CHAPTER 860
OPEN CHANNELS

Topic 861 - General

Index 861.1 - Introduction

An open channel is a conveyance in which water flows with a free surface. Although closed conduits such as culverts and storm drains are open channels when flowing partially full, the term is generally applied to natural and improved watercourses, gutters, ditches, and channels. While the hydraulic principles discussed in this section are valid for all drainage structures, the primary consideration is given to channels along, across, approaching and leaving the highway.

In addition to performing its hydraulic function, the drainage channel should be economical to construct and maintain. Open channels should be reasonably safe for vehicles accidentally leaving the traveled way, pleasing in appearance, convey collected water without damage to the highway or adjacent property and minimize the environmental impacts. These considerations are usually so interrelated that optimum conditions cannot be met for one without compromising one or more of the others. The objective is to achieve a reasonable balance, but the importance of traffic safety must not be underrated.

861.2 Hydraulic Considerations

An evaluation of hydraulic considerations for the channel design alternatives should be made early in the project development process. The extent of the hydrologic and hydraulic analysis should be commensurate with the type of highway, complexity of the drainage facility, and associated costs, risks, and impacts.

The hydraulic design of an open channel consists of developing a channel section to carry the design discharge under the controlling conditions, adding freeboard as needed and determining the type of channel protection required to prevent erosion. In addition to erosion protection, channel linings can be used to increase the hydraulic capacity of the channel by reducing the channel roughness. Both aspects of channel linings are discussed in Chapter 870.

The hydraulic capacity of a drainage channel is dependent on the size, shape, slope and roughness of the channel section. For a given channel, the hydraulic capacity becomes greater as the grade or depth of flow increases. The channel capacity decreases as the channel surface becomes rougher. A rough channel can sometimes be an advantage on steep slopes where it is desirable to keep flow velocities from becoming excessively high.

A good open channel design minimizes the effect on existing water surface profiles. Open channel designs, which lower the water surface elevation, can result in excessive flow velocities and cause erosion problems. A planned rise in water surface elevation can cause:

- Objectional flooding of the roadbed and adjacent properties;
- An environmental and maintenance problem with sedimentation due to reduced flow velocities.

Additional hydraulic considerations include those of channel and flood water characteristics such as: movable beds, heavy bedloads and bulking during flood discharges. A detailed discussion of sediment transport and channel morphology is contained in FHWA's HDS No. 6, "River Engineering for Highway Encroachments".

Reference is made to Volume VI of the AASHTO Highway Drainage Guidelines for a general discussion on channel hydraulic considerations.

861.3 Selection of "Design Flood"

As with other drainage facilities, the first step in the hydraulic design of an open channel is to establish the range of peak flows that the channel section must carry. The recommended design criteria for cross drainage type installations is discussed in Index 821.3. The desirable design storm and water spread criteria for roadway drainage type installations are presented in Table 831.3. Empirical and statistical methods for estimating design discharges are discussed in Chapter 810, "Hydrology".

861.4 Safety Considerations

An important aspect of highway drainage design is that of traffic safety.

The shape of a roadside channel section should minimize vehicular impact and provide a traversable section for errant vehicles leaving the traveled way. The ideal channel section, from a safety standpoint, will have flattened side slopes and a curved transition to the channel bottom.

861.5 Maintenance Consideration

Design of open channels and roadside ditches should recognize that periodic maintenance inspection and repair is required. Provisions should be incorporated into the design for access to a channel by maintenance personnel and equipment. When assessing the need for permanent or temporary access easements, entrance ramps and gates through the right of way fences, consideration should be given to the size and type of maintenance equipment required.

Damaged channels can be expensive to repair and interfere with the safe and orderly movement of traffic. Minor erosion damage within the right of way should be repaired immediately after it occurs and action taken to prevent the recurrence. Conditions, which require extensive repair or frequently recurring maintenance, may require a complete redesign rather than repetitive or extensive reconstruction. The advice of the District Hydraulics Engineer should be sought when evaluating the need for major restoration.

The growth of weeds, brush, and trees in a drainage channel can effectively reduce its hydraulic efficiency. The result being that a portion of the design flow may overflow the channel banks causing flooding and possible erosion.

Accumulation of sediment and debris may destroy vegetative linings leading to additional erosion damage.

Channel work on some projects may be completed several months before total project completion. During this interim period, the contractor must provide interim protection measures and possibly advance the planned erosion control program to assure that minor erosion will not develop into major damage.

