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COMMONWEALTH OF PENNSYLVANIA

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PennDOT Research Project 74-2
Optimal Dimensions of Inlet Gratings

OPTIMAL DIMENSIONS OF PENNSYLVANIA HIGHWAY DRAINAGE INLET GRATINGS

by
Arthur W. Brune
Andrew D. Spear
Kenneth C. Loush

This report was prepared in cooperation with the Pennsylvania Department of Transportation and the Federal Highway Administration.

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Lehigh University
Office of Research
Bethlehem, Pennsylvania
April 1978

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OPTIMAL DIMENSIONS OF PENNSYLVANIA HIGHWAY DRAINAGE INLET GRATINGS

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Federal Highway Administration

The results of testing an experimental model are presented about the optimal dimensions of gratings on drainage inlets that are installed in triangular channels, both grassed and paved, along highways. Each channel was on a grade of either 0.5%, 2%, or 4%.

Each grating was a half-scale model of the prototype. The capacity of each grating was obtained by actual measurement. The width of each grating, 36 in. for the prototype in a paved channel and 48 in. in a grassed channel, was held constant throughout the tests whereas the length of grating ranged from 18 in. to 48 in.

The tests showed that, with an increase in length of the inlet, the capacity increased; the increase depends also upon the grade of the channel, the swale slope, and the back slope. In a grassed channel equal side slopes carry more water than unequal side slopes; both at slopes of 6:1 are superior to both at 12:1; and a flat grade enables more water to enter a grating than a steep grade. A good modulus of the capacity of an inlet is that flow rate of which 98% enters into the inlet and 2% bypasses the inlet.
ABSTRACT

The results of an investigation on an experimental model are presented about the optimal dimensions of gratings on highway drainage inlets that are installed in channels along highways in Pennsylvania.

The channel considered was triangular in shape with swale slopes ranging from 48:1 to 12:1 for the paved channel and from 12:1 to 6:1 for the grassed channel and with back slopes ranging from 3:1 to 1/8:1 for the paved channel and from 6:1 to 1/2:1 for the grassed channel. The grade of the channel was either 0.5%, 2%, or 4%.

Each model grating was built to half of the scale of the prototype. Through model laws other prototype-model relationships were established. The capacity of each grating was obtained by actual measurement. The width of each grating, 36 in. for the prototype in a paved channel and 48 in. in a grassed channel, was held constant throughout the tests whereas the length of grating ranged from 18 in to 48 in.

The tests showed that, with an increase in length of the inlet, the capacity of the inlet increased; the increase depends also upon the grade of the channel, the swale slope, and the back slope. Additionally, in a grassed channel equal side slopes carry more water than unequal side slopes, that both at slopes of 6:1 are superior to both at 12:1, and that a flat grade enables more water to enter a grating than a steep grade. A good modulus of the capacity of an inlet is that flow rate of which 98% enters into the inlet and 2% bypasses the inlet.
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1. INTRODUCTION

1.1 Problem Statement

Runoff along highways from precipitation must be removed from the paved surfaces and adjacent areas. The surface runoff is channeled into drainage inlets and is removed by way of a subsurface system of conduits. The drainage inlets are spaced along the roadway at intervals which are determined by the design engineer.

Two difficulties exist with inlets currently being installed in drainage channels by the Pennsylvania Department of Transportation: (1) water bypasses the inlet owing to the fact either that the inlet is too narrow or that the inlet spacing allows too large of a flow to accumulate in the channel; and (2) part of the inlet grating is not covered entirely with water at times of high flow.

In consideration of these problems, a program of research was undertaken using a channel, that was either paved or grassed, to determine the optimal ratio of length:width of grating based upon the efficiency of the inlet in catching the water flowing in the channel. The back slopes of a channel ranged from 1/2:1 to 12:1 and the swale slopes ranged from 6:1 to 48:1; the side slopes were not necessarily the same for both grassed and paved channels. The lengths of the prototype inlet ranged from 18 to 48 inches. The widths of the inlet were 48 inches in the grassed channel, and 36 inches in the paved channel.
1.2 **Background**

The problem of draining highway areas has been solved commonly by employing empirical or intuitionial approaches, notwithstanding that drainage systems are of paramount importance in highway design. Drainage channels and inlets are placed along the roadways to catch surface runoff and to guide it into a subsurface drainage system. Without such drainage, flooding would occur causing damage to the pavement and base materials, deposition of sediment in low-lying areas, and hinderances to traffic safety.

Until recently, estimation of the capacity of inlet grat­nings had been based on past experience; furthermore, little consider­ation was given to different channel configurations or irregular­ities in the channel surface. Obviously, the hydraulic performance of any inlet grating must be known before it can properly be uti­lized along the highway.

PennDOT Research Project 68-31 at Lehigh University ent­itled "Development of Improved Drainage Inlets", which also used a model study, was completed in January, 1973 in accordance with PennDOT Agreement Numbers 42237 through 42237-H between Lehigh University and the Commonwealth of Pennsylvania. As a result of this project, reports were presented to PennDOT summarizing and evaluating (1) the results of past papers and studies pertaining to highway drainage inlets (Yucel, 1969); (2) new capacities for
inlets installed in paved channels (Yee, 1972), and (3) new capacities for inlets installed in grassed channels (Appel, 1973).

The investigators noted throughout the investigation that, for almost all flow rates, some water in the channel bypassed the drainage inlet because the width of the inlet, perpendicular to the direction of flow, was too narrow. This bypassing of water could probably be prevented by increasing the width of the grating.

Another observation of some importance was that the entire grating surface was not utilized in catching water flowing toward it during high flow situations. Part of some bars on the grating and all of other bars were exposed to the atmosphere in many instances. Specifically, those in the downstream portion of the grating near the channel invert were not covered by water.

Based upon these observations, an investigation was warranted to determine the optimal arrangement of the length:width ratio for an inlet grating which most efficiently utilized the superficial area of the grating and intercepted the maximal amount of inflow.

1.3 Objectives

The objectives of this research program are:

1. To develop a single grating for installation in grassed and paved highway drainage channels based upon maximal
surficial efficiency and inflow interception rates, and

2. To document, by means of photographs, those conditions which determine the optimal length of each respective inlet grating for every channel configuration.
2. MODEL LAWS

2.1 General Remarks

Two common procedures used in solving hydraulic problems are analytical methods and model studies. An analytical method might be more rapid and perhaps more economically feasible at times; however, certain situations do not lend themselves to analytical solutions owing to their complexity. Model studies, on the other hand, can simulate the prototype situation while providing visual as well as statistical means of evaluation. A model is usually smaller than the prototype; thus it is cheaper to fabricate. Working with a smaller apparatus in a controlled environment provides greater ease in handling, preparation, and repair. For these reasons, a model study was chosen to study the highway drainage inlets.

Prior to testing, the similitude between relevant properties of the model and the prototype must be computed, so that events which are noted in the model can be properly related to the prototype. This similitude is determined through model laws. Once the basic prototype:model scale ratio is known, data from the model study can be changed into the associated physical quantities, such as velocity, discharge, or depth, in the corresponding prototype.

The length ratio of 2:1 was determined for the prototype: model after considering (a) the space available in the laboratory, (b) the available pumping facilities, (c) the cost of fabricating
and operating a model of that size, (d) the effect of surface tension, and (e) the facilities were already installed.

It should be noted that the literature available on model laws is extensive and complete, notably, Stevens et al. (1942), Graf (1971), Morris (1963), and Hansen (1967), to name a few.

2.2 Hydraulic Similitude

The correlation between physical quantities in the model and the prototype is called the similitude. For complete similarity between model and prototype, three similitudes must be satisfied: they are geometric, kinematic, and dynamic similitudes.

![Diagram of Model and Prototype Similitude]

2.2.1 Geometric Similitude

Two objects are said to be geometrically similar provided the ratios of corresponding dimensions are equal. For the model
and prototype illustrated in Figure 1, geometric similitude will exist provided

$$L_R = \frac{L_p}{L_m} = \frac{D_p}{D_m}$$

(1)

where $L$ denotes the length of the inlet, $D$ the depth of flow, and $L_R$ the scale ratio. The subscripts, $p$ and $m$, indicate prototype and model, respectively. The similarity between areas and volumes can be easily obtained as well from the scale ratio:

$$L_R^2 = \frac{A_p}{A_m}$$

and

$$L_R^3 = \frac{V_p}{V_m}$$

(2a)

(2b)

where $A$ and $V$ are representative area and volume, respectively.

2.2.2 Kinematic Similitude

Two flow regimes are said to be kinematically similar provided (1) the flow fields have the same shape, and (2) the prototype:model ratios of velocities and accelerations are the same.

