spacing criteria set forth in DR-707 for the allowable maximum spacing of access points. It should be noted that some KYTC inlets provide manhole access as well.

Manholes and junction box construction shall comply with Section 710 of the "Standard Specifications for Road and Bridge Construction."

DR 703-2 MANHOLES

KYTC uses three different manhole types. Details for these manholes can be found in the Standard Drawings.

MANHOLE TYPE A

The designer shall use this manhole type (depicted on Standard Drawing RDM-001) when the manhole meets the following requirements:

- The manhole will not be more than nine feet tall
- No incoming or outgoing pipe will exceed 27 inches in diameter.

MANHOLE TYPE B

The designer uses this manhole (depicted on Standard Drawing RDM-005) when a deep structure is necessary. It shall be of a minimum height of 9'-1", and no taller than 60 feet. The maximum pipe size will be 27 inches in diameter.

MANHOLE TYPE C

The designer primarily uses this manhole (depicted on Standard Drawings RDM-010, RDM-011, RDM-012, and RDM-013) to accommodate pipes larger than 27 inches. The pipe chamber for this manhole will accommodate circular and elliptical pipe from 30 to 72 inches in diameter. Class A or Class B towers are required and must be specified on the Pipe Drainage Summary and the plans.

DR 703-3 CONCRETE CONES FOR MANHOLES

As depicted in the Standard Drawings RDM-005, RDM-010, and RDM-011, the concrete pipe cones constructed on the top of the pipe chambers for KYTC manholes can be constructed in an eccentric or concentric shape. This allows for shifting of the location of the top of the manhole.

DR 703-4 JUNCTION BOXES

GENERAL

Junction boxes can be used in lieu of manholes at pipe junctions. Junction boxes are more limited by the allowable depth of the structure when compared to manholes.

Junction boxes are bid by the unit and by the largest pipe dimension in the box.

JUNCTION BOX (STANDARD)

The standard KYTC junction box is depicted in Standard Drawing RDX-001. This junction box can be used in locations where it may be accessed by large pipe or short runs of smaller diameter pipe. This junction box is limited to a height of eight feet and will accommodate pipes from 12 to 72 inches in diameter. Since there is not access provided to the pipe chamber, this junction box should be used with caution. The Standard Junction Boxes are not recommended on mild slopes or in low velocity flow situations since debris would have a tendency to collect and there is no access for cleaning and maintenance.

JUNCTION BOX TYPE B

This junction box is depicted in Standard Drawing RDX-005. Junction Box Type B is similar to the Standard Junction Box except that it has an access lid. This junction box is limited to a height of eight feet and will accommodate pipes from 12 to 24 inches in diameter.

DR 703-5 FRAMES & LIDS

KYTC uses two different frame and lid types to provide access to certain inlets, manholes, and junction boxes. Frame & Lid Type 1 is a reversible, lightweight frame and lid for use in Curb Box Inlet Type A and for nontraffic manhole applications. Frame & Lid Type 2 is to be used in vehicular trafficked areas. The type of lid shall be indicated in the remarks column on the Pipe Drainage Summary.

Refer to Standard Drawing RDM-100 for Frame and Lid Type 1.
Refer to Standard Drawing RDM-105 for Frame and Lid Type 2.

DR 703-6 PIPE ANCHORS

GENERAL

Pipe anchors are constructed by pouring a solid concrete structure around the joint of two connecting pipes or at the end of a pipe run. Standard Drawing RDX-060 details pipe anchors for circular pipe and Standard Drawing RDX-065 details pipe anchors for noncircular pipe.

INTERMEDIATE ANCHORS

Intermediate anchors can be used to extend existing pipe or to butt adjoining pipes with small grade changes. They are limited to situations where the difference in grade between the two pipes is 0.002 feet per foot or less.

END ANCHORS

End anchors have historically been used at the end of steep pipe runs to provide stability to the pipe.

Intermediate and End Anchors are also used to provide stability to steep pipe runs. As a rule of thumb, a slope of 6% may require intermediate or end anchors.

Drainage	Chapter INLETS & STORM SEWERS
	Subject Inlet Hydraulics

DR 704-1 INLET LOCATIONS

There are several guidelines that should be used to locate inlets discussed in DR-702-3. Once these inlets have been located for the system, the designer locates the remaining inlets based purely on design hydraulics.

Inlets are divided into two groups for the purpose of design hydraulics: curb inlets and drop inlets.

Curb inlets are designed to intercept relatively shallow depths of pavement flow and are spaced based upon a maximum allowable spread of water into the driving lane.

Since drop inlets may be on or off pavement, spacing intervals are based upon either of the following:

- An allowable elevation of the water surface off pavement
- A maximum allowable spread of water into the driving lane on pavement

The FHWA's Hydraulic Engineering Circular 22 (HEC-22), "Urban Drainage Design Manual (2001)" documents the design equations and nomographic solutions discussed throughout DR-704.

DR 704-2 CALCULATING DISCHARGE TO INLETS

The discharge to each inlet shall be calculated by the Rational Formula (Q = CIA) discussed in DR-403-1.

For pavement drainage inlets, the design rainfall intensity shall be four (4) inches per hour. This is a long standing KYTC practice to prevent unreasonably high intensities derived from IDF tables. The contributing area will include the area of the roadway plus the adjacent property draining to the gutter and any bypass flows from upstream inlets. Off-pavement areas draining to pavement inlets should be minimized as much as practical due to the increased risk from offsite debris and spread issues.

For other inlets, the discharge to the inlet is calculated by standard Rational Formula procedures. Calculating the time of concentration to the inlet will be necessary to determine the design intensities. Use a minimum of 8 minutes for the time of concentration to these inlets.

DR 704-3 GUTTER CAPACITY & ALLOWABLE SPREAD

The spacing of inlets on pavement is highly dependant on the selection of allowable spread or depth in the gutterline. Refer to DR-707-1 “Allowable Spread for Pavement Inlets.” After determining the applicable spread criteria, the designer derives the spacing of inlets by:

- Determining the gutter flow at various points
- Selecting inlets for those points of maximum allowable spread

The typical roadway section determines the cross section of a gutter. The flow in the gutter varies with its cross section, longitudinal slope, roughness, and maximum allowable depth or spread.

The two types of gutters commonly used on KYTC projects are uniform and composite gutters. Both are shown in Figure 704-1.

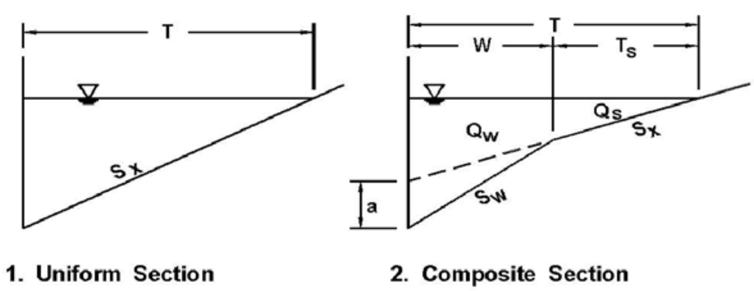


Figure 704-1
Gutter Types

DETERMINING GUTTER CAPACITY

Gutter capacity as a function of maximum depth in a uniform gutter section is determined by the equation:

EQUATION 704-1
GUTTER FLOW (DEPTH CAPACITY) EQUATION

$$Q = \frac{K_u}{(n \times S_x)} \times S_L^{0.50} \times d^{2.67}$$

Where:

Q = Maximum allowable discharge (ft^3/s)
K_u = 0.56 (English)
S_L = Clear area of opening (feet^2)
S_x = Roadway cross slope (feet per foot)
d = Maximum allowable depth of flow (feet)
n = Manning's roughness coefficient (**Table 705-1**,

standard pavement value of .015)

An integrated form of the gutter flow equation with capacity calculated in terms of spread is as follows:

EQUATION 704-2
GUTTER FLOW (SPREAD CAPACITY) EQUATION

$$Q = \frac{K_u}{n} \times S_x^{\ 1.67} \times S_L^{\ 0.5} \times T^{\ 2.67}$$

Where:

Q	=	Flow rate (ft^3/s)
K_u	=	0.56 (English)
S_x	=	Roadway cross slope (feet per foot)
S_L	=	Clear area of opening ($feet^2$)
S_L	=	Longitudinal slope of roadway (feet per foot)
T	=	Width of spread (feet)
n	=	Manning's roughness coefficient

For composite gutters, the relationships between spread, capacity, and roadway geometrics are more complex. Determining the spread at a known Q is an iterative process. It is important to note that these equations are applicable only for a uniformly depressed gutter or an inlet with only a local depression. A local depression at the inlet improves flow interception but the spread will be dictated by the general gutter section geometry.

