Development and Use of HYCHL for Channel Design

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The HYCHL program is introduced and ways it is an enhanced combination of Hydraulic Engineering Circulars 15 and 11 are described. HYCHL is a program that assists in designing roadside channel linings and riprap lining for irregular channels by analyzing lining stability on the basis of permissible shear stress. Enhancements discussed include (a) flexibility in the calculation of Manning's roughness coefficient by giving a designer both a choice of method and a default method; (b) ability to change Shields' parameter for riprap linings; (c) capability of analyzing irregular channel cross sections for riprap linings; and (d) ability to design riprap size on the basis of stability factors and channel shape. The use of the program for both roadside and natural channels is demonstrated with examples.

The design and analysis of linings for roadside channels and other drainageways is both an art and a science. It is a science because researchers have conducted experiments and developed theoretical constructs of lining behavior under varied geometric and hydraulic conditions. Such efforts have been synthesized by FHWA for guidance in the form of Hydraulic Engineering Circulars 15 (HEC-15) (*1*) and 11 (HEC-11) (*2*).

Lining design and analysis is also an art in which experience and intuition are keys to success. This is true because the "science" is incomplete and, at times, contradictory. The guidance provided in HEC-15 and HEC-11, for example, describes a limited range of conditions for channel design, leaving the designer without formulas or charts for other situations experienced in the field. Sometimes these helpful documents provide contradictory guidance and methodologies that the designer must resolve.

The development of HYCHL, a computer program to assist designers in channel lining analysis and design, involved a synthesis and expansion of the concepts provided in HEC-15 and HEC-11. The program standardizes and facilitates application of design concepts. This paper describes the principal areas in which enhancements have taken place, including Manning's roughness, Shields' parameter, irregular channel shapes, and the use of stability factors.

SCOPE OF HYCHL AND LINING GUIDANCE

HYCHL represents a consolidation of analysis and design techniques presented in HEC-15 (*1*) and HEC-11 (*2*). Although both documents address the analysis of lining stability, each focuses on different classes of problems. HEC-15 focuses on linings in roadside channels, which are characterized by relatively uniform cross sections on a constant slope. Types of lining include riprap, rigid, vegetative, gabion, and temporary. Alternatively, HEC-11 addresses natural channels with irregular cross sections, varying bottom slopes, and generally carrying larger flows. HEC-11 focuses on the design of riprap lining in such cases. Together, HEC-15 and HEC-11 provide a series of analysis and design tools that are present in HYCHL.

HYCHL is a part of the HYDRAIN computer system, but it can be operated separately. Documentation for HYCHL is found in Volume VII (*3*) of the overall HYDRAIN documentation. HYCHL allows the user to use English or SI units of measurement. The program performs all computations in English units because these are the common units for all the reference materials. If a designer prefers metric units, HYCHL performs the necessary conversions.

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Rigid, Vegetative, Gabion, and Temporary Linings

HEC-15 outlines procedures for analyzing channel linings based on tractive-force theory. The procedure involves comparing an estimated shear stress resulting from flow in a channel to the maximum permissible shear stress determined for a given lining type. If the shear from flowing water increases to the point at which it is greater than the permissible shear of the lining, failure may occur. An estimate of the maximum discharge that a channel can convey is calculated when the estimated shear is assumed to equal permissible shear.

The analysis of rigid, vegetative, gabion, and temporary linings in HYCHL is applicable to channels of uniform cross section and constant bottom slope. Roadside channels typically exhibit such characteristics. HYCHL offers a variety of design and analysis options, including

1. Rigid or flexible linings,
2. Permanent or temporary linings,
3. Single or composite linings,
4. Straight or curved channel sections,
5. Alternative regular channel shapes, and
6. Constant or variable channel flow.