861.6 Economics

Economical drainage design is achieved by selecting the design alternative which best satisfies the established design criteria at the lowest cost.

The economic evaluation of design alternatives should be commensurate with the complexity and importance of the facility. Analysis of the channel location, shape, size, and materials involved may reveal possibilities for reducing construction costs, flood damage potential, maintenance problems and environmental impacts.

861.7 Coordination with Other Agencies

There are many Federal, State and local agencies and private entities engaged in water related planning, construction and regulation activities whose interests can affect the design of highway drainage channels. Such agencies may request the channel design satisfy additional and perhaps governing design criteria. Early coordination with these agencies may help avoid delays in the project development process. Early coordination may also reveal opportunities for cooperative projects which may benefit both Caltrans and the water resources agency. For information on cooperative agreements refer to Index 803.2.

861.8 Environment

Many of the same principles involved in sound highway construction and maintenance of open channels parallel environmental considerations. Erosion, sedimentation, water quality, and aesthetics should be of prime concern to the highway design engineer. Refer to Index 110.2 for discussion on control of water pollution.

Proposed channel improvements may involve wildlife habitat and refuge areas. Where fish resources are a concern, the necessity to protect and preserve the ecosystem may affect decisions regarding low flow channel design, flow velocities, channel grades, channel stabilization techniques, and construction methods. Conservation and fish and wildlife agencies may be able to provide valuable information relating to channel planning and design. Early coordination with these agencies is also recommended.

861.9 References

Information on design of highway drainage channels is included in FHWA's Hydraulic Design Series No. 4, "Introduction to Highway Hydraulics" and Hydraulic Design Series No. 3, "Design Charts for Open Channel Flow".

For a general textbook discussion of open channel hydraulics, reference is made to "Open-Channel Hydraulics" by Ven Te Chow. In addition, many helpful design aids are included in "Handbook of Hydraulics", by Brater and King.

Topic 862 - Channel Location

862.1 General

Assuming adequate functional design, the next most important design consideration is channel location. Locations that avoid poorly drained areas, unstable soil conditions, and frequently flooded areas can greatly reduce drainage related problems. Refer to Index 110.4 for discussion on wetlands protection.

Often drainage and open channel considerations are not considered the primary decision factors in the roadway location; however they are factors which will often directly or indirectly affect many other considerations. Often minor alignment adjustments can avoid serious drainage problems.

If a channel can be located far enough away from the highway, the concerns of traffic safety and aesthetics can be somewhat mitigated. The cost of additional right of way may be offset somewhat by the reduced cost of erosion control, traffic protection, and landscaping.

862.2 Alignment and Grade

Ordinarily, the highway drainage channel must be located where it will best serve its intended purpose, using the grade and alignment obtainable at the site. Insofar as practicable, abrupt changes in alignment and grade should be avoided. A sharp change in alignment presents a point of attack for flowing water, and abrupt changes in grade can result in possible scour when the grade is steepened or deposition of transported material when the grade is flattened.

Ideally, a drainage channel should have flow velocities that neither erode nor cause deposition in the channel. This optimum velocity is dependent on the size and slope of channel, the quantity of flowing water, the material used to line the channel, the nature of the bedding soil and the sediment being transported by the flow. Refer to Table 862.2 for recommended permissible flow velocities in unlined channels.

The point of discharge into a natural watercourse requires special attention. Water entering a natural watercourse from a highway drainage channel should not cause eddies with attendant scour of the natural watercourse. In erodible embankment soils, if the flow line of the drainage channel is appreciably higher than that of the watercourse at the point of discharge, then the use of a spillway may be advisable to prevent erosion of the channel.

Table 862.2

Recommended Permissible Velocities for Unlined Channels

Type of Material in Excavation Section	Permissible Velocity (m/s)	
	Intermittent Flow	Sustained Flow
Fine Sand (Noncolloidal)	0.8	0.8
Sandy Loam (Noncolloidal)	0.8	0.8
Silt Loam (Noncolloidal)	0.9	0.9
Fine Loam	1.1	1.1
Volcanic Ash	1.2	1.1
Fine Gravel	1.2	1.1
Stiff Clay (Colloidal)	1.5	1.2
Graded Material (Noncolloidal)		
Loam to Gravel	2.0	1.5
Silt to Gravel	2.1	1.7
Gravel	2.3	1.8
Coarse Gravel	2.4	2.0
Gravel to Cobbles (Under 150 mm)	2.7	2.1
Gravel and Cobbles (Over 200 mm)	3.0	2.4

Topic 863 - Channel Section

863.1 Natural Channels

Natural channels are water conveying sections such as streams, rivers, creeks and swales which have been formed by natural forces. Good drainage design involving natural channels will maintain the existing flow characteristics such as size and shape of channel, flow velocities, and flow distributions.