2.2.3 Dynamic Similitude

Dynamic similarity exists between prototype and model provided corresponding forces are parallel and have the same prototype:model ratio of forces for all related points in the flow fields. From Fig. 1 the force ratios can be expressed as:

$$F_R = \frac{F'_p}{F'_m} = \frac{F''_p}{F''_m}$$

(3)
where $F_R$ is the force ratio; $F'_p$ and $F''_p$ are forces in the prototype, and $F'_m$ and $F''_m$ are the corresponding forces in the model. The forces which can affect a flow field are those due to inertia $F_I$, gravity $F_g$, pressure $F_p$, viscosity $F_v$, elasticity $F_E$, and surface tension $F_T$. Because water is nearly incompressible and because the model used is fairly large, elasticity and surface tension are negligible and can be ignored in this study. Thus, for complete dynamic similitude, the following equation must be satisfied:

$$
F_R = \left(\frac{F'_p}{F'_m}\right) \frac{F'_g}{F'_m} = \left(\frac{F''_p}{F''_m}\right) \frac{F''_g}{F''_m} = \left(\frac{F'_v}{F'_m}\right) \frac{F''_v}{F''_m}
$$

(4)

2.3 Dimensionless Numbers:

In a hydraulic model study, certain combinations of variables forming dimensionless numbers are more valuable than individual variables. In this case, the Euler number of $Eu$, the Froude number or $Fr$, and the Reynolds number or $Re$ are important dimensionless numbers. These numbers are expressed in the following manner:

$$
Eu = \frac{F_p}{F_I} = \frac{\Delta P}{\rho v^2 L} = \frac{\Delta P}{\rho v^2}
$$

(5)

$$
Fr = \left(\frac{F_I}{F_v}\right)^{1/2} = \left(\frac{\rho v^2 L}{\rho L^3 g}\right)^{1/2} = \frac{v}{(gL)^{1/2}}
$$

(6)

$$
Re = \frac{F_I}{F_v} = \frac{\rho v^2 L}{\mu v L} = \frac{\rho v L}{\mu}
$$

(7)
where \( \rho \) is density, \( v \) is a characteristic velocity, \( \Delta P \) is a pressure difference, \( g \) is the gravitational acceleration, and \( \mu \) is the dynamic viscosity. Only two of these three dimensionless numbers are independent, which means that the third number can be obtained provided the other two are known; thus dynamic similitude is possible provided two of these numbers are simultaneously satisfied. Unfortunately, acquiring complete similarity using only two of these dimensionless numbers is usually impossible owing to the limitations, such as certain characteristics of water and the limited space and facilities available. In most hydraulic engineering problems, however, some forces are orders of magnitude greater than others, which allows some relationships to be ignored. In this way, dynamic similitude can be obtained using but one dimensionless number. For this study, the force of gravity is considered greater than the force of friction, which indicates that Froude similarity alone is sufficient to ensure dynamic similarity between the model and the prototype.

2.4 Froude Model Law

The Froude number for both the model and prototype can be expressed as follows:

\[
Fr = \frac{v_p}{(gL)^{1/2}_p} = \frac{v_m}{(gL)^{1/2}_m}
\]  
(8)
For equal accelerations of gravity, the resulting velocity ratio is:

\[ \frac{v_P}{v_m} = \left( \frac{L_P}{L_m} \right)^{\frac{1}{2}} \]  

(9a)

For a scale ratio of 2.0, as used in the present study, the velocity ratio becomes:

\[ \frac{v_P}{v_m} = (2.0)^{\frac{1}{2}} = 1.41 \]  

(9b)

From Eq. (2) and (9a) the flow-rate ratio can be computed as:

\[ \frac{Q_P}{Q_m} = (L_R)^{2.5} \]  

(10a)

Therefore, with \( L = 2.0 \) in this study:

\[ \frac{Q_P}{Q_m} = 5.66 \]  

(10b)

Using this equation with the model flow rate, the corresponding prototype flow rate can be calculated. A complete list of Froude model similarities is presented in Table 2.1.

2.5 **Manning Model Law**

The effect of frictional forces on the flow regime has been ignored thus far, yet the frictional effect of the channel roughness (grass) on the flow pattern must influence the type of channel flow as well as the efficiency of the drainage inlet. Hence it would be favorable to consider both the frictional and the gravity forces simultaneously. As was mentioned in Section 2.3, it is impossible to satisfy the Froude and Reynolds model
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<td>5.10</td>
</tr>
</tbody>
</table>

$n_r = 0.014$  
$n_r = 0.012$  
$n_r = 0.035$  
$n_r = 0.028$

Table 2.1 Model Scales for Froude and Manning Similitudes
laws simultaneously provided the same fluid is used in both the model and the prototype. Another means of correlating friction and gravity must be adopted.

In open-channel flow, the Manning analogy is commonly introduced, which is derived from the Manning equation:

\[ v = \frac{1.49 \frac{R_h^{2/3} S^{1/2}}{n}}{n} \]  

(11a)

The Manning analogy can be given for model and prototype as:

\[ \left( \frac{R_h^{2/3} S^{1/2}}{v n} \right)_p = \left( \frac{R_h^{2/3} S^{1/2}}{v n} \right)_m \]  

(11b)

where \( R_h \) is the hydraulic radius for the channel, \( S \) is the slope of the energy line, \( V \) is the mean velocity, and \( n \) is the Manning roughness coefficient. Because geometric and kinematic similitudes are present between the model and the prototype, then \( S_m = S_p \), and \( R_h \) can be reduced to a suitable dimension \( L \). Therefore Eq. (11b) becomes:

\[ \left( \frac{L^{2/3}}{v n} \right)_p = \left( \frac{L^{2/3}}{v n} \right)_m \]  

(12)

Using Eq. (9a), Eq. (12) can be expressed as

\[ \frac{n_p}{n_m} = \left( \frac{L_p}{L_m} \right)^{1/6} \]  

(13)
Rearranging Eq. (12) enables the flow-rate ratio to be shown as:

\[
\frac{Q_p}{Q_m} = \left( \frac{L_p}{L_m} \right)^{8/3} \frac{n_p}{n_m}
\]  

(14)

Pertinent flow characteristics are indicated in Table 2.1.

To solve Eq. (14), the roughness coefficient for the model and prototype must be known. The prototype roughness, that of natural grass in this case, is 0.035 according to Chow (1959). An artificial grass known as "Astroturf" was used on the model to simulate grass and was found to have a roughness coefficient of 0.028, as determined by tests performed at Lehigh University. The actual roughness ratio \( n_p/n_m = 1.125 \) is in close agreement with the ratio \( n_p/n_m = 1.122 \) as obtained from Eq. (13). Using the actual roughness ratio and the scale ratio, Eq. (14) becomes for a grassed channel:

\[
\frac{Q_p}{Q_m} = 5.10 \tag{15a}
\]

Introducing the \( n_p:n_m \) ratio and the length ratio, \( L_R = 2.0 \), Eq. 14 then becomes for a paved channel:

\[
\frac{Q_p}{Q_m} = 5.45 \tag{15b}
\]

Turbulent flow is necessary in both the prototype and the model for the Manning analogy to be applicable. Nearly all open-channel flow in nature is turbulent, whereas flow occurring in a simulating model might very well be laminar. To ensure turbulence, the model should operate in such a way as to yield a high Reynolds Number, Re.
The Reynolds Number ratio is

\[
\frac{(\text{Re})_P}{(\text{Re})_m} = \frac{(vL)_P}{(vL)_m} = 2.72
\]  

(16)

A preliminary test was performed on the model, from which it was determined that turbulent flow did exist \((\text{Re} > 7000)\).

2.6 Concluding Remarks

Table 2.1 shows that the Froude similitude, involving gravitational effects, and the Manning analogy, involving frictional effects, give similar results. Either set of numbers could be used in this study. Because the gravitational forces are of obvious importance in this case, Froude similitude has been selected to transform model results into prototype data.
3. MODEL ROUGHNESS

3.1 Grassed Channel

The prototype surface, the highway embankment, is covered with natural grass. Inasmuch as natural grass would be difficult to install and maintain in a laboratory model, an artificial replacement had to be found with roughness characteristics such that its effect upon the flow regime would be comparable to that of the natural grass. Fulfilling both the Froude and Manning similitudes, Eq. (13) can be used to establish the ratio of prototype roughness to model roughness. With a prototype Manning coefficient of 0.035 and a scale ratio of 2.0, the model Manning coefficient becomes 0.031, which is the Manning roughness coefficient that the artificial surface must have.

3.2 Appropriate Artificial Surface: "Astroturf"

An artificial surface with a satisfactory Manning roughness coefficient was readily obtainable; this was "Astroturf". "Astroturf", a landscape surface produced by the Monsanto Chemical Company, is an imitation grass measuring 15/16 inch (2.38 cm) in height, made of green pliable plastic strips attached in groups of eight, spaced equidistantly at 2/5 inch (1.02 cm) from each other, and attached "checkerboard style" to a 1/16 inch (0.16 cm) thick mat. The strips in each cluster, collectively resembling a small bush, are well tangled and present an overall appearance similar to that of natural grass having equal height. The roughness of the "Astroturf" was investigated in a glass-walled rectangular channel, 24 feet (7.31 m) long, 18 inches (0.46 m) wide, having a
two percent longitudinal slope. A point gage mounted on a carriage which ran the length of the flume was used to take base level and depth measurements for different discharges. Manometers attached to a Venturi meter in the supply line indicated the discharge that was flowing for a given situation. Depth readings, which were found to be constant, were taken for a series of distances, the measurements indicating uniform flow over the channel surface.

A description of the artificial turf used and how it was tested follow herewith.

Table 3.1 gives the range of discharges, the corresponding depths, and the calculated Manning roughness coefficients for the tests here mentioned.