EQUATION 704-3
SPREAD CAPACITY EQUATIONS FOR COMPOSITE GUTTER SECTIONS

$$Q = \frac{K_u}{n} \times S_L^{\ 0.5} \times \left[S_X^{\ 1.67} \times (T - W)^{2.67} + S_W^{\ 1.67} \times \left\{ \left[W + (T - W) \times (S_X / S_W) \right]^{2.67} - \left[(T - W) \times (S_X / S_W) \right]^{2.67} \right\} \right]$$

$$Q_W = Q - Q_S$$

$$Q = \frac{Q_S}{(1 - E_o)}$$

$$S_W = S_X + a/W$$

$$E_o = 1 \Bigg/ \left\{ 1 + \frac{S_W / S_X}{\left(\left[1 + \frac{S_W / S_X}{(T/W - 1)} \right]^{2.67} - 1 \right)} \right\}$$

Where:

Q	=	Flow rate (ft^3/s)
K_u	=	0.56 (English)
S_X	=	Roadway cross slope (feet per foot)
S_L	=	Longitudinal slope of roadway (feet per foot)
T	=	Width of spread (feet)
n	=	Manning's roughness coefficient
W	=	Gutter width (feet)
Q_S	=	Flow capacity of the gutter section above the depressed section
Q_W	=	Flow capacity of the gutter section in the depressed section
S_w	=	Cross slope of the depressed gutter
E_o	=	Ratio of the flow in the width of a depressed gutter section to total gutter flow (Q_w/Q)
a	=	Gutter depression (See Figure 704-1)

DR 704-4 GRATE INLETS ON GRADE

The interception capacity of a grate inlet on grade depends on:

- The quantity of water flowing over the grate
- The size and configuration of the grate
- The velocity of flow in the gutter

The efficiency of a grate is dependent on the same factors and total flow in the gutter. Some considerations pertaining to grate inlets on grade are:

- At low velocities, all of the water flowing in the section of gutter occupied by the grate (called frontal flow) is intercepted.
- Only a portion of the flow outside of the grate is intercepted. This is called side flow.
- At steeper longitudinal slopes, only a portion of the frontal flow will be intercepted as the water starts to splash-over the inlet. This velocity is termed the splash-over velocity. At this point, grate capacity and efficiency is reduced.
- Grate efficiency increases with slope until splash-over velocity is reached.
- At low gutter flow velocities, grates with the same width perform equally.
- Increasing the length of a grate does not substantially increase its capacity except in a sag condition.
- Wider grates are needed to capture more flow.
- Vane grates offer improved performance in terms of intercepted flow.
- Clogging of grates must be considered in any design.

PARALLEL BAR GRATES

A parallel bar grate is an efficient type of inlet, however, when crossbars are added for bicycle safety, the efficiency is greatly reduced. Where bicycle traffic is a design consideration, the curved vane grate and the tilt bar grate are recommended for both their hydraulic capacity and bicycle safety features. In certain locations where leaves and debris may create constant maintenance problems, the parallel bar grate may be used more efficiently if bicycle traffic is not an issue.

GRATE DEBRIS HANDLING EFFICIENCIES

Where debris is a problem, consideration should be given to debris handling efficiency rankings of grate inlets from laboratory tests in which an attempt was made to qualitatively simulate field conditions. The following table shows the relative comparison of debris handling efficiencies of several grates types.

Table 704-1
Grate Debris Handling Efficiencies

Rank	Grate	Longitudinal Slope	
		0.005	0.04
1	Curved Vane	46	61
2	30° - 85° Tilt Bar	44	55
3	45° - 85° Tilt Bar	43	48
4	P-1-7/8	32	32
5	P-1-7/8-4	18	28
6	45° - 60° Tilt Bar	16	23
7	Reticuline	12	16
8	P-1-1/8	9	20

Source: "*Urban Drainage Design Manual*" (HEC-22), Federal Highway Administration, July 2001.

INTERCEPTION CAPACITIES

Inlet interception capacity has been investigated by various agencies and manufacturers of grates. For detailed inlet efficiency data for various sizes and shapes of grates, refer to FHWA's HEC-22 (2001) and inlet grate capacity charts prepared by the grate manufacturers, especially when using special design inlets.

As mentioned earlier, at low velocities, all water flowing over a grate will be intercepted. This flow is termed frontal flow. The ratio of frontal flow to total gutter flow, E_o, for a uniform cross slope is expressed by the following equation:

EQUATION 704-4
FRONTAL FLOW TO TOTAL GUTTER FLOW RATIO
(for uniform gutter section)

$$E_o = Q_w / Q = 1 - \left(1 - \frac{W}{T}\right)^{2.67}$$

Where:

Q = Total gutter flow (ft^3/s)

Q_w = Flow in width W (ft^3/s)
W = Width of depressed gutter or grate (feet)
T = Total spread of water in the gutter (feet)

The ratio of side flow, Q_s, to total gutter flow is:

EQUATION 704-5
SIDE FLOW TO TOTAL GUTTER FLOW RATIO

$$\frac{Q_S}{Q} = 1 - \frac{Q_W}{Q} = 1 - E_o$$

The ratio of frontal flow intercepted to total frontal flow, or R_F, is equivalent to frontal flow interception efficiency and is determined by the following equation:

EQUATION 704-6
FRONTAL FLOW INTERCEPTED TO TOTAL FRONTAL FLOW RATIO

$$R_F = 1 - 0.09 \times (V - V_o)$$

Where:
V = Velocity of flow in the gutter (ft/s)
V_o = Gutter velocity where splash-over occurs (ft/s)

The table below lists values for splash-over velocity for grates used on KYTC drop box inlets.

Note: Refer to *HEC-22* (2001), “Chart 4” for a nomograph to solve for velocity in a triangular gutter section with known cross slope, gutter slope, and spread.

Table 704-2
Splash-Over Velocities for KYTC Grates

DBI Type	Velocity (ft/s)	DBI Type	Velocity (ft/s)
1	10.5	7	6.6
2	12.0	10	5.1
3	6.6	11	5.5
4	7.8	13 (Curved Vane)	6.5
5	10.5	13 (Tilt Bar)	5.5
6	6.6	16	6.6

A part of the flow along the side of the grate, termed side flow, will be intercepted. The amount of side flow intercepted by the grate depends on the cross slope of the pavement, the length of the grate, and flow velocity. The ratio of side flow intercepted to total side flow (R_s or side flow interception efficiency) is expressed by:

EQUATION 704-7

SIDE FLOW INTERCEPTED TO TOTAL SIDE FLOW RATIO

$$R_S = 1 \Big/ \left(1 + \frac{0.15 \times V^{1.8}}{S_X \times L^{2.3}}\right)$$

Where:
L = Length of the grate (feet)

The efficiency, E, of a grate inlet is expressed as:

EQUATION 704-8
GRATE INLET EFFICIENCY

$$E = (R_F \times E_o) + R_S \times (1 - E_o)$$

The interception capacity of a grate inlet on grade, Q_I, is equal to the efficiency of the grate multiplied by the total gutter flow:

EQUATION 704-9
INTERCEPTION CAPACITY FOR GRATE INLETS ON GRADE

$$Q_I = E \times Q = Q \times \left[(R_F \times E_o) + R_S \times (1 - E_O)\right]$$

DR 704-5 CURB INLETS ON GRADE

Flow interception by slotted drain pipes and curb opening inlets is similar in that each is a side weir and its flow is subjected to lateral acceleration due to the cross slope of the pavement. The interception capacity of these inlets depends on:

- the flow depth at the curb
- inlet length

The efficiency depends on flow depth, inlet length, and total flow. Some consideration pertaining to curb inlets on grade are:

- Slotted drains and curb inlets lose efficiency and inlet capacity as longitudinal slope increases due to the spread and depth of water becoming smaller as velocity increases. This is opposite to grate inlets operating at less than splash over veloctiy.

- Although there is no splash over velocity effect with curb inlets, they do loose interception capacity as longitudinal slope in increased.

- Local depression of curb inlets increases their capacity.

- Curb inlets are less susceptible to clogging than grate inlets.

INTERCEPTION CAPACITY

The length for total interception of curb opening inlets and slotted drain pipes with slot widths greater than or equal to 1.75 inches can be computed by the equation:

EQUATION 704-10
LENGTH OF CURB OPENING INLETS/SLOTTED PIPES FOR TOTAL INTERCEPTION (SLOT WIDTHS ≥ 1.75”)

$$LTI = 0.60 \times \left[Q^{0.42} \times S_L^{\ 0.3} \times \left(\frac{1}{n \times S_E} \right)^{0.6} \right]$$

$$S_E = S_X + (S'_W \times E_o)$$

$$S'_W = \frac{a_{inches}}{W_{feet} \times 12_{in/foot}}$$

Where:

LTI	=	Curb opening/Slotted pipe length required for 100% interception (feet)
Q	=	Discharge (ft^3/s)
S_L	=	Longitudinal slope of pavement (foot per foot)
n	=	Manning's roughness coefficient for pavement
S_E	=	Equivalent pavement cross slope (foot per foot). For uniform cross slopes, $S_E = S_X$
S'_W	=	Cross slope of gutter measured from cross slope of the pavement, S_X , (foot per foot)
S_X	=	Roadway cross slope (foot per foot)
a	=	Gutter depression (inches)
E_o	=	Ratio of frontal flow to total gutter flow for composite gutters or depressed curb inlets. As calculated from the gutter configuration upstream of the inlet.