It should be recognized by the design engineer that streams have inherent dynamic qualities by which changes continually occur in stream position and shape. These changes may be slow or rapid, but all streams are subjected to the forces that cause these changes to occur. For example, in alluvial streams, i.e., streams whose beds and banks are composed of materials deposited in water, it is the rule rather than the exception that banks erode, sediments are deposited, and islands and side channels form and disappear with time. A general understanding of fluvial geomorphology and river mechanics can help evaluate and resolve problems associated with alluvial streams. Reference is made to the FHWA publication entitled Highways in the River Environment - Hydraulic and Environmental Design Considerations.

863.2 Triangular V-Ditch

The shape of a channel section is generally determined by considering the intended purpose, terrain, flow velocity and quantity of flow to be conveyed.

The triangular channel or V-ditch is intended primarily for low flow conditions such as in median and roadside ditches. V-shaped ditches are susceptible to erosion and will require lining when flow velocities exceed the permissible flow velocities in Table 862.2.

863.3 Trapezoidal

The most common channel shape for large flows is the trapezoidal section.

Trapezoidal channels are easily constructed by machinery and are often the most economical.

When a wide trapezoidal section is proposed, both traffic safety and aesthetics can be improved by rounding all angles of the channel cross section with vertical curves. The approximate length of these vertical curves can be determined by the formula:

$$L = {}^{12}/_{X}$$

where L = length of vertical curve in meters
X = horizontal component of side slopes expressed as x,y coordinates with y = 1

For narrow channels, L, is limited to the bottom width.

For large flows, consideration should be given to using a minimum bottom width of 4 m for construction and maintenance purposes, but depths of flow less than 0.3 m are not recommended.

863.4 Rectangular

Rectangular channels are often used to convey large flows in areas with limited right of way. At some locations, guardrail or other types of positive traffic barrier may be necessary between the traveled way and the channel.

Though rectangular channels are relatively expensive to construct, since the walls must be designed as earth retaining structures, the construction costs can be somewhat offset by the reduced costs associated with right of way, materials, and channel excavation.

Topic 864 - Hydraulic Design of Channels

864.1 General

Open channel hydraulic design is of particular importance to highway design because of the interrelationship of channels to most highway drainage facilities.

The hydraulic principles of open channel flow are based on steady state uniform flow conditions, as defined in Index 864.2. Though these conditions are rarely achieved in the field, generally the variation in channel properties is sufficiently small that the use of uniform flow theory will yield sufficiently accurate results.

864.2 Flow Classifications

(1) *Steady vs. Unsteady Flow.* The flow in an open channel can be classified as steady or unsteady. The flow is said to be steady if the depth of flow at a section, for a given discharge, is constant with respect to time. The flow is considered unsteady if the depth of flow varies with respect to time.

(2) *Uniform Flow.* Steady flow can further be classified as uniform or nonuniform. The flow is said to be uniform if the depth of flow and quantity of water are constant at every section of the channel under consideration. Uniform flow can be maintained only when the shape, size, roughness and slope of the channel are constant. Under uniform flow conditions, the depth and mean velocity of flow is said to be normal. Under these conditions the water surface and flowlines will be parallel to the stream bed and a hydrostatic pressure condition will exist, the pressure at a given section will vary linearly with depth.

As previously mentioned, uniform flow conditions are rarely attained in the field, but the error in assuming uniform flow in a channel of fairly constant slope, roughness and cross section is relatively small when compared to the uncertainties of estimating the design discharge.

(3) *Non-uniform Flow.* There are two types of steady state non-uniform flow:

- Gradually varied flow.

  Gradually varied flow is described as a steady state flow condition where the depth of water varies gradually over the length of the channel. Under this condition, the streamlines of flow are practically parallel and therefore, the assumption of hydrostatic pressure distribution is valid and uniform flow principles can be used to analyze the flow conditions.