Depending on the function of a channel, the availability of materials, costs, aesthetics, and desired service life, a designer may choose from a variety of lining types available in HYCHL. Rigid linings in HYCHL include concrete, grouted riprap, stone masonry, soil cement, and asphalt. Flexible linings in HYCHL include those that may be considered permanent and those considered temporary. Permanent flexible linings include vegetation, riprap, and gabions. Temporary linings include woven paper, jute mesh, fiberglass roving, straw with net, curled wood mat, synthetic mat, and bare soil (unlined).

HYCHL also provides for the analysis of these lining types when two are specified together as a composite lining. Composite linings are typically designed with a low-flow lining protecting the bottom of a channel, where higher shear stresses occur, and a sideslope lining protecting the channel sides. Composite linings are used when lining side slopes with the same material applied to the bottom is undesirable for reasons of economics, aesthetics, or safety.

The designer of rigid, vegetative, and temporary linings may apply HYCHL to a variety of geometric configurations. HYCHL calculates the shear stresses on linings in straight channel sections as well as the higher stresses found in bend sections. Channel cross sections available in HYCHL for these lining types are trapezoidal, parabolic, triangular, and triangular with rounded bottom.

The performance of rigid, vegetative, gabion, and temporary linings can be evaluated using a constant design flow or a variable inflow. The variable inflow is characterized as a uniform lineal flow that results in an increasing discharge with channel length. Under such conditions, HYCHL gives the designer an estimate of the length of channel for which a given lining may be suitable.

HEC-15 includes limited guidance for the analysis of gabion linings on steep slopes (10 to 25 percent), but provides no guidance on any other conditions. Therefore, calculating shear stress for gabion linings follows the same methodologies as described for riprap in HEC-15, using the median rock size (D_{50}) for the gabion fill material. This assumes that the wire enclosure does not significantly affect the roughness of the lining. Work by Simons et al. (*4*) supports this assumption.

Riprap Linings

HEC-15 and HEC-11 both outline procedures for analyzing riprap-lined channels. These procedures are based on the same logic, that is, the tractive-force theory, but they include additional considerations not necessary for analyzing rigid, vegetative, gabion, and temporary lining types. Although HEC-15 is recommended for design flows less than 50 ft^3/sec (1.4 m^3/sec) and HEC-11 for flows in excess of 50 ft^3/sec, the same basic principles are used in deriving the analysis and design equations in these documents. The tractive-force procedure is applied to develop the riprap analysis and design procedures used in HYCHL (in commenting on an earlier version of HEC-15, Blodgett (*5*) notes that the flow range limitations are related to the data available at the time but may not be justified).

A channel lined with riprap can be analyzed for stability, given the riprap size. Conversely, the riprap size can be determined on the basis of a user-supplied stability factor. Composite channels that have riprap for the low-flow lining or the sideslope lining can be analyzed. HYCHL can also analyze irregular channel shapes lined with riprap only.

In a riprap-lined channel, most hydraulic calculations are based on Manning's equation. An exception occurs when the flow depth is small compared with a characteristic riprap size. In such cases—for example, on steep slopes—the effects of the rock protruding into the flow field cannot be ignored. The Bathurst hydraulic procedure given in HEC-15 is then applied to determine the flow depth and velocity in a given channel.

HYCHL METHODOLOGIES

The analytical methodologies used in HYCHL are deceptively simple. They are deceptive because much judgment may be required to select appropriate parameters or assumptions for a given application. Most of the linings are analyzed following a common procedure. Riprap linings must be considered separately.

Rigid, Vegetative, Gabion, and Temporary Linings

The analysis and design of rigid, vegetative, gabion, and temporary linings in channels of constant cross section and slope, typical of roadside channels, is accomplished by the application of tractive-force theory. The procedure used to analyze temporary linings is identical to that applied for permanent linings. However, because temporary linings are intended to have a shorter service life, the design flow may be lower. The hydraulic characterization of the channel flow and the calculation of the shear stresses are presented for a variety of lining types and channel configurations.

Most roadside channels carry uniform flow that can be represented by Manning's formula. For analysis and design purposes, uniform flow conditions are assumed with the energy slope approximately equal to average bed slope. By making this assumption, flow conditions can be defined by a uniform flow equation such as Manning's equation. Depending on the type of lining, HYCHL determines the appropriate roughness coefficient and then calculates the depth and velocity for a given design flow.