These variables are shown graphically in Figure 704-2 below:

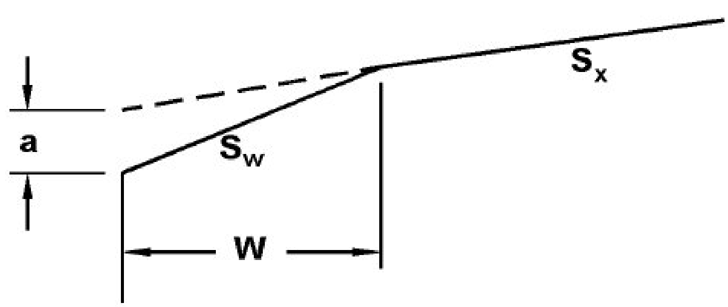


FIGURE 704-2
UNIFORM GUTTER & DEPRESSED CURB INLET

CURB INLET EFFICIENCY

Curb inlet efficiency is based upon a given inlet length versus the length required for total interception and is calculated as follows:

EQUATION 704-11
CURB INLET EFFICIENCY RATIO

$$E = 1 - \left(1 - \frac{L}{LTI}\right)^{1.8}$$

Where:

E	=	Efficiency of inlet
L	=	Length of inlet (feet)
LTI	=	Length of inlet for 100% interception (feet)

DR 704-6 SLOTTED DRAIN PIPE

Slotted pipe drain is assumed to have hydraulic characteristics similar to curb inlets for slot widths greater than 1.75 inches. Unlike curb inlets, clogging can be an issue. Due to clogging, they are not recommended in sag locations or at locations where a high degree of debris can be expected.

Slotted drain pipes on grade are analyzed like curb inlets on grade (DR-704-4).

DR 704-7 CURB INLETS IN SAG OR SUMP LOCATIONS

Curb inlets in a sag or sump function as a weir under low flows and as orifices under larger flows.

Examinations of the weir and orifice equations below reveal that the weir equation is most likely more prevalent than the orifice equation. Greater flow depths creating orifice flow often represent situations that exceed maximum allowable spread and situations that overtop the standard curb height.

INTERCEPTION CAPACITY FOR CURB INLETS OPERATING AS WEIRS
Weir flow may be calculated for depressed or non-depressed curbs.

The weir equation for depressed curbs is applicable to depths at the curb equal to approximately the height of the opening plus the depression depth. The equation for the interception capacity, Q_i, of a depressed curb-opening inlet operating as a weir is:

EQUATION 704-12
INTERCEPTION CAPACITY FOR DEPRESSED CURB-OPENING INLET
(operating as a weir)

$$Q_i = C_W \times (L + 1.8 \times W) \times d^{1.5}$$

Where:

C_W	=	2.3 (weir coefficient)
L	=	Length of curb opening (feet)

W = Width of depression (feet)
d = Flow depth at curb measured from the normal cross slope (i.e. $d = T \times S_X$) (feet)

The design equation for an inlet with no depression shows that the amount of intercepted flow is less than that of a curb with depression until the length of the opening exceeds twelve feet. At that point the inlet with no depression has a greater capacity. The equation for the interception capacity, Q_i, of a non-depressed curb-opening inlet operating as a weir is:

EQUATION 704-13
INTERCEPTION CAPACITY FOR NON-DEPRESSED CURB-OPENING INLET
(operating as a weir)

$$Q_i = C_W \times L \times d^{1.5}$$

Where:
C_W = 3.0

Since depressed inlets perform as well as non-depressed inlets for lengths greater than twelve feet, the non-depressed inlet equation, Equation 704-12, should be used for all situations where the length of the curb opening, L, is greater than twelve feet.

INTERCEPTION CAPACITY FOR CURB INLETS OPERATING AS ORIFICES
Curb-opening inlets act as orifices at depths greater than approximately 1.4 times the opening height. The equation for the interception capacity of a curb-opening inlet with a depression operating as an orifice is:

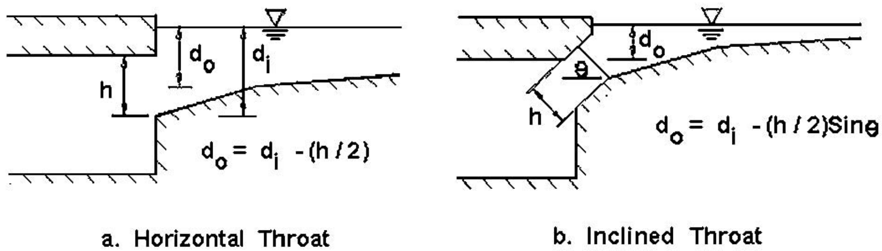
EQUATION 704-14
INTERCEPTION CAPACITY FOR DEPRESSED CURB-OPENING INLET
(operating as an orifice)

$$Q_i = C_O \times h \times L \times (2 \times g \times d_o)^{0.5} = C_O \times A_g \times \left[2 \times g \times \left(d_i - \frac{h}{2} \right) \right]^{0.5}$$

Where:
C_O = 0.67 (weir coefficient)
h = Height of curb-opening (feet)
L = Length of the orifice opening (feet)
A_g = Clear area of opening (feet^2)
d_o = Effective head on the center of the orifice throat (feet) (see calculation for d_o in figures below)
d_i = Depth at lip of curb opening (feet)
g = 32.16 ft/s^2

The drawing below illustrates how the variables mentioned above are defined for the two cases that KYTC curb inlet fall under.

FIGURE 704-3
DETERMINING EFFECTIVE HEAD HEIGHTS FOR KYTC CURB INLETS



Curb Box Type A has an inclined throat with an angle of inclination, θ, of approximately 40°. Curb Box Types B and F have horizontal throats.

Refer to Standard Drawing RDB-271 for CBI Type A details and to Standard Drawing RDB-281 for CBI Type B details. Additional hydraulic background information may be found in Chapter 4 of the FHWA's HEC-22 , "Urban Drainage Design Manual (2001)."

DR 704-8 PAVEMENT GRATE INLETS IN SAGS

For pavement drainage, grate inlets alone are not recommended for use in sag or sump locations because of their tendency to become clogged; thus, curb-opening inlets (DR-704-6 "Curb Inlets in Sag or Sump Locations") are preferred. Slotted Drain Inlets have similar limitations. The following equations apply to grate inlet operating for grate inlets in sag. Refer to Section (DR-704-11 "Median and Channel Inlets") for clogging assumptions when working with grate inlets.

EQUATION 704-15
INTERCEPTION CAPACITY FOR GRATE INLET IN SAG
(operating as a weir)

$$Q_i = C_W \times P \times d^{1.5}$$

Where:

C_W	=	3.0
P	=	Clear perimeter disregarding both the length of the side along the curb, if any, and the obstructed length and width due to bars and mesh of the grate (feet). Assume half of the width is ineffective due to clogs.
d	=	Average depth across the grate (feet)

EQUATION 704-16
INTERCEPTION CAPACITY FOR GRATE INLET IN SAG
(operating as a orifice)

$$Q_i = C_O \times A_g \times (2 \times g \times d)^{0.5}$$

Where:

C_O = 0.67

A_g = Area minus the obstructed area due to bars and meshing of the grate (feet). Assume half of the width is ineffective due to clogs.

d = Average depth across the grate (feet)

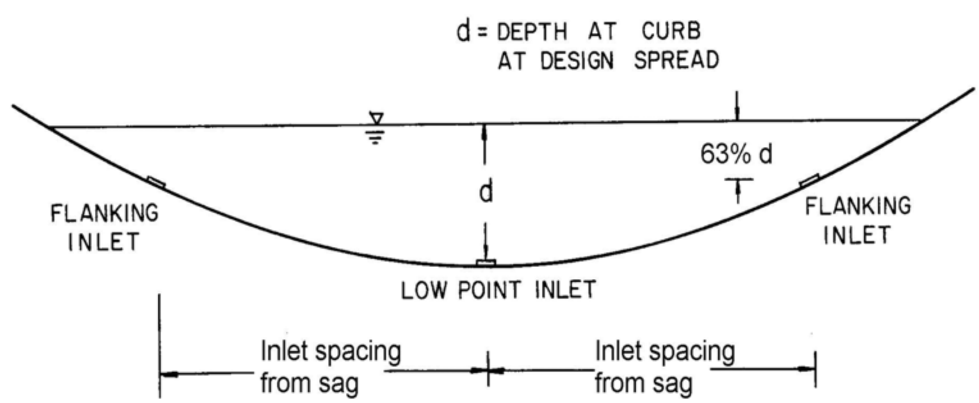
DR 704-9 FLANKING INLETS

It is good engineering practice to place flanking inlets on each side of the low-point inlet when in a depressed area that has no outlet except through the system. Flanking inlets act in relief of the inlet at the low point should the inlet become clogged or if the design spread is exceeded. AASHTO recommends a minimum grade of 0.3 percent within 50 feet of the level point in order to provide adequate drainage.