<table>
<thead>
<tr>
<th>Discharge cfs</th>
<th>Depth (m³/sec)</th>
<th>Depth ft</th>
<th>Depth m</th>
<th>Manning Roughness Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>(0.010)</td>
<td>0.13</td>
<td>(0.040)</td>
<td>0.031</td>
</tr>
<tr>
<td>0.52</td>
<td>(0.015)</td>
<td>0.17</td>
<td>(0.052)</td>
<td>0.031</td>
</tr>
<tr>
<td>0.74</td>
<td>(0.021)</td>
<td>0.20</td>
<td>(0.061)</td>
<td>0.029</td>
</tr>
<tr>
<td>0.98</td>
<td>(0.027)</td>
<td>0.25</td>
<td>(0.076)</td>
<td>0.030</td>
</tr>
<tr>
<td>1.21</td>
<td>(0.034)</td>
<td>0.27</td>
<td>(0.082)</td>
<td>0.028</td>
</tr>
<tr>
<td>0.45</td>
<td>(0.013)</td>
<td>0.30</td>
<td>(0.092)</td>
<td>0.028</td>
</tr>
<tr>
<td>0.69</td>
<td>(0.019)</td>
<td>0.33</td>
<td>(0.101)</td>
<td>0.028</td>
</tr>
<tr>
<td>1.87</td>
<td>(0.052)</td>
<td>0.35</td>
<td>(0.107)</td>
<td>0.028</td>
</tr>
</tbody>
</table>

TABLE 3.1: EXPERIMENTAL RESULTS FOR "ASTROTURF" MANNING ROUGHNESS

The average roughness coefficient was determined to be 0.028. Apparently, the Manning roughness coefficient of "Astroturf" had not been previously determined; therefore, a comparison with
results of other investigators was not possible. However, according to Chow (1959), the roughness coefficient for natural grass ranges from 0.010 to 0.050; PennDOT, at this time, assumes a coefficient of 0.035 for calculations involving natural grass. The roughness coefficient obtained in this study, 0.028, was thus found to be within this range, and therefore, "Astroturf" was suitable for use in simulating natural grass in the model study.

The Manning coefficient for pavement as used by the Pennsylvania Department of Transportation is $n = 0.014$, which is in good agreement with the literature (Chow, 1959). Plywood, 3/4 in. (1.91 cm) in thickness was used in the model to simulate the paved surface of the prototype. The Manning coefficient of plywood, as determined from flume tests performed at Lehigh University to be $n = 0.012$, again is in accordance with the literature (Chow, 1959). This roughness coefficient was used throughout the study where a paved surface was used.
4. EXPERIMENTAL INVESTIGATION

4.1 Laboratory Equipment

4.1.1 General Requirements of the Model

A full-sized model is ideal in performance tests of different inlet openings; however, as mentioned in Section 2.1, owing to the limitation of the space available, the cost involved, and the maximal discharge available in the laboratory, a prototype: model length ratio of 2:1 was chosen.

Uniform flow was required in the channel upstream from the inlet; consequently the channel had to be long enough with little distortion to insure this. Baffles or vanes could be installed at the headwater of the channel to aid in forming uniform flow.

The frame supporting the model had to be rigid yet versatile. Uncontrolled fluctuations in slopes during testing would lead to faulty data, whereas controlled slope adjustments were required to enable a full testing program of the inlet grating. Simple and rugged mechanisms for changing slopes and inlet grating lengths were required in order to reduce the time interval between tests.

The surface roughness of the channel must be designed to resemble closely the surface of the prototype. Tests must be run to find model surface materials which are easy to handle and which exhibit Manning roughness coefficients that closely resemble those of natural grass and concrete pavements.
For accurate results, care must be taken that no leakage occurs in the entire system and that flow rates be measured as accurately as possible.

4.1.2 Apparatus

A schematic diagram of the testing arrangement is shown in Fig. 41. Either or both of two pumps (B) raise water from the main sump (A) into the pressure tank (D). The two pumps can be operated, separately, in parallel, or in series by adjusting the three valves (C).

Each pump is driven by a Westinghouse 9B Type HF, 220-volt AC, induction motor equipped with a rheostatic control. One motor is rated at 40 hp, and the other at 35 hp. During a test, the pumps were adjusted to a rate of discharge that was constant over a period of time.

Each pump is a DeLaval single-stage, double-suction, centrifugal pump, Type I. One pump had a 10-inch (25.4 cm) suction line and an 8-inch (20.3 cm) discharge line, whereas the other pump had an 8-inch (20.3 cm) suction line and a 6-inch (15.2 cm) discharge line.

The cylindrical pressure tank (D) was 5½ feet (1.54 m) in diameter, and 34 feet (18.7 m) high. The rate of discharge delivered
Fig. 4.1 SCHEMATIC DIAGRAM OF MODEL.
to the manifold discharge pipe (M) in the head tank (N) was controlled by means of the supply valve (E). The rate of inflow was measured, using a 4-inch (10.2 cm) orifice (H) placed upstream from the supply valve in a 12-inch pipe (30.5 cm), by means of either a liquid-water manometer (G) for low discharges or a mercury-water manometer (F) for higher discharges. The manometer liquid had a specific gravity of 2.95. The 4-inch (10.2 cm) orifice had been calibrated numerous times over the previous five years and was re-checked twice during the testing period, each time with the same result, given as:

\[ Q = 0.428 \ H^{0.500} \]  

(17)

where \( H \) is the pressure drop across the orifice in feet of water and \( Q \) is the discharge in cubic feet per second.

From the head tank (N), the water flowed through the channel (J) toward the inlet (I). The water intercepted by the inlet was directed by a manual splitter (K) into a 420-cubic foot (11.9 m\(^3\)) volumetric tank (L). Any flow that bypassed the inlet was channeled into the main sump (A).

The testing tank which held the model was rectangular in shape (see Fig. 42): 33 feet long (10.1 m), 16 feet wide (4.9 m), and 3 feet deep (0.9 m). The tank was constructed on \( \frac{1}{2} \)-inch (0.64 m) steel plate framed by 3-inch (7.6 cm) by 3-inch (7.6 cm) angle iron, and it rested on 2-inch (5.1 cm) by 7-inch (17.8 cm) channel beams.
which were placed transversely on 4-foot (1.2 m) centers along the entire length of the testing tank.

The head tank containing the manifold discharge pipe was 2½ feet (0.76 m) long, 16 feet (4.9 m) wide, and 4 feet (1.2 m) deep.

Fig. 4.2 is a cutaway view of the testing tank, and Fig. 4.3 shows the model placed in the testing tank. A conveyance channel (R) carried the water intercepted by the drainage inlet to an opening (T) which was connected to the splitter and thence either to the volumetric tank or to the main sump. Another opening (U) nearer the downstream end of the testing tank was connected directly to the main sump. During the actual testing period, gates 1 and 4 were closed so that all intercepted flow went to the splitter for measurement if desired and all bypassing flow went directly to the main sump via opening (U).

4.1.3 Model Construction

Two steel frames were constructed to support the swale slope (O) and back slope (P) which formed a triangular channel, as shown in Fig. 4. The swale and back slopes, which were 28 feet (8.5 m) long, 12 feet (3.66 m) and 3½ feet (1.1 m) wide, respectively, were representations of a similar situation in the prototype, i.e., the roadside area. Both frames were made of S4 x 9.5 I-beams welded together. The welded joints were reinforced by clip angles to prevent failure and to minimize deflection. The outer edges of the
Figure 4.3 Testing Apparatus
frames were made of S7 x 15.3 I-beams.

Both frames were covered with 3/4-inch (1.9 cm) outdoor plywood; each piece, measuring 4 feet (1.2 m) by 8 feet (2.4 m), was treated with preservative and with enamel paint. The joints of the plywood were covered with 2-inch (5.1 cm) self-adhesive tape which was then also painted. "Astroturf" was then stapled in long 3-foot (0.92 m) wide sheets to the plywood slopes leaving the drainage inlet open. Hinges were welded to the invert of the channel to prevent lateral separation of the swale slope from the back slope, and also to allow rotation of the frames about the invert whenever changes in the side slopes were desired.

The invert rested on a W8 x 40 I-beam (S), which is 29 feet (8.8 m) in length and is hinged at its downstream end. The proper longitudinal slope was obtained by providing the proper height of support; this was performed by manually placing blocks under the upstream end of the I-beam with the downstream end being fixed. A survey using a rod and engineers' level was made to verify the channel slopes. Support at midspan was added also using blocks to reduce any midpoint deflection. An overhead crane in the laboratory was used to raise the upstream end into position.

The main supporting beam was cut just upstream and downstream from the inlet (see Fig. 43) and a box section, made of the same type of I-beam was installed to replace the piece that was cut
from the main beam. This modification was made to enable the water intercepted by the inlet to fall directly into the conveyance channel without splashing over any obstacle and to facilitate emplacement of the grating itself.

The outer edge of each frame was supported by two 3/4-inch (1.9 cm) threaded tension rods (Q), enabling the changing of each side slope independently of the other. Layers of 1/2-inch (1.3 cm) hardware cloth were soldered together to form a 1-foot (0.31 m) thick mat which was placed at the upstream end near the head tank; the cloth acted as a baffle to aid in developing uniform flow in the channel upstream from the inlet.