Usually, the analysis of depth/velocity and roughness coefficient must be iterative. Once the depth has been calculated, shear stress for the channel bottom is obtained from the following equation:

$$\tau_c = \gamma d_{\max} S_F \tag{1}$$

where

τ_c = calculated shear stress on the channel bottom [lb/ft^2 (N/m^2)],
γ = specific weight of water [lb/ft^3 (N/m^3)],
$d_{\max}$ = normal depth [ft (m)], and
S_F = friction slope [ft/ft (m/m)].

Shear stress is the force exerted on the lining by flowing water per unit area of the lining. Each lining has associated with it a permissible shear stress, τ_p. Most of the permissible shear values come from tables or charts in HEC-15 and are considered conservative; that is, they are appropriate for design purposes. For gabions, HYCHL calculates the permissible shear stress as a function of mattress thickness and median rock size.

With the permissible shear and calculated shear estimated, a stability factor is calculated as

$$SF = \frac{\tau_p}{\tau_c} \tag{2}$$

where

SF = stability factor,
τ_p = permissible shear stress [lb/ft^2 (N/m^2)], and
τ_c = calculated shear stress on the channel bottom [lb/ft^2 (N/m^2)].

If the stability factor is less than 1, the lining is considered unstable. In addition to analyzing the channel bottom, HYCHL calculates the stability factor on the side slopes, for composite linings, and in bends. Side slopes and composite linings are evaluated by multiplying τ_c by a side shear factor, K_{side}. K_{side} is a function of the channel geometry. Bends are evaluated analogously, by multiplying τ_c by a bend shear factor, K_B. K_B is a function of the radius of curvature and some characteristic width of the channel. For side shear and bends, HYCHL calculates separate stability factors.

Riprap Linings

Although it is based on the same underlying principles of tractive-force theory, the design of riprap linings has been separated to highlight the design process. Both HEC-15 and HEC-11 address components of riprap lining design under different flow conditions and channel types. HYCHL assists the designer by automatically recognizing the appropriate conditions and using the applicable lining design procedures for riprap-lined channels.

The stability factor was previously defined as the ratio of the riprap material's critical, or permissible, shear stress (τ_p) to the tractive force exerted by the flow (τ_c). τ_c is estimated using Equation 1. The permissible shear stress for riprap is given as

$$\tau_p = F_* (\gamma_s - \gamma) D_{50} \tag{3}$$

where

F_* = Shields' parameter,
γ_s, γ = specific weight of the riprap and water, respectively [lb/ft^3 (N/m^3)], and
D_{50} = median riprap size [ft (m)].

In the case of riprap analysis for the channel bottom, the stability factor is calculated as follows:

$$SF_b = \frac{\tau_p}{\tau_c} = \frac{F_* (\gamma_s - \gamma) D_{50}}{\gamma d_{max} S_F} = \frac{F_* (S_g - 1) D_{50}}{d_{max} S_F} \tag{4}$$

where SF_b is the stability factor for the channel bottom and S_g is the specific gravity of the riprap.

To simplify for design purposes, Manning's equation can be expressed as

$$S_F = \frac{V^2 n^2}{2.22 R^{1.333}} \tag{5}$$

Substituting for slope in Equation 4, the equation for calculating the stability factor for the channel bottom is given as

$$SF_b = \frac{F_* (S_g - 1) D_{50}}{d_{max}} \times \frac{2.22 R^{1.333}}{V^2 n^2} \tag{6}$$

For riprap design of the channel bottom, Equation 6 is solved for D_{50}

$$D_{50,b} = \frac{SF_b d_{max} V^2 n^2}{F_* (S_g - 1) 2.22 R^{1.333}} \tag{7}$$

where $D_{50,b}$ is the design riprap size for the channel bottom in feet.