The flanking inlets should be located so that they will receive all of the flow when the primary inlet at the bottom of the sag is clogged. They should do this without exceeding the allowable spread at the bottom of the sag.

If the flanking inlets are the same dimension as the primary inlet, they will each intercept one-half the design flow when they are located so that the depth of ponding at the flanking inlets is 63 percent of the depth of ponding at the low point, as seen in the figure below.

FIGURE 704-4 SAG CROSS SECTION SHOWING FLANKING INLET LOCATIONS



If the flanker inlets are not the same size as the primary inlet, it will be necessary to either develop a new factor or do a “trial and error” solution using assumed depths with the weir equation to determine the capacity of the flanker inlet at the given depths.

The following procedure may be used to determine spacing of flanking inlets as defined by the vertical curve length (L), approach grades (G1 and G2), and allowable spread (T) at the sag point.

1. Determine design depth, (d) , of flow at the curb
2. Determine the depth of flow, (d_f), at the flanker inlets
3. Determine depth differential, (Δd)
4. Determine the rate of vertical curve, (K)
5. Locate flanking inlets

The "Spacing of Flanking Inlets from Sump Inlet" Table 707-2 summarizes this procedure.

FLANKING INLETS EXAMPLE
Given:

- A 490-foot sag vertical curve with approach grades of –2.5% (G_1) and 2.5% (G_2)
- Roadway cross slope (S_x) = 0.02 feet/foot
- Allowable spread (T) = 8 feet (half a pavement lane plus two foot shoulder)
- Station of sag point = 45+00

Problem: What are the Stations where we need to place flanking inlets?

Solution:

1. Design depth at sag, $d = S_x \times T = 0.02 \times 8 = 0.16\,ft$
2. Design depth at flanker inlets $d_f = 0.63 \times d = 0.16 \times 0.63 = .10\,ft$
3. Depth difference $\Delta d = d - d_f = 0.16 - .10 = .06\,ft$
4. Rate of vertical curvature $K = L/(G_2 - G_1) = 490/(2.5 - (-2.5)) = 98\,ft/\%$
5. Distance from sag point $\Delta x = (200 \times \Delta d \times K)^{0.5} = (200 \times .06 \times 98)^{0.5} = 34\,ft$

Therefore flanking inlets of the same type and capacity will be located at station 44+66 and station 45+34.

DR 704-10 COMBINATION INLETS

Combination inlets consist of a grate along side a curb opening. When the grate is located on the downstream side of the curb opening inlet is referred to a "sweeper inlet." The curb opening in such an installation intercepts debris which might otherwise clog the grate. This combination results in a high capacity inlet which offers the advantages of both grate and curb opening inlets. The KYTC Curb Box Type B is a sweeper inlet.

A sweeper combination inlet has an interception capacity equal to the sum of the curb opening upstream of the grate plus the grate capacity, except that the frontal flow and thus the interception capacity of the grate is reduced by interception by the curb opening.

DR 704-11 MEDIAN & CHANNEL INLETS

The factors discussed in the previous sections also apply to grated inlets located in channels. KYTC drop box inlets are commonly located in median or channels along the roadside (to ensure that ditch flow capacity or allowable shear stress is not exceeded) or at required points of interception such as in a sag or other ponding locations. The primary differences between pavement inlets and channel/median inlets are:

- Channel inlets are not located in curb lines; therefore the effective perimeter of channel inlets is not blocked by the curb on one side.
- Less depth is available for head over pavement grate inlets due to the risk of water spreading out into a driving lane or rising above the curb height.
- Use of grated inlets in a sump condition is a common practice for channel/median inlets, but is strongly discouraged for pavement inlets in curbs due to the potential for clogging.

Drop Box Inlets 1, 2, 3, & 4 are designed to have a downstream dike that forces water into the inlet. Therefore, these inlets can be assumed to operate in a sag condition even if the overall channel slope continues to be graded in a downstream direction below the inlet. This assumption will be correct until the head over the grate exceeds the depth of the dike.

For channels not in a true sag, the depth of available headwater provided by these grates, as well as the capacity resulting from this headwater, is shown in Table 704-3 below. This chart is based on dimensions in the standard drawings and assumes that the surrounding grade does not provide more available headwater room.

For channels located in a true sump condition, such as two channels terminating into a downstream drop box, there will often be more room available for headwater than what is shown in Table 704-3, "Available Headwater for KYTC Drop Box Inlets Constructed on Grade with a Dike."

For median and channel inlets in sag condition, assume 50% clogging of the clear or effective area for orifice conditions due to the effective width being cut in half. The width being cut in half will reduce the effective perimeter by less than 50% depending on length and width ratio of the grate in question and whether or not the grate is along a curb. With most grates having about twice the effective length as width, it works out to be about 20%-25% reduction in perimeter for weir conditions. The curves in Exhibit DR-700-2 "Grate Inlet in Sag" compare the capacity of KYTC drop inlets in a sump condition based on these assumptions. The bottom half of the exhibit can be used to check the head resulting from losses in the pipe chamber caused by water entering the storm sewer pipe. This may occur when the grate can accept more water than the exiting pipe can handle based on the depth available in the box.

Table 704-3
Available Headwater for KYTC Drop Box Inlets Constructed on Grade with a Dike

DBI Type	Available* Headwater Room (Ft)	Capacity* (CFS)
1	1.5	24.5
2	1.5	32.0
3	1.5	21.0
4	1.5	28.5

* Assumes inlet constructed per Standard Drawings, no more available headwater room provided by the surrounding grade, and 50% clogging of effective perimeter and area

Drop box inlets in medians or channels that are constructed on grade, without a dike, will experience bypass flows when the width of flow passing over the inlet is wider than the grate.

DESIGN CALCULATIONS

The design calculations for bypass flows described in DR 704-3 "Grate Inlets on Grade" also apply to inlets located in medians and channels, except for the calculation of frontal flow over the grate. The equation used to calculate frontal flow over a grate is:

EQUATION 704-17
FRONTAL FLOW OVER A GRATE RATIO
(for inlets in medians and channels)

$$E_o = \frac{W}{\{B + (d \times z)\}}$$

Where:

E_o = Ratio of frontal flow over the grate
W = Width of the grate (feet)
B = Width of channel at grate level (feet)
d = Depth of flow in the channel (feet)
z = side slope of channel (feet per foot)

These variables are shown graphically below in Figure 704-5.

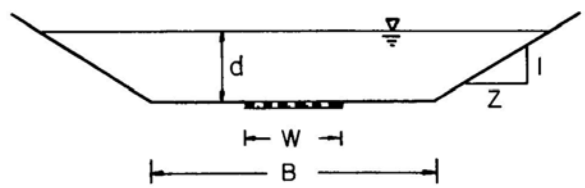


FIGURE 704-5 SAMPLE CHANNEL CROSS SECTION

Drainage	Chapter: INLETS & STORM SEWERS
	Subject: Storm Sewer Pipe

DR 705-1 STORM SEWER PIPE TYPES

The pipe culverts allowable for storm sewers are listed in DR-06.160.

The following types of circular culvert pipes may be used:

- Spiral Rib Steel Pipe
- Reinforced Concrete Pipe
- Corrugated Steel Pipe with Helical Seam
- Corrugated Steel Pipe with Longitudinal Seam
- Spiral Rib Aluminum Alloy Pipe
- Corrugated Aluminum Alloy Pipe with Helical Lock Seam
- Corrugated Aluminum Alloy Pipe with Longitudinal Seam
- High Density Polyethylene (HDPE)

The designer may use the following types of noncircular culvert pipes:

- Reinforced Concrete Pipe Arch
- Reinforced Concrete Horizontal Elliptical Pipe
- Reinforced Concrete Vertical Elliptical Pipe
- Corrugated Steel Pipe Arch
- Spiral Rib Steel Pipe Arch
- Corrugated Steel Elliptical Pipe
- Corrugated Aluminum Alloy Pipe Arch
- Corrugated Aluminum Alloy Elliptical Pipe
- Spiral Rib Aluminum Alloy Pipe Arch

See current Standard Drawings RDI-001 through RDI-035 and the Standard Specifications for Road and Bridge Construction, Sections 701 for construction and material requirements for the acceptable pipe types. Note that in some large fill locations a hydraulically acceptable pipe may have to be upsized to a larger pipe to meet fill requirements. For example, the 30’ is the largest fill height allowed over pipes with diameters from 12”-21”.