- Rapidly varied flow.

  With the rapidly varied flow condition, there is a pronounced curvature of the flow streamlines and the assumption of hydrostatic pressure distribution is no longer valid, even for the continuous flow profile. A number of empirical procedures have been developed to address the various phenomena of rapidly varied flow. For additional discussion on the topic of rapidly varied flow, refer to "Open-Channel Hydraulics" by Chow.

864.3 Open Channel Flow Equations

The equations of open channel flow are based on uniform flow conditions. Some of these equations have been derived using basic conservation laws (e.g. conservation of energy) whereas others have been derived using an empirical approach.

(1) *Continuity Equation.* One of the fundamental concepts which must be satisfied in all flow problems is the continuity of flow. The continuity equation states that the mass of fluid per unit time passing every section in a stream of fluid is constant. The continuity equation may be expressed as follows:

$$Q = A_1V_1 = A_2V_2 = ... = A_nV_n$$

Where Q is the discharge, A is the cross-sectional flow area, and V is the mean flow velocity. This equation is not valid for spatially varied flow, i.e., where flow is entering or leaving along the length of channel under consideration.

(2) *Bernoulli Equation.* Water flowing in an open channel possesses two kinds of energy: (1) potential energy and (2) kinetic energy. Potential energy is due to the position of the water surface above some datum. Kinetic energy is due to the energy of the moving water. The total energy at a given section as expressed by the Bernoulli equation is equal to:

$$H = z + d + \frac{V^2}{2g}$$

Where:

H = Total head, in meters of water

z = Distance above some datum, in meters

d = Depth of flow, in meters

$$\frac{V^2}{2g} = \text{Velocity head, in meters}$$

g = Acceleration of gravity

= 9.81 m/s^2

3) *Energy Equation.* The basic principle used most often in hydraulic analysis is conservation of energy or the energy equation. For uniform flow conditions, the energy equation states that the energy at one section of a channel is equal to the energy at any downstream section plus the intervening energy losses. The energy equation, expressed in terms of the Bernoulli equation, is:

$$z_1 + d_1 + \frac{V_1^2}{2g} = z_2 + d_2 + \frac{V_2^2}{2g} + h_L$$

Where:

h_L = Intervening head losses, in meters

(4) *Manning's Equation.* Several equations have been empirically derived for computing the average flow velocity within an open channel. One such equation is the Manning Equation. Assuming uniform and turbulent flow conditions, the mean flow velocity in an open channel can be computed as:

$$V = \frac{R^{2/3} S^{1/2}}{n}$$

Where V = Mean velocity, in meters per second

n = Manning coefficient of roughness

S = Channel slope, in meters per meter

R = Hydraulic Radius, in meters = A/WP

Where A = Cross sectional flow area, in square meters

WP = Wetted perimeter, in meters

Commonly accepted values for Manning's roughness coefficient, n, based on materials and workmanship required in the Standard Specifications, are provided in Table 864.3A. The tabulated values take into account deterioration of the channel lining surface, distortion of the grade line due to unequal settlement, construction joints and normal surface irregularities. These average values should be modified to satisfy any foreseeable abnormal conditions.

Direct solutions for Manning's equation for many channels of trapezoidal, rectangular, and circular cross sections can be found in FHWA's Hydraulic Design Series No. 3, "Design Charts for Open Channel Flow".

(5) *Conveyance Equation.* Often it is convenient to group the properties peculiar to the cross section into one term called the conveyance factor, K. The conveyance factor, as expressed by the Manning's equation, is equal to:

$$K = \frac{AR^{2/3}}{n}$$

For the non-pressure, full flow condition, the geometric properties and conveyance of a channel section can be computed. Then for a given channel slope the discharge capacity can be easily determined.

Table 864.3A

Average Values for Manning's Roughness Coefficient (n)

Type of Channel	n value
Unlined Channels:	
Clay Loam	0.023
Sand	0.020
Gravel	0.030
Rock	0.040
Lined Channels:	
Portland Cement Concrete	0.014
Air Blown Mortar (troweled)	0.012
Air Blown Mortar (untroweled)	0.016
Air Blown Mortar (roughened)	0.025
Asphalt Concrete	0.018
Sacked Concrete	0.025
Pavement and Gutters:	
Portland Cement Concrete	0.015
Asphalt Concrete	0.016
Depressed Medians:	
Earth (without growth)	0.040
Earth (with growth)	0.050
Gravel	0.055

NOTES:

For additional values of n, see "Introduction to Highway Hydraulics", Hydraulic Design Series No. 4, FHWA Table 14.