As is done for the other channel lining types, HYCHL calculates separate stability factors for side slopes and in bends. HYCHL can also evaluate riprap linings on irregular channel cross sections.

ISSUES IN INTEGRATING AND COMPUTERIZING HEC-15 AND HEC-11

The HYCHL program is a tool that applies a consistent methodology to a wide range of conditions. To accomplish this, four major issues were resolved during program development: (a) proper selection of Manning's n for riprap linings, (b) proper selection of Shields' parameter for riprap linings, (c) adaptation of methodologies to channel cross sections other than trapezoidal, and (d) proper use of stability factors.

The issue of the proper selection of Manning's n for riprap lining arises from the use of two methods for estimating roughness in HEC-15—Blodgett (*6*) and Bathurst (*7*)—and three methods for estimating roughness in HEC-11—Blodgett (*6*) (two equations), Jarrett (*8*), and Anderson (*9*). The evaluation was complicated by the fact that Appendix D of HEC-11 recommends the Anderson method be employed to generate a design equation, while Chapter 3 recommends the use of the Blodgett or Jarrett equations when applying the design equation. This generates an inherent inconsistency.

After reviewing the literature, a solution that is technically applicable and generally compatible with existing guidance was developed and incorporated into HYCHL. For riprap design, the default methodology for calculating the roughness coefficient depends on the ratio of the average depth (d_a) to the median riprap size (D_{50}). For d_a/D_{50} less than 2, the Bathhurst approach is used to estimate Manning's roughness. For d_a/D_{50} between 2 and 185, inclusive, the following equation from Blodgett and HEC-11 (Equation 2) is used:

$$n = \frac{0.0926 d_a^{1/6}}{0.724 + 1.85 \log \left(\frac{d_a}{D_{50}} \right)} \tag{8}$$

where d_a is the average flow depth in the main channel in feet.

For d_a/D_{50} greater than 185, the following equation, also from Blodgett and HEC-11 (Equation 3), is used:

$$n = 0.019\, d_a^{0.167} \tag{9}$$

For the advanced designer, who may have reason to use another approach, HYCHL allows for default calculations to be overridden. Regardless of the d_a/D_{50} ratio, a designer may select the Blodgett equation (Equation 2, HEC-11), the Anderson equation, or a user-supplied value (Equation 2 in HEC-11 is incomplete, probably because of a typographical error).

With the user-supplied option, the Jarrett equation or other approaches may be applied.

The second major issue involves the selection of a Shields' parameter. This issue was also created by the implicit or explicit use of different values in the guidance documents without clarifying the reasons for their selection in each case. HEC-15 uses values of 0.040 (in deriving Equation 8) and 0.15 (in the discussion of steep slopes in Appendix C). HEC-11 incorporates a value of 0.047 in its design equations.

A review of the literature suggests variation of this parameter with changing hydraulic conditions, as characterized by Reynolds' number. Wang and Shen (*10*) cite experimental data in which Shields' parameter assumes values of 0.15 and above for high ($>10^5$) Reynolds' numbers. Bathurst (*7*) also observed changes in boundary resistance in flow regimes with elevated Reynolds' numbers. Although Bathurst and Wang and Shen approached their investigations from different perspectives, they all observed changes in riprap behavior at high Reynolds' numbers. The solution for HYCHL was selected to be technically defensible and compatible with existing guidance. As with the issue of roughness coefficient, the approach was to use a default value, with an option of designer override. The default Shields' parameter in all cases is 0.047. However, HYCHL also computes Reynolds' number and provides a message when it exceeds 10^5. The designer may then choose to use a larger value; however, only experienced designers should make such an adjustment.

The third issue is one of expanding the guidance provided in HEC-15 and HEC-11 rather than resolving varied interpretations. Specifically, much of the guidance related to side slopes and bends is only directly applicable to trapezoidal channel cross sections. However, HEC-15 also discusses V-shaped, parabolic, and V-shaped–with–rounded-bottom cross sections, whereas HEC-11 focuses on irregular natural cross sections.