DR 705-2 SPECIFYING PIPE IN PLAN SHEETS

KYTC does not specify pipe types in the plan sheets. The plans will only specify the following required data for each pipe:

Table 705-1 Pipe Sheet Design Data	
Item	**Description**
PIPE DIAMETER	12 inch – 120 inch
COVER HEIGHT	Measured from the top of pipe to the top of the subgrade (ft)
DESIGN pH LEVEL	Low, Medium, or High
ABRASION LEVEL	Abrasive or Highly Abrasive

The contractor will use the above information to select a storm sewer pipe with the appropriate properties. Pipe restrictions not delineated in this manual or in the Standard Drawings shall require approval in writing by the Director, Division of Highway Design. Possible restrictions include:

- Short extensions of existing systems—extend in kind
- Pipes projecting out of the fill—omit concrete and plastic alternates
- Pipes that run down a steep slope (See Standard Drawing RDI-045)—omit concrete alternate
- Pipes in or near outlet control—fully line all sizes of corrugated metal pipe with longitudinal seam and 30-inch or larger corrugated metal pipe with helical seam

DR 705-3 pH REQUIREMENTS

Pipes shall be coated and paved based on pH level. Soils that have a pH greater than nine (9) are considered basic while soils that have a pH less than five (5) are considered highly acidic. Those soils that lie in-between these values are considered medium. Refer to Standard Drawing RDI-035 for complete pH requirements.

DR 705-4 PIPE ROUGHNESS

Pipe roughness may vary based on the different pipe materials and fabrication methods. For pipe diameters less than 24 inches, most pipe materials function like “smooth” pipe. However, helically corrugated metal pipe greater than 24 inches does not function like “smooth” pipe and offers greater resistance than concrete or plastic pipe. It is KYTC policy to fully line helically corrugated pipe with diameters greater than 24 inches. The reasoning behind RDI-035 “Coatings, Linings and Pavings for Non-Structural Plate Pipe” and the pipe fill table’s requirements, is to provide equivalent pipe roughness, regardless of the material chosen. Therefore, it is KYTC policy to design new storm sewer pipe as “smooth” pipe. Smooth pipe is assumed to have a Manning’s roughness number of 0.012. The following table below gives Manning’s n value for various pipe materials. This table applies to existing pipes or pipes that are installed without the lining treatments describe above.

Table 705-2 Manning's n Coefficients for Channels and pipes	
Conduit Material	Manning's n
Closed Conduits	
Asbestos-cement pipe	0.011 - 0.015
Brick	0.013 – 0.017
Cast iron pipe	
Cement-lined and seal coated	0.011 – 0.015
Concrete (monolithic)	0.012 – 0.014
Concrete pipe	0.011 – 0.015
Corrugated-metal pipe - 13 mm by 64 mm (½ inch by 2 ½ inch) corrugations	
Plain	0.022 – 0.026
Paved invert	0.018 – 0.022
Spun asphalt lines	0.011 – 0.015
Plastic pipe (smooth)	0.011 – 0.015
Vitrified clay	
Pipes	0.011 – 0.015
Liner plates	0.013 – 0.017
Open Channels	
Lined channels	
Asphalt	0.013 – 0.017
Brick	0.012 – 0.018
Concrete	0.011 – 0.020
Rubble or riprap	0.020 – 0.035
Vegetal	0.030 – 0.040
Excavated or dredged	
Earth, straight and uniform	0.020 – 0.030
Earth, winding, fairly uniform	0.025 – 0.040
Rock	0.030 – 0.045
Unmaintained	0.050 – 0.140
Natural channels (minor streams, top width at flood stage <30 m (100 ft))	
Fairly regular section	0.030 – 0.070
Irregular section with pools	0.040 – 0.100

Refer to Standard Drawing RDI-035, "Coatings, Linings and Pavings for Non-Structural Plate Pipe" for pipe coating and paving specifications.

DR 705-5 SANITARY OR COMBINED SEWER PIPE TYPES

Sanitary or combined sewer pipe materials should be governed by any local criteria.

DR 705-6 OUTSIDE PIPE DIMENSIONS & PIPE CHAMBERS

As depicted in the Standard Drawings, pipe chambers for KYTC inlets, junctions, and manholes are designed to fit the outer dimensions of the accepted pipes.

The largest outer dimension of a pipe must be considered when selecting the size of pipe chambers for inlets, manholes, or junction boxes. Since concrete pipes have the largest outside diameter for a given pipe size, they should be used to size pipe chamber. An estimate of the outside diameter of a circular concrete pipe can be obtained from the following formula:

EQUATION 705-1
OUTSIDE DIAMETER OF CIRCULAR CONCRETE PIPE

$$D_O = D_I + 2 \times \left(\frac{D_I}{12} + 1 \right)$$

Where:

D_O = Outside Diameter (inch)

D_I = Inside Diameter (inch)

DR 602 & 603 discusses wall thicknesses for other types of concrete structures commonly used for storm sewer systems such as elliptical pipe and precast reinforced box culvert sections

For pipes (or box sections) entering a pipe chamber at a skew, the outside dimensions of the pipe may also need to be adjusted for this skew to determine if the pipe will fit within the inside walls of the pipe chamber.

◈◈◈

Drainage	Chapter INLETS & STORM SEWERS Subject Storm Sewer Hydraulics

DR 706-1 GENERAL

The hydraulic design of a storm sewer system consists of determining the location, sizes, slopes, and elevations for a system of underground conduits necessary to transport surface runoff to a disposal site. The following data is necessary for a storm sewer system design:

- Location and geometric design of the highway, including elevations
- Location and elevation of existing outlets
- Location and elevation of existing inlets
- Map delineating drainage areas and pertinent topography
- Location of underground utilities, bridge substructures, buildings, and other installations that may affect the location of the storm sewer
- Location of existing or planned storm sewers that may connect to the proposed system

Storm sewers may be designed by open channel or pressure flow methods. For new systems, the open channel method is preferred due to the following benefits:

- A margin of safety is provided to accommodate an increase in flow due to unplanned future development.
- A margin of safety is provided due to the imprecise nature of runoff estimates.
- The need to remove or replace an undersized storm sewer in the future will be reduced.

Although it is KYTC policy to design new storm sewer systems in open channel flow, there may be situations where pressure flow design is desirable. For example, on some projects, there may be adequate headroom between the conduit and inlet/access hole elevations to tolerate pressure flow. In this case, a significant cost savings may be realized over the cost of a system designed to maintain open channel flow. Sometimes it may be necessary to use an existing system which must be placed under pressure flow to accommodate the proposed design flow rates. In these instances, there may be advantages in making a cursory hydraulic and economic analysis of a storm drain using both design methods before making a final selection.

In pressure flow design, energy grade line calculations are performed and the hydraulic grade line of the design storm must not be allowed to surcharge the junction to the point of flooding the roadway. Pressure flow design will be used where necessary or where it has been shown to be economically practical and feasible.

DESIGN AND CHECK STORMS

It is KYTC policy to use open channel design methodology for the design flow where possible. Storm sewer systems are typically designed to accommodate a 10-year design storm. Pipes located in sags are designed to accommodate the 25-year storm. In this context, sag refers to the situation where water has no way out except through the pipe itself, such as the outlet of a storm sewer system at the lowest point in the road. The 100-year storm is used to ensure that off-site impact is acceptable.

DR 706-2 HYDRAULIC CAPACITY

The hydraulic capacity of a storm drain is controlled by its size, shape, slope, and friction resistance. Several friction flow formulas have been advanced that define the relationship between flow capacity and these parameters. The most widely used formula for gravity and pressure flow in storm drains is Manning's Equation. For circular storm drains flowing full, Manning's Equation becomes:

EQUATION 706-1
MANNING'S EQUATION
(for circular storm drains flowing full)

$$Q = \frac{0.463}{n} \times D^{8/3} \times S_O^{\ 1/2}$$

Where:

Q	=	Rate of flow (ft^3/s)
n	=	Manning's coefficient
D	=	Storm drain diameter (ft)
S_O	=	Slope of the pipe for open channel (also, slope of hydraulic gradient line) (ft/ft)

Note: "Flowing full" implies that the pipe is flowing just full and not under pressure flow.