(6) *Critical Flow.* A useful concept in hydraulic analysis is that of "specific energy". The specific energy at a given section is defined as the total energy, or total head, of the flowing water with respect to the channel bottom. For a channel of small slope;

$$E = d + \frac{V^2}{2g}$$

Where E = Specific energy, in meters

d = Depth of flow, in meters

$\frac{V^2}{2g}$ = Velocity head, in meters

When the depth of flow is plotted against the specific energy, for a given discharge and channel section, the resulting plot is called a specific energy diagram (see Figure 864.3C). The curve shows that for a given specific energy there are two possible depths, a high stage and a low stage. These flow depths are called alternate depths. Starting at the upper right of the curve with a large depth and small velocity, the specific energy decreases with a decrease in depth, reaching a minimum energy content at a depth of flow known as critical depth. A further decrease in flow depth results in a rapid increase in specific energy.

Flow at critical depth is called critical flow. The flow velocity at critical depth is called critical velocity. The channel slope which produces critical depth and critical velocity for a given discharge is the critical slope.

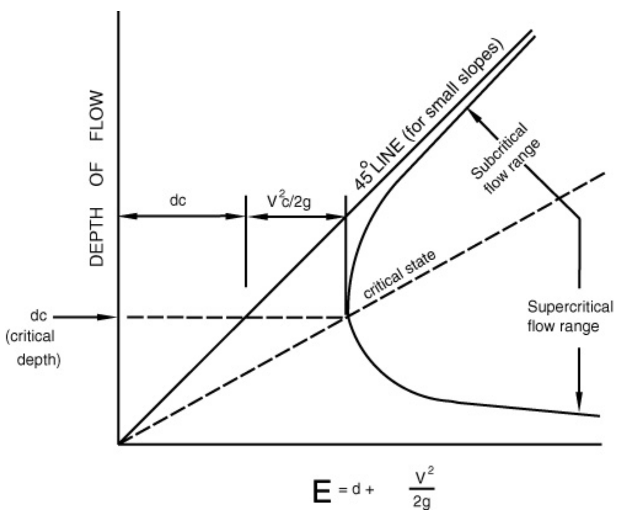
Uniform flow within approximately 10 percent of critical depth is unstable and should be avoided in design, if possible. The reason for this can be seen by referring to the specific energy diagram. As the flow approaches critical depth from either limb of the curve, a very small change in energy is required for the depth to abruptly change to the alternate depth on the opposite limb of the specific energy curve. If the unstable flow region cannot be avoided in design, the least favorable type of flow should be assumed for the design.

When the depth of flow is greater than critical depth, the velocity of flow is less than critical velocity for a given discharge and hence, the flow is subcritical. Conversely, when the depth of flow is less than critical depth, the flow is supercritical.

When velocities are supercritical, air entrainment may occur. This produces a bulking effect which increases the depth of flow. For concrete lined channels, the normal depth of flow with bulking can be computed by using a Manning's "n" value of 0.018 instead of the 0.014 value given in Table 864.3A. Air entrainment also causes a reduction in channel friction with a resulting increase in flow velocity. A Manning's "n" value of about 0.008 is recommended for computing the velocity and specific energy of flow in concrete-lined channels carrying supercritical flow

Figure 864.3C

Specific Energy Diagram



Critical depth is an important hydraulic parameter because it is always a hydraulic control. Hydraulic controls are points along the channel where the water level or depth of flow is limited to a predetermined level or can be computed directly from the quantity of flow. Flow must pass through critical depth in going from subcritical flow to supercritical flow. Typical locations of critical depth are at:

(a) Abrupt changes in channel slope when a flat (subcritical) slope is sharply increased to a steep (supercritical) slope,

(b) A channel constriction such as a culvert entrance under some conditions,

(c) The unsubmerged outlet of a culvert on subcritical slope, discharging into a wide channel or with a free fall at the outlet, and

(d) The crest of an overflow dam or weir.

Critical depth for a given channel is dependent on the channel geometry and discharge only, and is independent of channel slope and roughness.