The guidance shows how to use the geometry of a trapezoidal channel to evaluate the change of stability of riprap on the side slope, the attenuation of shear stress on the sides, and the bend shear stress—bend shear stress being a function of the radius of curvature of the channel alignment and the bottom width. Application of these concepts to other channel shapes is not apparent in the guidance.

For irregular channel shapes, the solution in HYCHL is to ask the designer to identify the points on the cross section that best represent the channel bottom and that divide the main channel from the overbanks (four points in all). From those data and the cross section itself, HYCHL constructs a geometrically and hydraulically equivalent trapezoid. This trapezoid is then used to complete the stability analyses for side slopes and bends.

For the three other regular shapes, a series of adjustments are made. To analyze sideslope stability of riprap, it is noted that the slope of the sides increases or remains constant as the water level rises. Therefore, the tendency to fail due to the sideslope angle is greatest at the water surface. Therefore, the slope at the surface is used to analyze riprap stability. Although this is a somewhat conservative approach, it is consistently applied and is appropriate for design purposes.

To analyze the attenuation of shear on the side slopes, a review of the Anderson report (*9*), from which the trapezoidal approach was derived, revealed that he had also completed an analysis of V-shaped channels. This information was retrieved and incorporated into HYCHL. It was observed in reviewing Anderson's analysis that the attenuation of shear stress (from the maximum computed as a function of depth) results from the sharp corners in the trapezoidal and V-shaped cross sections that do not allow the full shear stress to develop. Because the parabolic and V-shaped–with–rounded-bottom cross sections do not have such corners, no attenuation is expected; HYCHL reflects this interpretation.

For bends, it is necessary to identify some characteristic width such that the "sharpness" of the bend can be evaluated. For a trapezoidal channel, the bottom width is used. For all other channel cross sections, the characteristic width is calculated as the flow area divided by the maximum depth.

The final major issue in developing HYCHL was an issue of interpretation. Much of the channel lining design and analysis process is based on empirical data and depends significantly on engineering judgment. Therefore, it was undesirable for HYCHL to evaluate a lining and indicate whether or not it is stable. The dividing line is obscure.

To overcome this, the notion of a stability factor—defined as τ_p/τ_c—is used. If the stability factor is less than 1, the lining can be clearly labeled unstable, given the hydraulic conditions used to make the evaluation. However, if the stability factor is equal to or greater than 1, the lining may still not be stable. Uncertainty in the data and the degree to which a situation is simplified for analysis may lead the designer to require a stability factor of 1.6 or higher. The HYCHL document provides guidance in this matter. For uniform roadside channels, a stability factor near 1 may be adequate.

EXAMPLE APPLICATIONS

Two hypothetical examples are included to illustrate the methodologies used in HYCHL. For each example, the problem is described and the resulting output discussed.

Example 1: Composite Linings

This example shows how to analyze a channel with a composite lining. It is taken from Example 13 of HEC-15. A trapezoidal channel on a slope of 0.02 ft/ft has a 3-ft base width and 3:1 (horizontal:vertical) side slopes. The flow is 10 ft³/sec, the low-flow lining is concrete, and the sideslope lining is vegetative (Class C). The lining transition depth is 0 ft, meaning the low-flow lining only lines the channel bottom. Figure 1 displays the cross section.

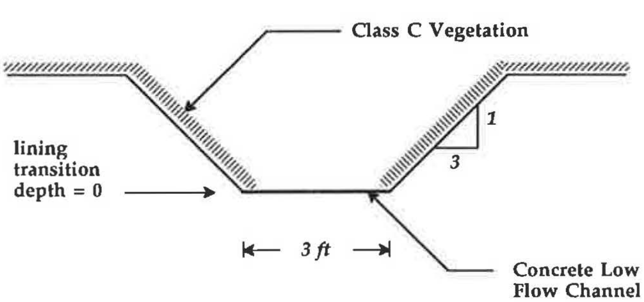

FIGURE 1 Composite lining example.