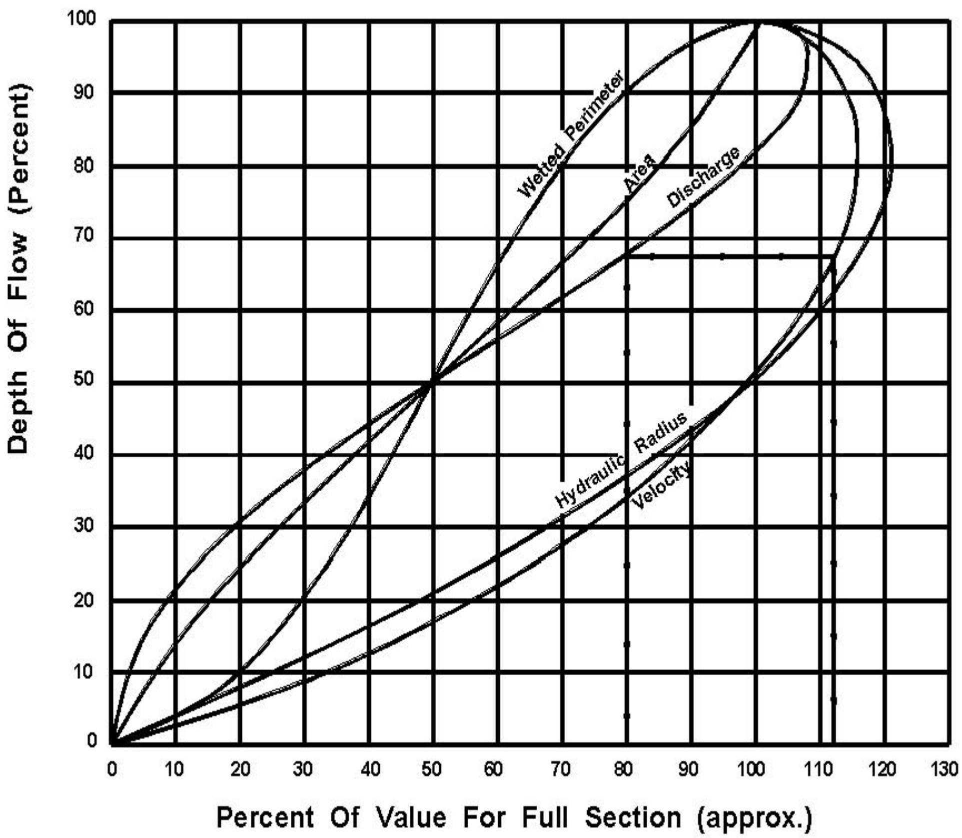
DR 706-3 PARTIALLY FULL PIPE HYDRAULICS

Calculating the hydraulic properties for a circular pipe flowing full is a simple procedure based on circular geometry. Realistically a pipe will rarely flow full and not be in pressure flow. Usually a pipe will be under pressure or flowing at a depth less than the diameter of the pipe. For pipes flowing partially full, the designer can use the Hydraulic Elements Chart shown below to determine the hydraulic properties of a pipe. The chart gives hydraulic properties for pipes flowing partially full in relation to their full flow values. Upon inspection of the Hydraulic Elements Chart the following points should be noted:

- Peak flow occurs at 93% of the height of the pipe; therefore, if the pipe is designed for full flow, the design will be lightly conservative.

- Full flow capacity is the same as the capacity with the pipe flowing at 82% of the depth.
- The velocity in a pipe flowing half-full is the same as the velocity for full flow. Maximum velocity occurs at 82% flow.
- Flow velocities for flow depths greater than half-full are greater than velocities at full flow.
- As the depth of flow drops below half-full, the flow velocity drops off rapidly.

Chart 706-1
Hydraulic Elements
(for pipe flowing partially full)

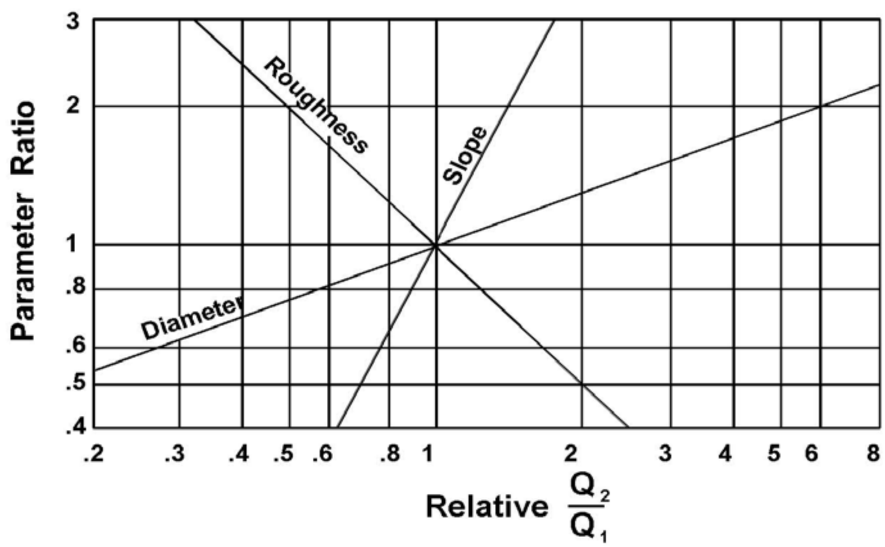


Using the example noted in the chart, a circular pipe flowing at a depth equal to 68% of the full depth (diameter of the pipe) will have a discharge and velocity of 80% and 112% of the respective full flow values. It is KYTC practice to size pipes for 80% depth of flow (maximum flow velocity in the pipe).

DR 706-4 SENSITIVITY OF PIPE CAPACITY VARIABLES

Varying the physical parameters of a storm drain pipe will have differing effects on the capacity. The chart below illustrates storm drain capacity sensitivity to the parameters in the Manning's equation. The designer can use in the chart to study the effect that changes in individual parameters will have on storm drain capacity. For example, if the diameter of a storm drain is doubled, its capacity will be increased by a factor of 6.0; if the slope is doubled, the capacity is increased by a factor of 1.4; however, if the roughness is doubled, the pipe capacity will be reduced by 50%.

Chart 706-2
PIPE CAPACITY SENSITIVITY



DR 706-5 STORM SEWER OPEN CHANNEL DESIGN PROCEDURE

In open channel design, the storm sewer system is sized based on the Manning equation presented in DR-706-2. As mentioned in DR-706-3, maximum pipe flow occurs at approximately 93% of depth; therefore designing for 80% flow depth will be slightly conservative. It is standing KYTC practice to design pipes to carry the design storm at 80% flow depth, which is hydraulically nearly the same as full pipe flow (see Chart 706-1 and the bullet points above). To design a storm sewer system using the open channel design, the designer shall:

1. Locate and calculate the existing flows at the proposed outlets while maintaining the existing drainage patterns to these outlets where possible to avoid flow diversions.

2. Select the types of inlets to be used, locate the drop inlets that will be connected to the system and space the curb inlets to intercept the expected design discharges for the allowable spread.

3. Lay out the storm sewer system on a map or schematic drawing of the project, connecting all inlets to available outfall areas. The designer must remember to incorporate the existing drainage patterns into the design as determined in the first step.

4. Plot a profile of the proposed highway and existing ground surface along the proposed location of the storm sewer and include the location of all proposed

manholes, inlets, and junctions.

Note: During this process, the designer should keep in mind the relative elevations between the outfall pipe and all proposed inlets and manholes. Avoid abrupt changes in slope from steep to mild. Design slopes to maintain a velocity of at least two (2) fps to avoid deposition of sediment. Also avoid deep trenches, particularly in rock or where shoring will be required.

5. Consider the location of utilities, particularly those that cannot be changed or otherwise disturbed, such as sanitary sewers, especially those constructed of brick.

6. The impact on any new construction such as bridge piers, abutments, or other structure foundations must be considered.

7. Starting at the most remote upstream intake structure of the storm sewer system, number each pipe junction systematically using appropriate labels, such as MH1 (ManHole #1), I2 (Inlet #2), J3 (Junction #3), and OF (Outfall) or by station.

   Note: This labeling system is to be shown on the drainage maps, computer input and output, and all summary forms.

8. Determine the land use and acreage or CA (runoff coefficient times drainage area, in acres) that contributing runoff to each inlet in the system for the rational method.

   Note: It may be necessary to sum the CA values for areas with different runoff coefficients.

9. Determine the maximum time of concentration to the first intake structure. This is the sum of the overland flow from the drainage area and any travel time through existing conduits, channels, swales to this structure.

10. Determine the rainfall intensity (I) for a storm with a duration equal to the time of concentration (Step 9) for the selected design frequency.

    Note: The product of this rainfall intensity (I) and the total CA to the first intake structure equals the discharge for the section of pipe from the first intake structure to the next downstream structure or junction (Q = CIA).

11. Determine an appropriate pipe size that meets approximately 80% flow depth at design flow criteria for the first pipe.

12. At the second junction, determine the value of CA, if any, for the additional area contributing at that point and add this value to the CA value for the first junction.

13. Compute storm sewer travel time from the first to the second junction (in minutes) through the pipe and add it to the time of concentration to the first junction to compute a cumulative travel time to the second junction through

the storm sewer system.

14. Calculate the time of concentration for any drainage area contributing to the second junction.

15. Use the larger of the two values calculated in steps 13 and 14 to compute rainfall intensity at the second junction. Use this intensity and the cumulative CA at the second junction (step 12) to compute the discharge and to size the pipe from the second junction to the next downstream junction.

16. Repeat the above procedure for the remainder of the system, obtaining new values of rainfall intensity and increasing discharge values at each successive junction.

DR 706-6 PRESSURE FLOW DESIGN

The designer shall follow pressure flow design procedure when gravity flow design is exceeded. Pressure flow design requires the calculation of the Hydraulic Grade Line (HGL). The HGL is a line coinciding with the level of flowing water at any point along an open channel. In closed conduits flowing under pressure, the hydraulic grade line is the level to which water would rise in a vertical tube at any point along the pipe. The designer uses the HGL to determine the acceptability of a proposed storm drainage system by establishing the elevation to which water will rise at the inlets when the system is operating under design conditions.