4.2 The Drainage Inlet

4.2.1 The Drainage Inlet in Grassed Channels

The drainage inlet grating for grassed channels and as used in this study was made of wood with diagonal bars (see Fig. 4.6). The overall drainage inlet size of the model was 36 inches (0.92 m) in length and 24 inches (0.61 m) in width, corresponding to 72 inches (1.8 m) by 48 inches (1.2 m) in the prototype. For median slopes the grating was placed symmetrically with the invert, whereas for swale (cut) slopes one edge coincided with the invert. The width was held constant; however, the length of the drain was altered by covering downstream portions of it with metal plates mounted on triangular wedges which coincided with the slope of the sides. "Astroturf" was attached to the metal plates to give continuity of surface roughness. A rubber skirt was installed around the inlet and under the wedges to prevent leakage. Figure 4.7 shows the installation of a model grating in a grassed channel.
Figure 4.4 is a picture of the apparatus looking upstream. The position of the inlet grating is shown as it was installed in the grassed median, which in the model is covered with "Astroturf". Dressing of the slopes adjacent to the inlet is not shown. On the right side is the discharge end of the model. The slope near the observer was termed the swale, and the far one, the back slope.

Figure 4.5 is a view of the head tank, showing the hardware cloth that was placed downstream from the tank in order to aid in developing uniform flow in the channel.
Figure 4.4 Upstream View of Testing Apparatus

Figure 4.5 Upstream End of Model Apparatus

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Fig. 4.6 Inlet Grating for Grassed Channel with Prototype Dimensions
Figure 4.7 Installation of Model Grating in Grassed Channel
4.2.2 The Drainage Inlet in Paved Channels

The drainage inlet grating for paved channels and as used in this study was made of wood with diagonal bars (see Fig. 4.8). The overall grating size of the model was 36 in. (0.92 m) in length and 18 in. (0.46 m) in width, corresponding to 72 in. (1.84 m) by 36 in. (0.92 m) in the prototype. The grating was installed with one side directly along the invert of the swale slope. The width was held constant at 18 in. (0.46 m) for the model, while the length of the grating was altered by covering downstream portions of it with thin metal plates. A rubber skirt was installed around the inlet and under the plates to prevent leakage. The plates were covered with enamel paint to give continuity to surface roughness. Figure 4.9 shows the installation of a model grating in a paved channel.
Figure 4.8 Inlet Grating for Paved Channel with Prototype Dimensions
Figure 4.9 Installation of Model Grating in Paved Channel
4.3 Procedure

4.3.1 Flow Measurements

As mentioned in Section 4.1.2, the flow rate into the head tank and subsequently into the channel was determined by reading manometers attached to a 4-inch (10.2 cm) orifice installed in the supply line. The liquid manometer, which had a specific gravity of 2.95, was used at low discharges yielding accurate readings, whereas the mercury manometer, which had a specific gravity of 13.6 was used at higher discharges because it fluctuated far less than the liquid manometer at high flow rates. No particular flow rate was chosen as a transition point for switching from one manometer to the other. The switch was made during testing for convenience, as the precision of both manometers was within the accuracy of the other measurements taken. Figure 4.10 is a sample data sheet used during the study.

Water flowed down the channel and was totally or partly intercepted by the inlet depending upon the flow rate. The intercepted water was then channeled to the splitter which directed it to a volumetric tank for measurement or to the main sump for recirculation. That flow which bypassed the inlet was directed into the main sump. The total flow, \( Q_1 \), was calculated either from the manometer readings and Eq. 16 or, for very low rates of flow, as the sum of \( Q_2 \) and \( Q_3 \). The intercepted flow, \( Q_2 \), determined by measuring water levels in the volumetric tank over a suitable time interval. The bypassing flow, \( Q_3 \), was obtained by taking the difference between \( Q_1 \) and \( Q_2 \). Very low flow rates were determined by noting the time required to obtain a known volume of water.
Figure 4.10 Sample Data Sheet for Flow at Inlet with Dressed Slopes
4.3.2 Depth and Width Measurements

Depth measurements were taken in the invert at stations 1 ft. (0.31 m), 2 ft. (0.61 m), and 3 ft. (0.92 m) upstream from the inlet during each test. A point gage graduated to 0.001 ft. (0.03 cm) was used for all depth measurements. The depth was determined by subtracting the gage reading for the channel bottom at the invert from the gage reading at the water surface. The point gage was mounted on an aluminum beam 3-inch (7.6 cm) by 5-inch (12.7 cm), which spanned the model perpendicular to the channel invert, and was supported by a monorail system at each end that enabled it to travel freely above the channel. This facilitated depth measurements at any point in the channel.

For this experiment, steady uniform flow was required upstream from the inlet for accurate measurements. Near the grating, reduction in the vertical and lateral dimensions of flow existed owing to the convergence of the water into the grating, thus disturbing the uniform flow. In this situation, it was desirable to maintain a cross-sectional area of constant shape. Consequently, width of flow measurements were taken at the same stations as mentioned above to serve as a check. A tape measure mounted on the aluminum beam was used as a range finder together with a plumb bob that was lowered to the edge of the water. This is shown in Fig. 4.11.
Fig. 4.11 Device for Measuring Depth and Width of Water
4.3.3 **Technique**

Before each test, the appropriate longitudinal slope was set using a surveyor's level as a guide. Next the side slopes were adjusted as required using a triangular template and a level, and then the length of the open grating was set. Inasmuch as setting the longitudinal slope was the most time consuming and difficult of the adjustments, all tests with the same longitudinal slope were performed in succession, thus reducing the number of these more difficult changes to a minimum.

Subsequently, the pumps were started, and the supply valve was opened to provide a flow rate which was visually determined to be the maximum flow rate possible without allowing any water to bypass the drainage inlet.

After a period of several minutes had elapsed to allow steady flow to develop, the splitter was set to direct the intercepted flow into the volumetric tank for 60 seconds. The increase in volume divided by time gave $Q_2$. Next the reading of the manometers at the orifice in the supply line enabled $Q_1$ to be calculated, and consequently $Q_3$ was determined, which was zero for no bypassing flow. Finally, the different depth and width measurements were made and recorded, and photographs were taken.
The run was completed by following the same procedure for flow rates of 175%, 150%, 125%, and 50% of the maximal flow rate as determined in the first step. Occasionally the flow rate of 200% was used. The experimental data are summarized in part in Section 5.

The equation for the 4-inch orifice, Eq. 17, was examined at low rates of flow which produced readings on a leg of the manometer, using a liquid with a specific gravity of 2.95, that ranged from 0.05 inch to 0.3 inch. Each flow rate was compared with that obtained volumetrically. The error within that range lay between +25% and -6%. For flow rates above those mentioned, that is, from a prototype flow of 0.8 cfs and higher, the discrepancy was a maximum of 6%.
5. RESULTS

5.1 Introduction

The results of the tests that were performed on the models are shown in tabular and graphical forms. The tables are given for the prototype units; the same is true of the graphs. The results of tests made on gratings, installed in grassed channels are shown, followed by the results for paved channels.

The tables and graphs are presented in conventional or English units, that is, feet and seconds, and in System Internationale or SI units, that is, meters and seconds. The SI tables are given in the Appendix.

In order to make comparisons between gratings of different lengths, an attempt was made to establish a common base. The $Q_{100}$ flow is the maximum that is intercepted by an inlet with zero bypass, or $Q_3 = 0$. However, owing to the accuracy of the equipment and to different personnel making the tests, the $Q_{100}$ flow was somewhat subjective. The units associated therewith are cubic foot per second (cfs) and cubic meter per second ($m^3/s$).

The next step was to divide that flow rate, $Q_{100}$, by the length of the grating. The resulting quantity is called Specific Capacity; this is the capacity per unit length of grating. The concomitant units are either cubic foot per second per foot (cfs/ft) or cubic meter per second per meter ($m^3/s/m$).

Previously tests had been made by Lehigh University personnel on standard gratings used by PennDOT; those tests were accomplished in PennDOT Research Project 68-31. The results of some of those tests are included in this report.
5.2 Inlet in Grassed Channel with Mild Slopes

The capacities of gratings installed in grassed channels having mild slopes, such as medians, are listed in Table 5.1 for grades of 0.5%, 2%, and 4%, and they are plotted in Figures 5.2, 5.3, and 5.4 as well. Additionally in the tables are shown the results of slopes that were dressed at 2:1 adjacent to the inlet, Fig. 5.1a. The purpose of a dressed inlet is to aid in directing the flow of water into an inlet. On those plots a solid line designates the results for a back slope of 6:1, and a dashed line designates the results for a back slope of 12:1. The data for those conditions but nondressed, Fig. 5.1b, are shown in the diagrams as a dotted line.

The specific capacity of each grating is listed in Table 5.2 and is plotted in Figures 5.5, 5.6, and 5.7, for grades of 0.5%, 2%, and 4%, respectively; the swale and back slopes are indicated also. The result of each test having a back slope of 6:1 is shown as a solid line, whereas the result for a back slope of 12:1 is shown as a dashed line.

The specific capacity is the least for a grating on a 4% grade, and the other grades are equal in specific capacity. The graphs show that any of the three grades having equal slopes, swale and back, has a higher capacity than a grade with unequal side slopes. The plots reflect the advantage of having equal side slopes, especially at 6:1; on grades of 0.5% and 2% this feature is particularly outstanding. This point was not as noticeable in the results of tests on the Type 4-ft Special and the Type 6-ft Special which had been previously investigated.