When flow occurs at critical depth the following relationship must be satisfied

$$A^3/T = Q^2/g$$

Where A = Cross sectional area, in square meters
T = Top width of water surface, in meters
Q = Discharge, in m^3/s
g = Acceleration of gravity, 9.81 m/s^2

Critical depth formulas, based on the above equation, for various channel cross-sections include:

- Rectangular sections,

  $d_c = (q^2/g)^{1/3}$

  Where q = Flow per unit width, in m^3/s

- Trapezoidal sections. The tables in King's "Handbook of Hydraulics" provide easy solutions for critical depth for channels of varying side slopes and bottom widths.

- Circular sections. The tables in King's "Handbook of Hydraulics" can be used for obtaining easy solutions for critical depth.

(7) *Froude Number*. The Froude number is a useful parameter which uniquely describes open flow. The Froude number is a dimensionless value:

$Fr = V/(gD)^{1/2}$

Where D = A/T = Hydraulic depth, in meters

Fr < 1.0 ==> Subcritical flow

Fr = 1.0 ==> Critical flow

Fr > 1.0 ==> Supercritical flow

864.4 Water Surface Profiles

(1) *General.* For the gradually varied flow condition, the depth of flow must be established through a water surface profile analysis. The basic principles in water surface profile analysis are where:

(a) Water surface approaches the uniform depth line asymptotically,

(b) Water surface approaches the critical depth line at a finite angle,

(c) Subcritical flow is controlled from a downstream location, and

(d) Supercritical flow is controlled from an upstream location.

There are 13 possible water surface profiles depending on the particular flow conditions. A complete discussion of water surface profile analysis is contained in most open channel hydraulics textbooks.

(2) *Methods of Analysis.* Two methods of performing a water surface profile analysis are:

- The Direct Step method
- The Standard Step method

Both methods make use of the energy equation to compute the water surface profile. The direct step method can be used to analyze straight prismatic channel sections only. The standard step method is applicable to non-prismatic and non-straight channel alignments. For a complete discussion of both refer to Open-Channel Hydraulics, by Chow.

(3) *Computer Programs.* The analysis of water surface profile problems is best performed by computer. The recommended personal computer program is the US Army Corps of Engineers HEC-RAS River Analysis System. The Program was specifically developed for analysis of highway bridge and culvert backwater. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. HEC-RAS is capable of importing HEC-2 and GIS/CADD data. The basic computational procedure is based on the solution of the energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

The effects of various obstructions such as bridges, culverts, weirs, and structures in the flood plain may be considered in the computations. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements, and levees.

Special features of the steady flow component include: multiple plan analyses; multiple profile computations; scour computations; and multiple bridge and/or culvert opening analysis.

Where one-dimensional models fail, such as at significantly skewed bridge crossings, confluences, tidal environments, guide bank design, superelevated flow, complex floodplain analysis, sediment transport, and dynamic flow analysis, the FESWMS-2DH/SMS two-dimensional model that was developed by FHWA may be used.

FESWMS-2DH is an acronym for Finite Element Surface Water Modeling System Two Dimensional Flow in a Horizontal Plane. SMS is an acronym for Surface-water Modeling System. SMS is a pre- and post- processor for use with hydraulic models. It does not perform modeling, but an interface has been specifically developed for FESWMS-2DH.

FESWMS-2DH is a two-dimensional depth averaged model that employs the finite element method to solve two-dimensional (in a horizontal plane) momentum and continuity equations.

FESWMS-2DH has also been specifically designed to model highway crossings and structures such as bridges, culverts, drop structures and weirs.

Both steady state and dynamic (time varying) modeling may be performed.

864.5 Stage-Discharge Relationships

The stage-discharge relationship is an important consideration in the analysis and design of an open channel. The depth of flow for various discharges can be plotted to create a "rating curve" which provides a visual display of the relationship.

Depending on the site conditions, accuracy required, and risks involved, a single section analysis may be sufficient to adequately describe the channel stage discharge relationship. The basic assumptions to a single section analysis are uniform cross section, slope, and Manning's "n" values.

Where uniform flow conditions do not adequately describe the actual flow conditions or where additional accuracy is desired, the computation of complete water surface profiles for each discharge value may be necessary.

Topic 865 - Channel Changes

865.1 General

A channel change is any realignment or change in the hydraulic characteristics of an existing channel.