The HGL, a measure of flow energy, is determined by subtracting the velocity head ($V^2/2g$) from the Energy Grade Line (EGL). The EGL represents the total available energy in the system (kinetic plus potential). The EGL equals the sum of the pressure head, the velocity head, and the elevation head. If the HGL is above the inside top (crown) of the pipe, pressure flow exists. Conversely, if the HGL is below the crown of the pipe, open channel flow conditions exist.

Inlet surcharging and possible access hole or manhole lid displacement can occur if the HGL rises above the ground surface. A design based on open channel conditions must be carefully planned as well, including evaluation of the potential for excessive and inadvertent flooding created when a storm event larger than the design storm pressurizes the system. As hydraulic calculations are performed, the designer should frequently verify the existence of the desired flow condition. Storm drainage systems can often alternate between pressure and open channel flow conditions from one section to another.

DR 706-7 HGL / EGL CALCULATIONS

The computation of the hydraulic grade line requires that all energy losses be determined. These losses result from:

- Pipe Friction Losses
- Exit Losses
- Bend Losses
- Transition Losses

- Junction Losses
- Inlet and Access Hole Losses
    - Energy Loss Methodology
    - Power Loss Methodology

Pipe friction losses account for most of the major loss in a storm sewer system. Inlet and access hole losses are the most prevalent type of minor losses in a storm sewer system. Inlet and access hole losses apply to inlets, manholes, and junctions that have pipe chambers to receive the connected pipes. Inlet and access hole loses have been subject to considerable research. A thorough discussion of these losses may be found beginning in section 7.1.6, of the FHWA's HEC-22, "Urban Drainage Design Manual (2001)."

Drainage	Chapter: INLETS & STORM SEWERS
	Subject: Inlet & Storm Sewer Design Criteria

DR 707-1 ALLOWABLE SPREAD FOR PAVEMENT INLETS

After considering the “General Placement Rules” presented in DR-702-3, the designer will place pavement inlets in a manner that will limit the spread in driving lanes according to Table 707-1. The rainfall intensity used to develop flow rates to pavement inlets shall be four (4) inches/hour.

Table 707-1
Allowable Spread for Pavement Inlet Spacing

Traffic Volume	Speed	Design Spread Encroachment Into Driving Lane
Interstate or Parkway	All Speeds	0’
Non Interstate or Parkway ADT > 1500	> 45 mph	3’
	≤ 45 mph	6’
Non Interstate or Parkway ADT < 1500	All Speeds	6’

DR 707-2 FLANKING INLETS

Flanking inlets shall be located on either side of a sump inlet in a manner that will not violate spread criteria at the sump inlet located between them. The designer may use the procedure discussed in DR-704-8 “Flanking Inlets” or interpolate the information from Table 707-2 to space flanking inlets from their associated sump inlet. As noted above, four (4) inches/hour rainfall intensity is used for pavement inlet design.

Note: As cited in DR-704-8, AASHTO recommends a minimum grade of 0.30 percent within 50 feet of the level point in order to provide adequate drainage (AASHTO’s “*A Policy on Geometric Design for Highways and Streets”,* 2004 Edition, pg 274).

Table 707-2 Spacing of Flanking Inlets From Sump Inlet (ft)										
∆d (ft)	K (ft/%)									
	20	**30**	**40**	**50**	**70**	**90**	**110**	**130**	**160**	**167**
0.05	14	17	20	22	26	30	33	36	40	41
0.10	20	24	28	32	37	42	47	51	57	58
0.15	24	30	35	39	46	52	57	62	69	71
0.20	28	35	40	45	53	60	66	72	80	82
0.25	32	39	45	50	59	67	74	81	89	91
0.30	35	42	49	55	65	73	81	88	98	100
0.35	37	46	53	59	70	79	88	95	106	108
0.40	40	49	57	63	75	85	94	102	113	116
0.45	42	52	60	67	79	90	99	108	120	123
0.50	45	55	63	71	84	95	105	114	126	129
0.55	47	57	66	74	88	99	110	120	133	136
0.60	49	60	69	77	92	104	115	125	139	142
0.65	51	62	72	81	95	108	120	130	144	147
0.70	53	65	75	84	99	112	124	135	150	153
0.75	55	67	77	87	102	116	128	140	155	158
0.80	57	69	80	89	106	120	133	144	160	163

1. $\Delta x = (200 \times \Delta d \times K)^{0.5}$ where Δx = distance from sag point to flanker.

2. $\Delta d = d - d_f$ where:

$d =$ design depth of flow at the curb

$d_f = 0.63 \times d$, 63 percent of depth of flow at flanker inlet (See Figure DR-704-4).

3. Drainage maximum K =167 for Type III vertical curves (+G% and –G% curve). See AASHTO's "*A Policy on Geometric Design for Highways and Streets",* 2004 Edition, pg 274.

DR 707-3 INLETS IN CHANNELS

The designer shall place drop inlets in median and roadside channels at the following locations:

- Where the channel capacity is unable to contain the design storm due to either of the following situations:

- ♦ Depth in channel becomes deep enough to violate freeboard criteria for roadside channels
- ♦ Depth in channel becomes deep enough to violate allowable shear stress criteria for the channel

- ➢ In sag locations created by the surrounding grade
- ➢ Where convenient outlet points are available to dispose of water

Other considerations include:

- ➢ Locate inlets in channels in a manner that will maintain existing drainage patterns.
- ➢ Check headwater elevations over grates and in channels for the 100-year check storm to ensure damage to surrounding property is not occurring.

DR 707-4 MAXIMUM ACCESS POINT SPACING

The designer shall provide an inlet, manhole, or junction box at every break in horizontal or vertical alignment and at minimum distances along the storm sewer network to provide access for maintenance. Use Table 707-3 from AASHTO's "Model Drainage Manual" to determine the maximum spacing between access points in a storm sewer.

Table 707-3
Maximum Access Point Spacing

Pipe Size (in)	Suggested Maximum Spacing (ft)
12 - 24	300
27 - 36	400
42 - 54	500
≥ 60	1000

DR 707-5 PHYSICAL PIPE REQUIREMENTS

Design all storm sewer pipe to have a minimum cover one (1) foot from the top of the pipe to the bottom of the pavement subgrade if under pavement and one (1) foot to the top of the ground if not under the pavement.

The minimum size of pipe permitted in any storm sewer system with regards to traffic is:

- ➢ For storm sewer pipe **not under traffic**:
  - ♦ Twelve (12) inches for pipe lengths less than twenty-five (25)feet
  - ♦ Fifteen (15) inches for pipe lengths greater than or equal to twenty-five (25) feet
- ➢ For storm sewer pipe **under traffic**:

- ♦ Eighteen (18) inches for all lengths:
  - o Where flow from two (2) or more curb or drop inlets must be transported under the pavement to join the main trunk line on the opposite side of the road
  - o Where the inlet end of a pipe has a headwall or the pipe is projecting and subject to possible debris problems
- ♦ Fifteen (15) inches for all lengths where flow from a single curb or drop box must be transported under the pavement to join the main trunk line on the opposite side of the road.

DR 707-6 PHYSICAL INLET, JUNCTION & MANHOLE REQUIREMENTS

The inlets, junctions, and manholes used by KYTC all have physical limitations. Design these structures according to the following guidelines:

- ➢ Ensure that pipes entering these structures fall within the ranges for the maximum and minimum pipe sizes listed on the Standard Drawings.
- ➢ Ensure that the heights of the inlets, junctions, and manholes meet the limitations noted on the Standard Drawings.
- ➢ Ensure that pipe chambers are large enough to intercept the incoming pipes.

  Note: These dimensions should be checked assuming concrete pipe will be used and should account for adverse angles of the pipes entering the chambers.

- ➢ When not noted otherwise in the Standard Drawings, set minimum heights for KYTC inlets as follows:
  - ♦ For cross drainage (pipe under pavement), the minimum height is the pipe diameter, plus the pipe thickness, plus one foot cover, plus pavement thickness (D + t + 1.0’ + pavement thickness).
  - ♦ For pipes outside cross drainage limits parallel to or leading away from the roadway, the minimum height is the pipe diameter, plus the pipe thickness, plus one foot cover, measured from the gutter line elevation to the top of the pipe (D + t + 1.0’).

DR 707-7 STORM SEWER HYDRAULICS

The designer shall design storm sewer systems to:

- ➢ Convey the 25-year storm (design storm) at a depth equal to or less than 80% of the diameter or rise for pipes located in sags which have no exit except through the pipe. If project restrictions will not allow this, design the system for pressure flow and ensure that the resulting hydraulic grade line elevations will not surcharge into to the roadway.

- ➢ Convey the 10-year storm (design storm) at a depth equal to or less than 80% of the diameter or rise for pipes not located in a sag condition. If project restrictions will not allow this, design the system for pressure flow and ensure that the resulting hydraulic grade line elevations will not surcharge into to the roadway.