Throughout most of the investigation of inlets installed in grassed channels, the side edges of the top of the grating were below the lower
edge of each side slope. However, for some of the last tests, inserts were made to be placed adjacent to the grating. The inserts had a slope of 2:1 and dressed the slopes adjacent to the inlet so as to direct flow from the slopes into the grating. Figure 5.1a shows the slopes as they were dressed at 2:1, the upstream dressing being shown in white and the side slopes as gray.

5.3 Inlet in Grassed Channel with Steep Slopes

Table 5.3, Capacity of Prototype Gratings in Grassed Channels, Steep Back Slopes (English Units), shows the Q_{100} rate of flow in cfs that each grating captured without any water bypassing the inlet. The grades used were 0.5%, 2%, and 4%. The swale slope was either 6:1 or 12:1, and the back slope was either 1/2:1 or 2:1. The data are plotted in Fig. 5.8 for a grade of 0.5%; in Fig. 5.9 for a 2% grade; and in Fig. 5.10 for a 4% grade.

In order to compare the results, each capacity in the two foregoing tables was divided by its pertinent length of grating to give its specific capacity in cubic foot per second per foot of length of grating; this information appears in Table 5.4. The specific capacities are shown in graphical form in Fig. 5.11 for a grade of 0.5%; in Fig. 5.12 for a 2% grade, and in Fig. 5.13 for a 4% grade.
Fig. 5.1a  Dressed Slopes Adjacent to Inlet

Fig. 5.1b  Inlet with Nondressed Slopes
### TABLE 5.1 CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, MILD BACK SLOPES (English Units)

<table>
<thead>
<tr>
<th>Grade Slope (%)</th>
<th>Slope</th>
<th>Swale</th>
<th>Back</th>
<th>Length of Grating (in.)</th>
<th>Capacity (cfs) $Q_{100}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>½</td>
<td>12:1</td>
<td>6:1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6:1</td>
<td>7.08</td>
<td>9.00</td>
<td>10.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>3.11</td>
<td>3.40</td>
<td>3.74</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>6:1</td>
<td>3.34</td>
<td>3.62</td>
<td>3.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*6:1</td>
<td>6:1</td>
<td>4.08</td>
<td>4.92</td>
<td>6.74</td>
<td>8.32</td>
</tr>
<tr>
<td></td>
<td>6:1</td>
<td>5.89</td>
<td>8.60</td>
<td>10.58</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>3.62</td>
<td>4.02</td>
<td>4.70</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>12:1</td>
<td>6:1</td>
<td>2.21</td>
<td>2.72</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*6:1</td>
<td>6:1</td>
<td>3.12</td>
<td>3.68</td>
<td>4.19</td>
<td>5.38</td>
</tr>
<tr>
<td></td>
<td>6:1</td>
<td>1.92</td>
<td>4.47</td>
<td>6.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>3.28</td>
<td>3.17</td>
<td>3.40</td>
<td></td>
</tr>
</tbody>
</table>

(1) Table 5.7, Report 364.4, column heading "TYPE 4-FT: CAPACITY (cfs) WITHOUT DIKE"

(2) Table 5.7, Report 364.4, column heading "TYPE 6-FT: CAPACITY (cfs) WITHOUT DIKE"

*Slopes dressed at 2:1
Figure 5.2 Capacity vs. Length of Grating, Grassed Channels with Mild Slope; Prototype; 0.5% Grade.
Figure 5.3 Capacity vs. Length of Grating, Grassed Channels with Mild Slopes; Prototype; 2% Grade.
Figure 5.4 Capacity vs. Length of Grating, Grassed Channels with Mild Slopes; Prototype; 4% Grade.
### TABLE 5.2 SPECIFIC CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, MILD BACK SLOPES (English Units)

<table>
<thead>
<tr>
<th>Grade Slope (%)</th>
<th>Swale Back</th>
<th>Specific Capacity (cfs/ft length)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Length of Grating (in.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>3/4 12:1</td>
<td>6:1</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.57</td>
</tr>
<tr>
<td>* 6:1</td>
<td>6:1</td>
<td>4.39</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.07</td>
</tr>
<tr>
<td>2 12:1</td>
<td>6:1</td>
<td>2.23</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.49</td>
</tr>
<tr>
<td>* 6:1</td>
<td>6:1</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.41</td>
</tr>
<tr>
<td>4 12:1</td>
<td>6:1</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.45</td>
</tr>
<tr>
<td>* 6:1</td>
<td>6:1</td>
<td>2.08</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>2.19</td>
</tr>
</tbody>
</table>

Source: Table 5.1, CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS (English Units)  
Each capacity in Table 5.1 is divided by the pertinent length of grating.  
Note: (1) See notes 4 and 5, Table 5.1  
*Slopes dressed at 2:1
Figure 5.5 Specific Capacity vs. Length of Grating, Grassed Channels with Mild Back Slopes; Prototype; 0.5% Grade.
Figure 5.6 Specific Capacity vs. Length of Grating, Grassed Channels with Mild Back Slopes; Prototype; 2% Grade.
Figure 5.7 Specific Capacity vs. Length of Grating, Grassed Channels with Mild Back Slopes; Prototype; 4% Grade.
TABLE 5.3 CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, STEEP BACK SLOPES (English Units)

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Capacity (cfs) Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Length of Grating (in.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>6:1</td>
<td>1/2:1</td>
<td>5.43</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4.13</td>
</tr>
<tr>
<td>12:1</td>
<td>1/2:1</td>
<td>2.77</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4.53</td>
</tr>
<tr>
<td>6:1</td>
<td>1/2:1</td>
<td>4.41</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4.64</td>
</tr>
<tr>
<td>12:1</td>
<td>1/2:1</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4.13</td>
</tr>
<tr>
<td>6:1</td>
<td>1/2:1</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>4.02</td>
</tr>
<tr>
<td>12:1</td>
<td>1/2:1</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>2:1</td>
<td>3.00</td>
</tr>
</tbody>
</table>

(1) Table 5.1, Report 364.4, Type H inlet grating with diagonal bars.
Figure 5.8 Capacity vs. Length of Grating, Grassed Channels
with Steep Back Slopes; Prototype; 0.5% Grade
Figure 5.9  Capacity vs. Length of Grating, Grassed Channels
with Steep Back Slopes; Prototypes; 2% Grade.
Figure 5.10  Capacity vs. Length of Grating, Grassed Channels with Steep Back Slopes; Prototype; 4% Grade.
<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Swale</th>
<th>Back</th>
<th>Specific Capacity (cfs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H Diag</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18</td>
</tr>
<tr>
<td>½</td>
<td>6:1</td>
<td>½:1</td>
<td>3.62</td>
<td>4.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>2.75</td>
<td>2.49</td>
</tr>
<tr>
<td>12:1</td>
<td>½:1</td>
<td>1.85</td>
<td>2.15</td>
<td>2.02</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>3.02</td>
<td>2.83</td>
</tr>
<tr>
<td>2</td>
<td>6:1</td>
<td>½:1</td>
<td>2.94</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>3.09</td>
<td>2.49</td>
</tr>
<tr>
<td>12:1</td>
<td>½:1</td>
<td>1.62</td>
<td>1.79</td>
<td>1.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>2.75</td>
<td>2.35</td>
</tr>
<tr>
<td>4</td>
<td>6:1</td>
<td>½:1</td>
<td>2.11</td>
<td>2.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>2.68</td>
<td>2.55</td>
</tr>
<tr>
<td>12:1</td>
<td>½:1</td>
<td>1.21</td>
<td>1.39</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>2.00</td>
<td>1.81</td>
</tr>
</tbody>
</table>

Source: Table 5.3 CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, STEEP BACK SLOPES (English Units)
Each capacity in Table 5.3 is divided by the pertinent length of grating.
Length of Type H grating is 60 in or 5 ft; PennDOT Standard Drawing "Miscellaneous Inlets - Supplemental Sheet A", Revised July 20, 1955.
Figure 5.11 Specific Capacity vs. Length of Grating, Grassed Channels with Steep Back Slopes; Prototype; 0.5% Grade.
Figure 5.12 Specific Capacity vs. Length of Grating, Grassed Channels with Steep Back Slopes; Prototype; 2% Grade.
Figure 5.13 Specific Capacity vs. Length of Grating, Grassed Channels
with Steep Back Slopes; Prototype; 4% Grade.
5.4 Nominal Capacity of Inlet in Grassed Channel

The capacity of a grating that has been termed $Q_{100}$ is the highest flow rate that enters the grating with none bypassing. However, it is not a good modulus of the reasonable capacity of a grating. A better measure of capacity is one wherein some water is permitted to bypass or overflow the grating, although the percentage that is bypassing at a so-called nominal capacity is a subjective matter.

Nevertheless a series of tests were made on the gratings installed in grassed channels with dressed slopes and side slopes of 6:1. In each test the rate of flow was carefully increased until approximately 10% of the flow was bypassing the inlet. The relative capacities, as efficiency, are plotted on Figures 5.14, 5.15, and 5.16, for grades of 0.5%, 2%, and 4%, respectively, using prototype grating lengths that ranges from 18 in. to 48 in. in increments of 6 in. Efficiency in percent is plotted on the y axis, efficiency being defined as the ratio of the rate of water flowing into the grating to the rate of water approaching the grating; the approach flow rate of the prototype is plotted on the x axis.

By agreement with personnel from PennDOT an efficiency of 98% was selected as the nominal capacity of the gratings; at that percentage, as marked on the plots, the slope of each curve no longer is changing markedly as it does in going from an efficiency of 100% to 98%.