The output, given in Figure 2, shows that both linings are stable; the vegetative lining has a stability factor of 1.07. It is almost flowing with maximum discharge, which is 12.0 ft^3/sec. The depth is 0.87 ft, and the effective Manning's n value is 0.071. The final line shows that K_{SU}—the ratio of side lining shear to bottom lining shear—is 0.86.

Example 2: Irregular Channel Design

This example illustrates the design of a riprap-lined channel for an irregular cross section. Figure 3 shows a sketch of the cross section detailing the main channel and the left and right floodplains. Input includes a field-measured maximum depth of 12.5 ft and a main channel velocity of 7 ft/sec. The design incorporates a stability factor of 1.2 and a Shields' parameter of 0.047.

The x-, y-coordinates describing the cross section are printed along with the x-value of the four coordinates that bound the main channel in the output shown in Figure 4. Because of a high Reynolds' number, a message is printed, and the advanced designer may consider using a higher Shields' param-

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     ******  HYCHL  ****** (Version 1.1) ******              Date 05-30-91

Commands Read From File: C:\HYCHAN\JB2.CHL

      JOB EXAMPLE 1
      UNI 0
** UNITS PARAMETER = 0  (ENGLISH)
      CHL .02    10
      TRP 3      3
** LEFT SIDE SLOPE     3.0 AND RIGHT SIDE SLOPE     3.0
** THE BASE WIDTH OF THE TRAPEZOID (FT)     3.00
      LRG 1 1
** THE MAXIMUM CHANNEL DEPTH (FT) IS     1.00
      CPS 0
      LVG C
      END
****************END OF COMMAND FILE************

EXAMPLE 1
------------
INPUT REVIEW
------------
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (CFS):              10.00
      CHANNEL SHAPE:                   TRAPEZOIDAL
      CHANNEL SLOPE (FT/FT):                .020
      LINING TRANSITION HEIGHT (FT):        .00
----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
----------------------------------------

                          DESIGN     MAXIMUM
                          ------     -------
FLOW (CFS)                10.00       12.00
DEPTH (FT)                  .87         .93
AREA (FT^2)                4.86        5.39
WETTED PERIMETER (FT)      8.49        8.89
HYDRAULIC RADIUS (FT)       .57         .61
VELOCITY (FT/SEC)          2.06        2.23
MANNINGS N (LOW FLOW)      .013        .013
MANNINGS N (SIDE SLOPE)    .093        .087
EFFECTIVE MANNINGS N       .071        .068
------------------
STABILITY ANALYSIS
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                     LINING        PERMIS SHR   CALC. SHR  STAB.
  CONDITION          TYPE          (LB/FT^2)    (LB/FT^2)  FACTOR   REMARKS
  ---------          ---------     ----------   ---------  ------   -------
LOW FLOW LINING
 BOTTOM; STRAIGHT    CONCRETE       *******        1.08    ******   STABLE
SIDE SLOPE LINING
  SIDE; STRAIGHT     VEGETATIVE C     1.00          .93      1.07   STABLE

