Environmental Engineering Support Services
Design Considerations for Stream Groynes

October, 1975
ABSTRACT

Types of groynes are described and illustrated. Factors to be considered in the design of a groyne installation are discussed, with emphasis on the local scour at the head of a groyne. Scour estimation methods are discussed and illustrated. Results from a review of the current literature are summarized in the form of a recommended design procedure. Recommendations for future study and research are also given.
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>NOMENCLATURE</td>
<td>vi</td>
</tr>
<tr>
<td>1.0 INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Groynes</td>
<td>2</td>
</tr>
<tr>
<td>1.2 Types of Groynes</td>
<td>2</td>
</tr>
<tr>
<td>2.0 DESIGN CONSIDERATIONS</td>
<td>5</td>
</tr>
<tr>
<td>2.1 Permeability</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Height</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Spacing</td>
<td>7</td>
</tr>
<tr>
<td>2.4 Shape in Plan</td>
<td>10</td>
</tr>
<tr>
<td>2.5 Projection into Stream</td>
<td>11</td>
</tr>
<tr>
<td>2.6 Orientation to Flow</td>
<td>11</td>
</tr>
<tr>
<td>2.7 Scour</td>
<td>13</td>
</tr>
<tr>
<td>2.7.1 Definitions</td>
<td>13</td>
</tr>
<tr>
<td>2.7.2 Scour Estimation</td>
<td>14</td>
</tr>
<tr>
<td>2.7.3 Dimensional Analysis</td>
<td>15</td>
</tr>
<tr>
<td>2.7.4 Orientation to Flow</td>
<td>16</td>
</tr>
<tr>
<td>2.7.5 Side Slope of the Head</td>
<td>17</td>
</tr>
<tr>
<td>2.7.6 Contraction</td>
<td>18</td>
</tr>
<tr>
<td>2.7.7 Summary</td>
<td>19</td>
</tr>
</tbody>
</table>
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Groyne Spacing Ratios</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Timber Groynes - Pembina River at Manola</td>
<td>10</td>
</tr>
<tr>
<td>2.3</td>
<td>Groyne Inclination to Flow</td>
<td>13</td>
</tr>
<tr>
<td>A1</td>
<td>Groyne Scour Estimation Comparison</td>
<td>B2</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure No:</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>General Drawing Impermeable Round Head Gravel Groyne</td>
<td>31</td>
</tr>
<tr>
<td>2</td>
<td>Permeable Timber Groyne</td>
<td>32</td>
</tr>
<tr>
<td>3</td>
<td>Types of Groynes</td>
<td>33</td>
</tr>
<tr>
<td>4</td>
<td>The Principle of Groynes</td>
<td>34</td>
</tr>
<tr>
<td>5</td>
<td>Forms of Spurs</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>Pembina River Groynes near Manola</td>
<td>36</td>
</tr>
<tr>
<td>7</td>
<td>Impermeable Hooked Groynes</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>Water Movement Associated with T-Head Groyne</td>
<td>38</td>
</tr>
<tr>
<td>9</td>
<td>(Tison's Contour Maps for Groynes of Varying Inclination)</td>
<td>39</td>
</tr>
<tr>
<td>10</td>
<td>Group Groyne Action</td>
<td>40</td>
</tr>
<tr>
<td>11</td>
<td>Illustration of Key Parameters</td>
<td>41</td>
</tr>
<tr>
<td>12</td>
<td>Length Requiring Protection as a Function of Spur Inclination</td>
<td>42</td>
</tr>
<tr>
<td>13</td>
<td>Contour Maps with Groynes</td>
<td>43</td>
</tr>
<tr>
<td>14</td>
<td>Idealized Location of Three Groynes</td>
<td>44</td>
</tr>
<tr>
<td>15</td>
<td>Tying in Groyne to Bank</td>
<td>45</td>
</tr>
<tr>
<td>A1</td>
<td>(Garde's Scour Coefficients)</td>
<td>A10</td>
</tr>
<tr>
<td>A2</td>
<td>Design Curve for Maximum Depth of Scour in Clear Water Flow</td>
<td>A11</td>
</tr>
<tr>
<td>A3</td>
<td>Design Curve for Maximum Scour Depth for Clear Water Flow</td>
<td>A12</td>
</tr>
<tr>
<td>A4</td>
<td>Design Curve for Maximum Scour Depth in Sediment Transporting Flow</td>
<td>A13</td>
</tr>
<tr>
<td>A5</td>
<td>Karaki's Scour Prediction Equation</td>
<td>A14</td>
</tr>
<tr>
<td>A6</td>
<td>Relationship of Blench's 'Zero Bed Factor' to the Size of Bed Material</td>
<td>A15</td>
</tr>
</tbody>
</table>
**NOMENCLATURE**

- **A**: factor of proportionality (Mukhamedov's equation (9)).
- **a**: length of groyne
- **B**: average width of approach channel
- **b**: average width of contracted channel
- **b_l**: the average channel width at half of the depth d, corresponding to Q (Blench's equation (12)).
- **b_w**: the net width of the proposed waterway opening normal to flow, at half of the depth d_f (Blench's equation (13)).
- **C**: sediment concentration by weight
- **C_D**: drag coefficient
- **D**: representative size of bed material
- **D_85****: grain sizes of which the given percent by weight of the bed material is finer
- **D_50****: average depth for discharge Q (Blench's equation (14)).
- **d_i**: average 'flood depth' in the controlled waterway opening (Blench's equation (14)).
- **d_f**: 'zero flood depth', (Blench's equation (15)).
- **d_f_o**: limiting depth of scour below original bed level
- **F**: Froude Number of normal (approach) flow = v/√(gh)
- **F_b_o**: 'zero bed factor', (Blench's equation (15), and Figure No. A6).
- **g**: acceleration due to gravity
- **h**: average depth of normal (approach) flow
- **h_m**: maximum depth of normal (approach) flow
- **K_c**: the non-dimensional factor; accounting for the effect of groyne characteristics (Mukhamedov's equation (9)).
\( K_\xi \) the non-dimensional factor for the effect of self-armouring of a scour hole (Mukhamedov's equation (9)).