The Nominal Capacity, $Q_{98}$, of Gratings Installed in Grassed Channels, Dressed Slopes (English Units) is shown in Table 5.5.
Figure 5.14 Efficiency of Inlet Gratings vs. Flow Rate in Grassed Channels with Dressed Slopes; Prototype; 0.5% Grade.
Figure 5.15 Efficiency of Inlet Gratings vs. Flow Rate in Grassed Channels with Dressed Slopes; Prototype; 2% Grade.
Figure 5.16 Efficiency of Inlet Gratings vs. Flow Rate in Grassed Channels with Dressed Slopes; Prototype; 4% Grade.
TABLE 5.5 NOMINAL CAPACITY, $Q_{98}$, OF GRATINGS
IN GRASSED CHANNELS, DRESSED SLOPES (English Units)

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Capacity (cfs)</th>
<th>Prototype Length of Grating (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>0.5</td>
<td>9.18</td>
<td>11.88</td>
</tr>
<tr>
<td>2.0</td>
<td>7.90</td>
<td>10.60</td>
</tr>
<tr>
<td>4.0</td>
<td>5.78</td>
<td>8.92</td>
</tr>
</tbody>
</table>

Side slopes are 6:1.

5.5 Inlet in Paved Channel

Table 5.6, Capacity of Prototype Gratings in Paved Channels (English Units), lists the $Q_{100}$ rate of flow to each inlet without any water bypassing the opening; the units of measure being cubic foot per second. These data have been plotted in Fig. 5.18 for grades of 0.5%, 2%, and 4%.

The specific capacity, cubic feet per second per foot of length is listed in Table 5.7, and the data are plotted in Fig. 5.19.
TABLE 5.6  CAPACITY OF PROTOTYPE GRATINGS IN PAVED CHANNELS (English Units)

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Capacity (cfs)</th>
<th>Q100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Length of Grating (in.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>½</td>
<td>12:1</td>
<td>1/8:1</td>
<td>1.47</td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.91</td>
</tr>
<tr>
<td>4</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.40</td>
</tr>
</tbody>
</table>

¹ Table 4.2, Report 354.3, p 42
² Table 4.3, Report 364.3, p 43
<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Specific Capacity (cfs/ft)</th>
<th>Length of Grating (in.)</th>
<th>4-ft Special</th>
<th>6-ft Special</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>18 21 24 27 30 33 36 42 48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>½</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.981 0.995 0.885 0.813 0.836 0.767 0.740 0.703 0.665</td>
<td>0.368</td>
<td>0.443</td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.607 0.714 0.710 0.778 0.792 0.967 0.957 0.929 0.958</td>
<td>0.693</td>
<td>0.670</td>
</tr>
<tr>
<td>4</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.267 0.309 0.350 0.378 0.488 0.520 0.523 0.583 0.575</td>
<td>0.850</td>
<td>0.680</td>
</tr>
</tbody>
</table>

Source: TABLE 5.6 CAPACITY OF PROTOTYPE GRATING IN PAVED CHANNELS (English Units)  
Each capacity in Table 5.6 is divided by the pertinent length of grating.
Figure 5.17 Capacity vs. Length of Grating, Paved Channels;
Prototype; Grades of 0.5%, 2%, 4%.
Figure 5.18  Specific Capacity vs. Length of Grating, Paved Channels; Prototype; Grades of 0.5%, 2%, 4%.
6. DISCUSSION

6.1 Remarks

Each plot of capacity against length of grating for any one inlet shows that the capacity increases as the length of grating is increased; or the longer the inlet, the more water it can take. This was an expected result.

In considering the relation of specific capacity to length, a similar condition does not occur. Rather for some gratings the relation is almost constant, whereas for others a decrease, although slight, is noticed with an increase in length.

6.2 Inlet in Grassed Channel with Mild Slopes

The plots of capacity vs length for an inlet in a grassed channel that has mild side slopes, Figures 5.2, 5.3, and 5.4, show an increase in capacity as the length of the inlet is increased. The capacity is highest for a grade of 0.5% and lowest for a grade of 4%; this point is very noticeable for equal side slopes of 6:1. For side slopes with the other ratios used, that difference is not marked. Side slopes that are equal lead to higher capacity of an inlet than an installation with unequal side slopes, probably owing to the fact that the center of gravity is toward the flatter slope and not in coincidence with the invert as is true of an inlet installed on a grade having equal side slopes.

On each of the plots, Figures 5.2 to 5.7, two sets of lines are shown for the condition wherein both side slopes were equal at 6:1. The solid line refers to the data obtained for the condition where the slopes adjacent to the inlet were dressed at 2:1; the dotted line refers to the
condition in which the slopes were not dressed. The lines for the dressed slopes show an increase in capacity with an increase in length, as do the other lines. The Specific Capacity plots, Figures 5.5 to 5.7, generally show a decrease of specific capacity with an increase in length, except for equal side slopes of 6:1 on a 2% grade.

The data seem to indicate that an inlet with dressed slopes has a lower capacity than one with no dressing. However several points must be borne in mind in considering the results as shown in Table 5.1. Each flow rate was that which was designated as $Q_{100}$, meaning the maximal amount of water that could enter the inlet with none either overflowing or bypassing the inlet. In comparing the raw-data sheets for the different test configurations, there was an obvious difference in the $Q_{100}$ as recorded. The difference, as seen in Table 5.1, appears to be due to a change in observers, and, consequently, each $Q_{100}$ is subjective. The difficulty in selecting $Q_{100}$ can be noted in Table 6.1. Depending on the observer, $Q_{100}$ could have been selected from the range between 0.555 cfs and 1.09 or 2.18 cfs. A second factor causing the difference in rates of flow in the model, the two conditions at the inlet were determined to be on one leg of the manometer as low as 0.02 inch and as high as 7.7 inches, the latter being in the data for the 2% grade.

A superior measure of the capacity of an inlet is that flow of which a small amount overflows or bypasses the inlet. This was done in the determination of the nominal capacity of the inlets on the dressed slopes during which tests as much as 10% was permitted to bypass the inlet. The nominal capacity is that where 2% of the approaching water overflowed or bypassed the inlet, and the overflow as well as the water falling into the inlet were
both measured volumetrically, not depending on the manometer and orifice. Consequently, the Q₉₈ is a better estimate of the inflow. The results for the Q₉₈ of the dressed inlet were greater than the flow for an inlet with slopes that were not dressed.

6.3 **Inlet in Grassed Channel with Steep Slopes**

Figures 5.8, 5.9, and 5.10 are capacity plots for prototype gratings installed in a grassed channel with steep side slopes, showing the relation between capacity and length of grating exposed to the approaching flow of water for grades of 0.5%, 2%, and 4%, respectively. The results from previous tests of the Type H inlet grating were also plotted, and those results, in spite of the different width of grates (31 in.), tend to fall along the paths of the concomitant gratings used in the current study. Each line has, of course, the general shape that occurs as the length of any inlet becomes greater. The capacity of the inlet increases with an increase in length of the inlet. Particularly noticeable is the higher capacity in a channel that has a swale slope of 6:1 for almost each condition tested, that channel having both a higher capacity and a steeper slope than the channel with a swale slope of 12:1. For comparative purposes such a plot must be modified by dividing each capacity by the length of the particular grating involved, resulting in the specific capacity of each grating in units of cfs/ft of length. These data were plotted in Figures 5.11, 5.12, and 5.13 for the same grades as mentioned previously. The plot for almost every grating sloped downward with increasing length. No particular geometric combination of grade and side slopes was outstanding. The back slope of ½:1 was unusual in that, with swale slopes of 6:1 and 12:1, it showed the highest and lowest specific capacity for grades of 0.5% and 2%, respectively.

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6.4 Nominal Capacity of Inlet in Graded Channel

Table 5.5 lists the capacity of each grating in a grassed channel having slopes dressed at 2:1 adjacent to the inlet; the data are taken from Figures 5.14, 5.15, and 5.16 at a condition where 2% of the water approaching the inlet bypasses the grating, which is another way of stating that 98% of the approaching water enters into the inlet.

The tabulation shows a great increase in capacity as the grating is lengthened, but a decrease in capacity as the grade is increased from 0.5% to 4%. However the increase in length has a greater effect on capacity than the increase in grade.

Specifically, for each 6-in. increase in length the capacity increased an average of 2.4 cfs, ranging from a low of 1.60 cfs to a high of 3.14 cfs; both of these occurred on the 4% grade. In considering the change in capacity for an inlet of any one length on different grades, the data show an average decrease in capacity of 1.7 cfs, the lowest such change being 0.71 cfs and the highest change as 3.03 cfs.

6.5 Inlet in Paved Channel

Figure 5.17 is a plot, for a prototype inlet installed in a paved channel, showing the relation between capacity and length of grating exposed to the approaching flow of water. As is to be expected, the
capacity increases with length of grating; this is also shown by the points pertaining to the Type 4-ft Special (26½ in. wide) and the Type 6-ft Special (26½ in. wide) which points were determined in a previous study.

The trends of the 2% and 4% lines are approximately the same, whereas the 0.5% line is somewhat flatter, crossing the 2% line near the center of the range of tests. The capacity of inlets installed on a 2% grade ranges from ½ cfs to 1 cfs greater than that of inlets on a 4% grade.