RATIO OF SIDE SHEAR TO BOTTOM SHEAR =     .86

*** NORMAL END OF HYCHL ***
```

FIGURE 2 Output for Example 1.

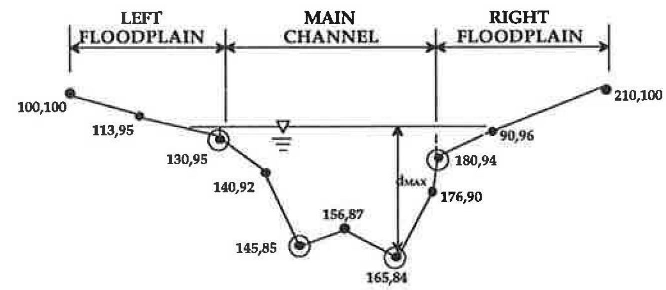

FIGURE 3 Irregular channel example.

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     ******  HYCHL  ****** (Version 1.1) ******              Date 11-18-91

Commands Read From File: C:\HYCHL\EXAMPLE6.CHL

      JOB EXAMPLE 6
      UNI 0
** UNITS PARAMETER = 0  (ENGLISH)
      CHL -12.5  -7.0
      GR  100    100      113    98      130    95      140    92
** NUMBER  X-COORD(FT)  Y-COORD(FT)
**    1       100.00       100.00
**    2       113.00        98.00
**    3       130.00        95.00
**    4       140.00        92.00
**    5       145.00        85.00
**    6       156.00        87.00
**    7       165.00        84.00
**    8       176.00        90.00
**    9       180.00        94.00
**   10       190.00        96.00
**   11       210.00       100.00
      SA  130      145      165      180
**    LOCATION      X COORD (FT)
    LEFT BANK          130.00
    LEFT BASE          145.00
    RIGHT BASE         165.00
    RIGHT BANK         180.00
      LRR -1.2    2 0 2.65    0.047
** STABILITY FACTOR     1.20
** SPECIFIC GRAVITY     2.65
** SHIELDS PARAMETER     .047
      END
**************END OF COMMAND FILE************

EXAMPLE 6
------------
INPUT REVIEW
------------
  DESIGN PARAMETERS:
      DESIGN VELOCITY (FT/S):              7.00
      CHANNEL SHAPE:                   IRREGULAR
      MAXIMUM FLOW DEPTH (FT):            12.50
-------------------------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH FOR MAIN CHANNEL
-------------------------------------------------------

                          DESIGN
                          ------
FLOW (CFS)               2849.00
MAX DEPTH (FT)             12.50
AREA (FT^2)               407.00
WETTED PERIMETER (FT)      57.90
HYDRAULIC RADIUS (FT)       7.03
AVG VELOCITY (FT/SEC)       7.00
MANNINGS N (LOW FLOW)        .050
Davg / D50                 10.22
EQUIVALENT SLOPE (FT/FT)     .004
REYNOLDS NUMBER (10^5)     70.79
*** WARNING *** REYNOLDS NUMBER IS LARGER THAN 10^5

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RIPRAP DESIGN
-------------
                     LINING    PERMIS SHR   CALC. SHR   STAB.
  CONDITION          TYPE      (LB/FT^2)    (LB/FT^2)   FACTOR    D50(FT)
  ---------          ------    ----------   ---------   ------    -------
  BOTTOM; STRAIGHT   RIPRAP       3.86         3.24      1.20       .80
  SIDE; STRAIGHT     RIPRAP       2.63         2.21      1.20       .99

*** NORMAL END OF HYCHL ***
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FIGURE 4 Output for Example 2.

eter. In the riprap design section, D_{50} was sized for both the channel bottom and the channel side slope for a stability factor of 1.2. From a practical standpoint, it is likely that the designer would choose to line the sides and bottom with the same riprap size. In this case the D_{50} would have to be greater than or equal to 0.99 ft.

SUMMARY AND CONCLUSIONS

The HYCHL computer program was developed as an implementation of FHWA guidance in designing and analyzing channel linings found in HEC-15 and HEC-11. During the design process, it became clear that inconsistencies within the two documents are present and that their scope is limited to a subset of common problems. Because the objective of HYCHL was not only to be the computer version of HEC-15 and HEC-11 but to be a generally useful tool, it was necessary to resolve the issues and expand the scope of problem types.

A thorough review of the channel-lining design literature was instrumental in making the necessary adjustments. A few features went beyond the literature but resulted in conservative solutions. The major issues discussed in this paper are (a) appropriate selection of Manning's n, (b) appropriate selection of Shields' parameter, (c) evaluation of channel geometrics other than trapezoidal, and (d) proper interpretation of stability.

The result of the implementation effort is a generally useful design and analysis tool that applies to a wide range of channel shapes, linings, and hydraulic conditions. The program can be used independently or within the integrated hydraulic design system, HYDRAIN.

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