The main reasons for channel changes are to:

- Permit better drainage
- Permit better culvert alignment
- Eliminate the need for bridges and culverts where a stream recrosses a highway
- Improve flow conditions
- Protect the highway from flood damage
- Reduce right of way requirements

The effects of a channel change can vary greatly depending on the site conditions. For example certain streams may have a great tolerance to changes, whereas with others, small changes may have significant impacts. When potentially detrimental effects can be foreseen, plans should be developed to mitigate the effects to within tolerable limits.

865.2 Design Considerations

Channel changes should be designed with extreme caution. Careful study of the stream characteristics upstream and downstream as well as within the channel change area is required to achieve a safe and effective design.

Channel changes usually decrease the surface roughness and increase the channel slope. As a result the following may occur:

- Higher velocities which result in damage due to scour
- Sedimentation and meandering at downstream end of channel change
- A flattened downstream gradient which progresses upstream undercutting the channel banks or highway fill
- Flattened downstream gradient or channel restrictions may create undesirable backwater conditions.

Modification to a natural channel may reduce the available cover for fish and other wildlife in and around the water and eliminate the natural food supplies available in the old channel. The design of new channels involving rivers or streams supporting fish or wildlife must be coordinated with the Department of Fish and Game in accordance with current practices.

On intermittent streams the problems are generally erosion or silting. For a discussion of temporary measures to be made a part of the contract, see Index 110.2.

A channel change perched above the bottom of an old flood stage stream bed may cause the stream to return to its old channel during a subsequent flood. This is most likely to occur in arid or semi-arid locations.

Topic 866 - Freeboard Considerations

866.1 General

Freeboard is the extra height of lining above the design depth where overflow is predicted to cause damage. Freeboard allowances will vary with each situation.

When the possibility of damage is slight or non-existent, or where the type of facility is minor, freeboard need not be provided.

866.2 Height of Freeboard

(1) *Straight Alignment*. In channels where overflow may cause substantial damage, a guide for freeboard height, for channels on a straight alignment, is provided in Table 866.2

Table 866.2

Guide to Freeboard Height

Shape of Channel	Subcritical Flow	Supercritical Flow
Rectangular	0.1 He	0.20 d
Trapezoidal	0.2 He	0.25 d

Where He = Energy head, in meters
d = Depth of flow, in meters for a straight alignment

(2) *Critical Flow*. An unstable zone of flow occurs where the flow is near critical state. This is characterized by random waves. An allowance for waves should be added to the normal depth when the slope of the channel is between 0.7 S_c and 1.3 S_c.

$$H_w = 0.25\, d_c(1 - 11.1\, (S/S_c - 1)^2)$$

where H_w = height of wave, in meters
d_c = critical depth, in meters
S = slope of channel, in meter per meters
S_c = critical slope, in meter per meters

(3) *Superelevation.* The height of freeboard discussed above does not provide for superelevation of the water surface on curved alignments.

Flow around a curve will result in a rise of the water surface on the outside of the curve and extra lining is necessary to guard against overtopping.

Supercritical flow around a curve will cause the water to rise alternately on the outside and inside of the curves due to cross waves. This cross wave pattern may persist for a considerable distance downstream. Extra height of lining must be provided on both sides of the channel.

The heights required by this superelevation of the water surface can be computed by the following Natural Resources Conservation Service (NRCS) formulas:

- Rectangular Channels.

Subcritical flow $$E = \frac{3V^2 b}{4gr}$$

Supercritical flow $$E = \frac{1.2V^2 b}{gr}$$

$$Ø = \cos^{-1}\left(\frac{r - \frac{b}{2}}{r + \frac{b}{2}} \cos B\right) - B$$

- Trapezoidal Channels.

Subcritical flow $$E = \frac{V^2(b + 2Kd)}{2(gr - 2KV^2)}$$

Supercritical flow $$E = \frac{V^2(b + 2Kd)}{gr - 2KV^2}$$

Where E = Maximum height of water surface in meters above depth "d".

V = Average velocity for the flow cross section in m/s at entrance to curve.

b = Width of rectangular channel or bottom width of trapezoidal channel in meters.

g = Acceleration of gravity
= 9.81 m/s^2.

r = Radius of channel centerline in meters.

K = Cotangent of bank slope.

d = Depth of flow in meters for straight alignment at entrance to curve.

Ø = Central angle of curve from B.C. to point of beginning of zone of maximum depth in degrees.

B = Wave angle in degrees, defined as:

$$\sin B = \frac{(gd)^{1/2}}{V}$$