Figure 5.18, which shows the specific capacity of hose gratings, obviates or nullifies the effect of the length of inlet with the result that the lines are approximately horizontal. Inlets installed on a 4% grade have less specific capacity that those on flatter grades.

Both Figure 5.17 and 5.18 show that the grade of a channel is a very significant feature about the rate at which water can enter an inlet.

On the graphs are plotted the results of tests previously conducted on the Type 4-ft Special and the Type 6-ft Special inlet gratings. The graphs show that the capacities of those inlets, in spite of the different width of grates (26½ in.), fall in the same range as those that were observed in this study.
6.6 Photographs of Flow to an Inlet

Figures 6.1 to 6.5 are photographs which show the area of an inlet grating that is covered for different rates of flow. The geometry of the situation consisted of a grade of 0.5%, a "swale" slope of 12:1, a back slope of 3:1, and a model length of 9 inches or a prototype length of 18 inches. A pictorial series of flows to an inlet in a paved channel was chosen to be shown because flow in a paved channel can be seen in a photograph far better than flow in a channel covered with an artificial turf.

Table 6.1 lists the pertinent data about the flow.

**Table 6.1 Flow in a Paved Channel; Prototype Flow Rate (cfs)**

<table>
<thead>
<tr>
<th>Q</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Efficiency (%)</th>
<th>Figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>.555</td>
<td>.555</td>
<td>----</td>
<td>----</td>
<td>6.1</td>
</tr>
<tr>
<td>1.0</td>
<td>1.09</td>
<td>1.09</td>
<td>----</td>
<td>100</td>
<td>6.2</td>
</tr>
<tr>
<td>2.0</td>
<td>2.18</td>
<td>2.15</td>
<td>.03</td>
<td>98.6</td>
<td>6.3</td>
</tr>
<tr>
<td>2.5</td>
<td>2.77</td>
<td>2.54</td>
<td>.23</td>
<td>91.5</td>
<td>6.4</td>
</tr>
<tr>
<td>3.0</td>
<td>3.28</td>
<td>2.95</td>
<td>.33</td>
<td>90.1</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Prototype length: 18 in.; width: 36 in.
Grade: 0.5%
Swale Slope: 12:1
Back Slope: 3:1

In Figure 6.1 the water extends to three-fourths of the width of the inlet; a very small length of the inlet has water on it. Figure 6.2 shows the water extending to the full width of the inlet; no flow is bypassing the inlet. Figure 6.3 has twice the flow rate of Figure 6.2 with a decrease of efficiency of 1.4%. Much of the grating is not covered with water. The
wooden bar marked in 1/2-foot intervals was placed so as to show clearly the extent of the water up the swale slope. Figure 6.4 has a flow of 2.5 Q, and Figure 6.5, a flow of 3Q. Notwithstanding the large increase of approach flow, Figure 6.5 shows that almost one half of the grating has no water on it, although the inlet is capturing nine tenths of the water coming to it.
Figure 6.1  Flow in a Paved Channel; 0.555 cfs

Figure 6.2  Flow in a Paved Channel; 1.09 cfs
Figure 6.3  Flow in a Paved Channel; 2.18 cfs

Figure 6.4  Flow in a Paved Channel; 2.77 cfs
Figure 6.5 Flow in a Paved Channel; 3.28 cfs
7. CONCLUSION

The investigators have drawn the following conclusions from the study:

7.1 **Inlet in Grassed Channel with Mild Slopes**

Figures 5.2, 5.3, and 5.4, Capacity vs Length of Grating for three different grades, show that the capacity of a grating increases with an increase in length. Furthermore, the capacity for any one length decreases as the grade of the channel becomes steeper.

Additionally, a channel which has equal side slopes has a greater capacity than one with unequal side slopes, and, provided a channel has equal side slopes of 6:1, it will have a capacity that is greater than one with 12:1 slopes; for the flatter grades this difference is outstanding.

Figures 5.5, 5.6, and 5.7, Specific Capacity vs Length for three different grades, generally indicate that a decrease in specific capacity occurs as the grating is made longer.

7.2 **Inlet in Grassed Channel with Steep Slopes**

In referring to Figures 5.8, 5.9, and 5.10, Capacity vs Length for the three grades, the higher capacity of a grassed channel, having a swale slope of 6:1 and a back slope of either 2:1 or \( \frac{1}{2} : 1 \), is immediately evident, whereas a swale slope of 12:1 and a back slope of \( \frac{1}{2} : 1 \) always shows as having the least capacity. The plots again show that an inlet is able to capture more water as its length is increased.
Additionally, the plots point out that, as tests went from a grade of 0.5% to a grade of 4%, the capacity of the particular combinations of side slopes decreased, indicating that flatter slopes have a greater capacity than steep slopes.

The figures further show that in 5 of 6 instances a swale slope of 6:1 has a higher capacity than a swale slope of 12:1, and that a back slope of \( \frac{1}{2}:1 \) usually has a higher capacity than a back slope of 2:1 for the 6:1 swale slope, whereas, for the 12:1 swale slope, the 2:1 back slope has the higher capacity.

Generally, the plots of Specific Capacity vs Length, Figures 5.11, 5.12, and 5.13, show a decrease in specific capacity as an inlet is lengthened.

7.3 Nominal Capacity of Inlet in Grassed Channel

The nominal capacity of a inlet should be based on the grating catching 98% of the approaching flow and letting 2% of that flow pass by the grating because a capacity based on all of the approaching flow being caught by the grating leads to only a small difference in capacity for different lengths of grating. With some water bypassing or overflowing the inlet, more of the grating will be used to capture the approaching water with the result that the nominal or \( Q_{98} \) capacity is larger than the \( Q_{100} \) capacity where no water bypasses the inlet. This point is clearly seen by observing the efficiencies of 100% and 98% in Figures 5.14, 5.15, and 5.16, Efficiency vs Flow Rate for the three grades considered.
7.4 Inlet in Paved Channel

The capacity of an inlet installed in a paved channel increases with an increase in length of the inlet, the rate of increase being almost constant for any one grade. The flatter grades had higher capacities than the 4% grade, and thus are preferable to the steeper grade. The spread in capacity between the 4% line and the highest line is almost constant over the lengths of inlets tested.

7.5 Arrangement of Grating Bars

That no one configuration of grating bars at the surface of an inlet is able to capture more of the approach flow than any other configuration, for an inlet that is installed in a conventional channel, triangular in shape, along a highway, whether the channel be grassed or paved.
8. RECOMMENDATIONS

As a result of the study, the following points are recommended about inlets being installed by PennDOT along highways:

8.1 That grassed channels be designed to have equal side slopes.

8.2 That grassed channels have equal side slopes of 6:1 in preference to equal side slopes of 12:1.

8.3 That highways be designed so that flow channels have flat grades in preference to steep grades.

8.4 That the nominal capacity here shown be used for an inlet with a width of 48 in., a length of 27 in., having diagonal bars, and installed in a grassed channel:

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope Swale</th>
<th>Slope Back</th>
<th>Capacity (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>6:1</td>
<td>6:1</td>
<td>13.3</td>
</tr>
<tr>
<td>2</td>
<td>6:1</td>
<td>6:1</td>
<td>12.1</td>
</tr>
<tr>
<td>4</td>
<td>6:1</td>
<td>6:1</td>
<td>9.7</td>
</tr>
</tbody>
</table>

The capacities were obtained by interpolation from data in both Table 5.5 and Figures 5.14, 5.15, and 5.16.

8.5 That the practice be continued of dressing slopes immediately adjacent to an inlet which is installed in a grassed channel.
This research was sponsored by the Pennsylvania Department of Transportation in conjunction with the United States Federal Highway Administration. It was conducted in Fritz Engineering Laboratory (Department of Civil Engineering) of Lehigh University in Bethlehem, Pennsylvania, by the following personnel of the Hydraulics Department: Dr. Arthur W. Brune, Project Director, and Mr. Andrew D. Spear, Research Assistant, and Mr. Kenneth C. Loush, Research Assistant.

The Director of Fritz Engineering Laboratory is Dr. Lynn S. Beedle; the Chairman of the Department of Civil Engineering is Dr. David A. VanHorn; the Director of the Office of Research is Professor George R. Jenkins.

The authors are indebted to Mr. Elias Dittbrenner who assisted in the work, to the secretaries of Fritz Laboratory who typed the manuscript, and to Mr. John M. Gera who prepared the drawings.