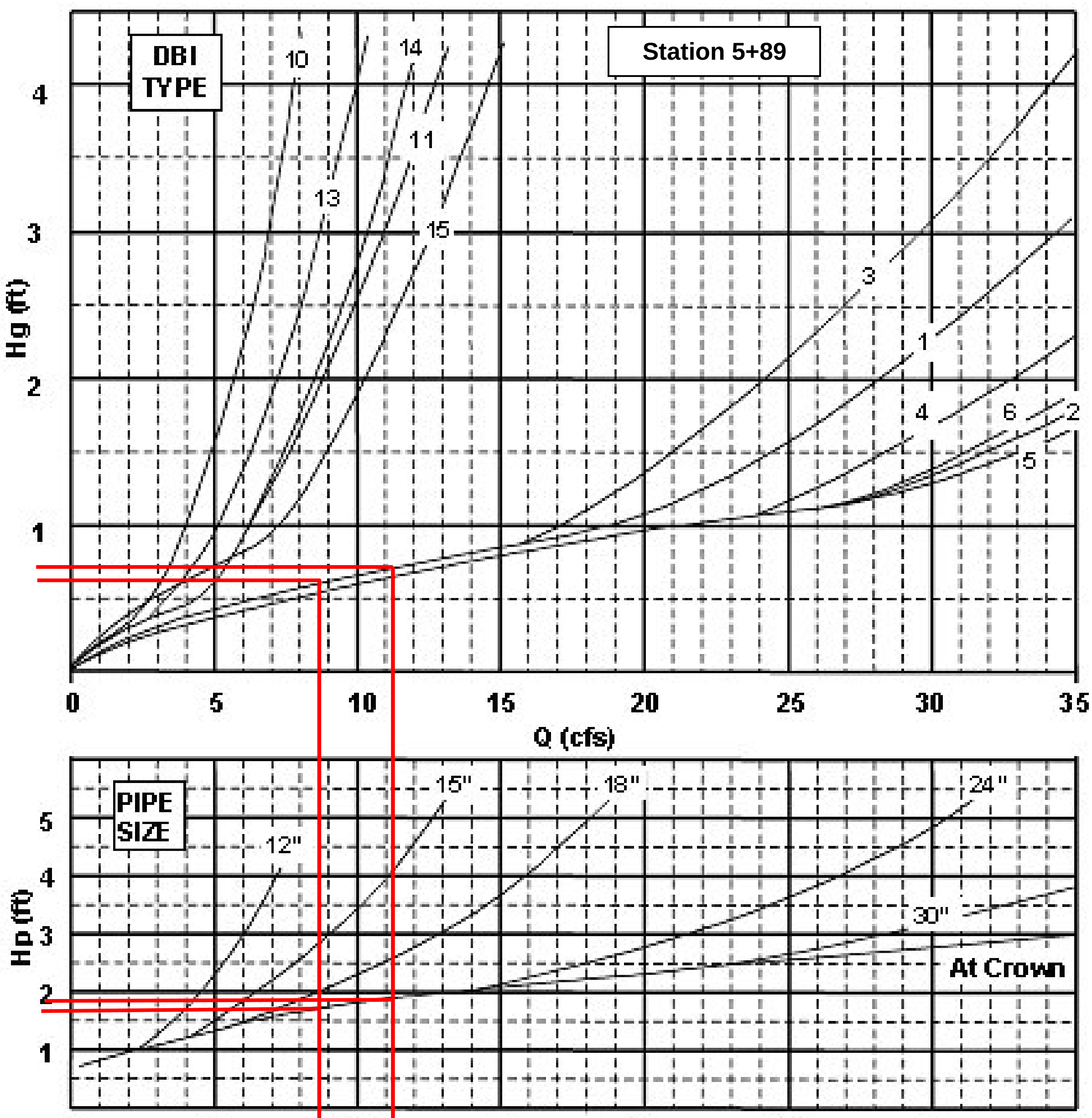
- Keep Hydraulic Grade Line elevations for the 100-year storm (check storm) below levels that will cause damage to adjacent property

- Maintain a minimum velocity of 2 feet per second.

PHYSICAL ATTRIBUTES OF KYTC GRATED INLETS											
DBI Type	**Gross Grate Size**			**Gross Opening**			**Clear Opening**			**Net Area (%)**	**Pipe Size**
	Width	**Length**	**No.**	**Width (ft)**	**Length (ft)**	**Area (sf)**	**Width (ft)**	**Length (ft)**	**Area (sf)**		
1	1'-5 5/8"	3'-4 1/4"	2	2.938	3.354	9.85	2.271	3.292	7.47	75.9	15" - 24"
2	1'-5 5/8"	4'-4 1/4"	2	2.938	4.354	12.79	2.271	4.292	9.75	76.2	30" - 36"
3	1'-5 5/8"	3'-4 1/4"	2	2.938	3.354	9.85	2.313	3.010	6.96	70.7	15" - 24"
4	1'-5 5/8"	4'-4 1/8"	2	2.938	4.344	12.76	2.313	3.906	9.03	70.8	30" - 36"
5	1'-11 3/4"	3'-4 1/4"	2	3.958	3.354	13.28	2.958	3.292	9.74	73.3	15" - 30"
6	1'-11 3/4"	3'-4 1/4"	2	3.958	3.354	13.28	3.146	3.010	9.47	71.3	15" - 30"
7	1'-5 5/8"	3'-4 1/4"	2	2.938	3.354	9.85	2.313	3.010	6.96	70.7	42" - 60"
10	1'-6 3/4"	2'-6"	1	1.542	2.500	3.85	0.729	2.000	1.46	37.8	15", 18"
11	1'-11 1/2"	2'-6"	1	1.958	2.500	4.90	1.125	2.083	2.34	47.9	15" - 24"
12	1'-2"	1'-11 7/8"	3	1.167	5.969	20.89	0.917	2.750	2.52	12.1	12" max.
13	vane grate (grade)			1.479	2.479	3.67	1.229	2.188	2.69	73.3	12" - 48"
13	tilt bar 45° (grade)			1.500	2.354	3.53	1.344	2.010	2.70	76.5	12" - 48"
14	radial grate					2.82					15" max.
15	beehive grate					2.82			1.33	47.0	15" max.
16	vane grate with slotted drain			1.479	2.479	3.67	1.229	2.188	2.69	73.3	12" - 48"
F (CBI)	1'-5 3/4"	1'-11 3/4"	1	1.479	1.979	2.93	0.083	0.385	0.90	30.7	15", 18"
4"x 12"	3 3/4"	12"	1	0.313	1.000	0.31	0.229	0.958	0.22	70.3	3 3/4"
9"x 9"*	8 5/8"	9"	1	0.792	0.750	0.59	0.729	0.500	0.36	61.4	3 3/4"
R4014S	8"	36"	1	0.667	3.000	2.00	0.583	2.333	1.36	68.1	6"
R4014T	9.25"	38"	1	0.771	3.167	2.44	0.646	2.344	1.51	62.0	6"
P-1-7/8	2'-2 1/8"	1'-1/4"	1	26.125	12.250	320.03	20.875	11.250	234.84	73.4	N/A
P-1-1/8	3'	4'	1	36.000	48.000	1728.00	28.125	39.875	1121.48	64.9	N/A
P-1-7/8-4	2'-2 1/8"	4'-3/8"	1	26.125	48.375	1263.80	20.875	43.750	913.28	72.3	N/A

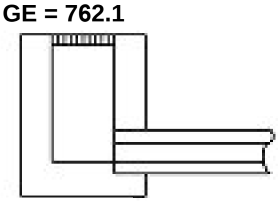
NOTES:

* Refer to Neenah type R-4006.
P-1-7/8 grates have 3/8" longitudinal bars @ 1.875" spacing.
P-1-1/8 grates have 3/8" long. bars @ 1.125" spacing and 1.625" transverse spacers @ 11.25" spacing.
P-1-7/8-4 grates have 3/8" longitudinal bars @ 1.875" spacing and 3/8" transverse bars @ 4" spacing.
DBI type 1 and 2 grates have 1.25" longitudinal bars @ 3" spacing.
DBI types 3 and 4 grates have 3/8" long. bars @ 1.875" spacing and 3/8" transverse bars @ 4" spacing.
DBI type 5 has 1" longitudinal bars @ 3" spacing.
DBI type 6 grate has 3/8" longitudinal bars @ 1.5" spacing and 3/8" transverse bars @ 4"spacing.
DBI type 7 grate has 3/8" longitudinal bars @ 1.5" spacing and 3/8" transverse bars @ 4"spacing.
DBI type 12 grates are based on a construction length of 6 feet per specifications.
4x12 Bridge Deck Drain is similar to DBI type 5.



DBI Type = 1

GE = 762.1



IE = 758.1

HW = GE + Hg
OR
HW = IE + Hp

Diameter = 24”

Design Flows

	Q_{10} = 8.8	Q_{100} = 11.1
Hg	0.6	0.7
HW	762.7	762.8
Hp	1.6	1.9
HW	759.7	760.0