Recognition is here given to personnel of PennDOT who aided materially in the study; specifically, Mr. Charles J. Churilla, PE, Research Coordinator, whose guidance was very helpful. Additionally, the authors offer their thanks to Mr. David Fetterman, PE, Bureau of Design, and, from District 8-0, Mr. William J. Green, PE, and Mr. Marshall M. Sellers, PE. Appreciation is also extended to the following personnel of FHWA: Mr. Kenneth Foster and Dr. D. C. Woo.
10. NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>area of flow, ft$^2$</td>
</tr>
<tr>
<td>D</td>
<td>depth of flow, ft</td>
</tr>
<tr>
<td>Eu</td>
<td>Euler number</td>
</tr>
<tr>
<td>Fr</td>
<td>Froude number</td>
</tr>
<tr>
<td>g</td>
<td>gravitational acceleration, ft/sec$^2$</td>
</tr>
<tr>
<td>ΔH</td>
<td>change in head, in.</td>
</tr>
<tr>
<td>L</td>
<td>length of inlet, in.</td>
</tr>
<tr>
<td>$L_r, L_R$</td>
<td>scale ratio</td>
</tr>
<tr>
<td>n</td>
<td>Manning roughness coefficient</td>
</tr>
<tr>
<td>ΔP</td>
<td>difference in pressure, psi</td>
</tr>
<tr>
<td>Q</td>
<td>flow rate, cfs</td>
</tr>
<tr>
<td>$Q_1$</td>
<td>total flow rate, cfs</td>
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<tr>
<td>$Q_2$</td>
<td>intercepted flow rate, cfs</td>
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<tr>
<td>$Q_3$</td>
<td>bypassing flow rate, cfs</td>
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<tr>
<td>Re</td>
<td>Reynolds number</td>
</tr>
<tr>
<td>$R_h$</td>
<td>hydraulic radius, ft</td>
</tr>
<tr>
<td>S</td>
<td>slope of energy line</td>
</tr>
<tr>
<td>v</td>
<td>velocity, fps</td>
</tr>
<tr>
<td>V</td>
<td>volume of flow, ft$^3$</td>
</tr>
<tr>
<td>$\rho$</td>
<td>density, lb-sec$^2$/ft$^4$</td>
</tr>
<tr>
<td>$\mu$</td>
<td>dynamic viscosity, (lb-sec/ft$^2$)</td>
</tr>
<tr>
<td>cfs</td>
<td>cubic feet per second</td>
</tr>
<tr>
<td>cms</td>
<td>cubic meters per second</td>
</tr>
<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
</tr>
<tr>
<td>PennDOT</td>
<td>Pennsylvania Department of Transportation</td>
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<tr>
<td>m subscripted</td>
<td>model</td>
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DEVELOPMENT OF IMPROVED DRAINAGE INLETS, PHASE 1: LITERATURE SURVEY, Lehigh University, Fritz Engineering Laboratory Report No. 364.2 (1969)
12. APPENDIX

The Appendix contains the identical tables of capacity that are in Section 5, Results, of this report except that the data in each table are given in units of the International System or SI units. The conversion from English units to SI units was based on 1 foot for 0.3048 meter and 1 cubic foot per second for 0.02832 cubic meter per second.
### TABLE A.1 CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, MILD BACK SLOPES (SI Units)

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Swale Back</th>
<th>Capacity (m³/s)</th>
<th>Length of Grating (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>6:1</td>
<td>0.083 0.090 0.099</td>
<td>0.114 0.138</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>0.109 0.123 0.139</td>
<td>0.131 0.178</td>
</tr>
<tr>
<td>* 6:1</td>
<td>6:1</td>
<td>0.186 0.224 0.270 0.321 0.401 0.420 0.253 0.365</td>
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</tr>
<tr>
<td></td>
<td>6:1</td>
<td>0.201 0.255 0.293</td>
<td>0.122 0.172</td>
</tr>
<tr>
<td></td>
<td>12:1</td>
<td>0.088 0.096 0.106</td>
<td>0.088 0.103 0.107</td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>0.095 0.103 0.107</td>
<td>0.096 0.125</td>
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<tr>
<td></td>
<td>12:1</td>
<td>0.106 0.125 0.149</td>
<td>0.106 0.127</td>
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<tr>
<td>* 6:1</td>
<td>6:1</td>
<td>0.116 0.139 0.191 0.236 0.321 0.361 0.255 0.312</td>
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<td>6:1</td>
<td>0.167 0.244 0.300</td>
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<td>0.103 0.114 0.133</td>
<td>0.103 0.114 0.127</td>
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<td>0.093 0.090 0.096</td>
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(1) Table 5.7, Report 364.4, column heading "Type 4-Ft: Capacity (cfs) without Dike"; converted using 0.02832 m³/s
(2) Table 5.7, Report 364.4, column heading "Type 6-Ft: Capacity (cfs) without Dike"; converted using 0.02832 m³/s

*Slopes dressed at 2:1
<table>
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<tr>
<th>Grade Slope (%)</th>
<th>Swale</th>
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<th>Length of Grating (m)</th>
<th>Specific Capacity ($m^3/s/m$ length)</th>
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<td>1/2 12:1</td>
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<td>6:1</td>
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</tr>
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<td></td>
<td></td>
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<td>0.237</td>
</tr>
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<td></td>
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</tr>
<tr>
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<td>6:1</td>
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<td>6:1</td>
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<td>6:1</td>
<td>0.253</td>
<td>0.229</td>
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<td>6:1</td>
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<td>0.171</td>
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</tbody>
</table>

Source: Table A.1, CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS (SI Units)
Each capacity in Table A.1 is divided by the pertinent length of grating.

Note: (1) See notes 4 and 5, Table A.1
*Slopes dressed at 2:1
<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Swale Back</th>
<th>Capacity (m³/s)</th>
<th>Length of Grating (m)</th>
<th>H Diag (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>½</td>
<td>6:1</td>
<td>⅛:1</td>
<td>0.154 0.228 0.281</td>
<td></td>
<td>0.385</td>
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<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>0.117 0.141 0.160</td>
<td></td>
<td>0.465</td>
</tr>
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<td>12:1</td>
<td>⅛:1</td>
<td>0.078 0.122 0.143</td>
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<td>0.229</td>
</tr>
<tr>
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<td></td>
<td>2:1</td>
<td>0.128 0.160 0.181</td>
<td></td>
<td>0.207</td>
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<td>2:1</td>
<td>0.131 0.141 0.155</td>
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<td>0.069 0.101 0.114</td>
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<td>0.117 0.133 0.154</td>
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<td>2:1</td>
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<td>0.255</td>
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<td>⅛:1</td>
<td>0.051 0.078 0.104</td>
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<td>0.085 0.103 0.146</td>
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<td>0.168</td>
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</table>

(1) Table 5.1, Report 364.4, Type H inlet grating with diagonal bars. Length of grating is 60 in or 1.52 m
TABLE A.4 SPECIFIC CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, STEEP BACK SLOPES (SI Units)

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Specific Capacity (m³/s/m length)</th>
<th>Length of Grating (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.46</td>
</tr>
<tr>
<td>½</td>
<td>6:1</td>
<td>½:1</td>
<td>0.335</td>
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<tr>
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<td>2:1</td>
<td>0.254</td>
</tr>
<tr>
<td>12:1</td>
<td>½:1</td>
<td>0.170</td>
<td>0.200</td>
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<td></td>
<td>2:1</td>
<td>0.278</td>
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<tr>
<td>2</td>
<td>6:1</td>
<td>½:1</td>
<td>0.272</td>
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<td>2:1</td>
<td>0.285</td>
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<td>12:1</td>
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<td>0.150</td>
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<td></td>
<td></td>
<td>2:1</td>
<td>0.254</td>
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<tr>
<td>4</td>
<td>6:1</td>
<td>½:1</td>
<td>0.196</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
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</tr>
<tr>
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<td>0.128</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:1</td>
<td>0.185</td>
</tr>
</tbody>
</table>

Source: Table A.3 CAPACITY OF PROTOTYPE GRATINGS IN GRASSED CHANNELS, STEEP BACK SLOPES (SI Units)
Each capacity in Table A.3 is divided by the pertinent length of grating
Length of Type H grating is 60 in or 1.52 m; PennDOT Standard Drawing "Miscellaneous Inlets - Supplemental Sheet A", Revised July 20, 1955
**TABLE A.5 NOMINAL CAPACITY, \( Q_{98} \), OF GRATINGS IN GRASSED CHANNELS, DRESSED SLOPES (SI Units)**

<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Length of Grating (m)</th>
<th>Capacity (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.46</td>
<td>0.61</td>
</tr>
<tr>
<td>0.5</td>
<td>0.260</td>
<td>0.336</td>
</tr>
<tr>
<td>2.0</td>
<td>0.224</td>
<td>0.300</td>
</tr>
<tr>
<td>4.0</td>
<td>0.164</td>
<td>0.253</td>
</tr>
</tbody>
</table>

Side slopes are 6:1
<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>Length of Grating (m)</th>
<th>Capacity (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.46</td>
<td>0.53</td>
</tr>
<tr>
<td>1/2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.042</td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.026</td>
</tr>
<tr>
<td>4</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.011</td>
</tr>
</tbody>
</table>

1 Table 4.2, Report 364.3, p 42; units converted.
2 Table 4.3, Report 364.3, p 43; units converted.
<table>
<thead>
<tr>
<th>Grade (%)</th>
<th>Slope</th>
<th>4-ft Special</th>
<th>6-ft Special</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.091 0.093 0.082 0.075 0.078 0.071 0.069 0.065 0.062 0.034 0.041</td>
</tr>
<tr>
<td>2</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.057 0.066 0.066 0.073 0.074 0.089 0.089 0.086 0.089 0.064 0.062</td>
</tr>
<tr>
<td>4</td>
<td>12:1</td>
<td>1/8:1</td>
<td>0.024 0.028 0.033 0.035 0.046 0.049 0.050 0.054 0.053 0.079 0.063</td>
</tr>
</tbody>
</table>

Source: TABLE A.6 CAPACITY OF PROTOTYPE GRATINGS IN PAVED CHANNELS (SI Units)
Each capacity in Table A.6 is divided by the pertinent length of grating.