\( K_\rho \) the non-dimensional factor for the effect of sediment concentration (Mukhamedov's equation (9)).

\( \lambda \) projection of groyne into stream (normal to flow)

\( m \) contraction ratio \( = (B-b)/B \)

\( N \) dimensionless term of roughness (Awazu's equations (16) to (19) inclusive).

\( n \) an exponent (Garde's equation (1)).

\( Q \) normal approach discharge

\( Q_i \) the bankfull discharge, or the highest non-spilling discharge for an incised reach, (Blench's equation (12)).

\( Q_f \) the design flood discharge (Blench's equation (13)).

\( q \) unit discharge in contracted section

\( q_i \) the average incised discharge intensity under bankfull or highest non-spilling conditions, (Blench's equation (12)).

\( q_f \) the average design discharge intensity in the proposed waterway opening (Blench's equation (13)).

\( s \) an exponent (Blench's equation (14)).

\( U_m \) maximum velocity of the approach flow

\( v \) mean velocity of the normal approach flow

\( w \) width of groyne

\( x \) an exponent (Mukhamedov's equation (9)).

\( z \) Blench's scour factor

\( \alpha \) opening ratio \( = 1 - m \)

\( \beta \) angle between side slope of groyne and the vertical plane

\( \eta_1 \) scour coefficient which is a function of sediment characteristics (Garde's equation (1)).

\( \eta_2 \) scour coefficient which is a function of length-to-width ratio of the obstruction and Froude Number (Garde's equation (1)).
\( \eta_3 \) scour coefficient which is a function of shape of the obstruction for a given length-to-width ratio (Garde's equation (1)).

\( \eta_4 \) scour coefficient which is a function of angle of inclination of the obstruction (Garde's equation (1)).

\( \theta \) angle between center line of groyne and the bank or thalweg

\( v \) kinematic viscosity

\( \varepsilon_{85\%} \) ratio of \( D_{85} \) to \( D_{50} \) of the bed material (Mukhamedov's equations (10,11)).

\( \rho_s \) specific density of bed material

\( \rho_w \) specific density of water

\( \sigma_{gd} \) term describing size gradation of the bed material

\( \tau_c \) critical bed shear stress

\( \tau_{ns} \) normal (approach) channel bed shear stress (Awazu's equation (16)).

\( \tau_{ns*,b} \) normal (approach) channel bed shear stress at beginning of scouring motion (Awazu's equation (17)).

\( \tau_1 \) normal (approach) channel bed shear stress
1.0 INTRODUCTION

Groynes or spurs have long been used as a means of training streamflow or for controlling bank erosion. While a great deal of the design work concerning these structures has been based on practical experience, considerable laboratory research in recent years has been performed to better define the qualitative and quantitative effects of various design parameters on the action of a groyne in a stream.

This report attempts to bring together the presently available information on groyne design and operation. Information has been drawn from case studies of actual groyne installations, and extensive laboratory studies contained in professional journals, government publications and books from around the world. While not exhaustive in its treatment of the subject, this report serves to cover the basics of groyne design and operation. Readers are advised to refer to original articles and laboratory reports for more detailed and complete information.

The dearth of information on the design of permeable groynes has made an examination of this type almost impossible. As a result, this report will, of necessity, limit itself to the design of impermeable groynes. (See 1.2-(a) for definitions of permeable and impermeable groynes).

Other topics relating to groynes not included in this report include construction methods and techniques and apron design.
1.1 Groynes

A groynemay be defined as an elongated obstruction having one end (the root) in the bank of the stream and the other (the head) projecting out into the flow, (FIGURE No. 1). Groynes are known by many other names including spurs, spur dykes, and transverse dykes. Groynes may serve one or more of the following functions:

i) Training the stream along a desired course by changing direction of the flow in the channel;

ii) Aid siltation near the banks by creating slack flow, i.e. land reclamation;

iii) Protecting stream banks, (including bridge abutments) by keeping high velocity erosive flow away from sensitive areas; and

iv) Narrow floodways to induce scouring along defined lines to create a narrow, deep, straightening channel instead of one which is wider, shallower and wandering. i.e. channel improvement for navigation.

The above basically lists the possible objectives a system of groynes could have as they pertain to a river or stream channel. However, groynes also may be used for the stabilization of coastal beaches, and for land reclamation in areas where littoral drift may be accumulated.

1.2 Types of Groynes

Groynes vary greatly in their construction, appearance and action on streamflow. A full and complete description of a groyne should include the following:
a) Groynes are classified according to the method and materials of construction, i.e. permeable or impermeable.

The terms permeable and impermeable are self-explanatory and are differentiated by the ability of the construction material to transmit flow. Permeable groynes slow down the current while impermeable (solid) groynes deflect the current. It is beyond the scope of this report to discuss all the available materials and/or construction methods for each type of groyne.

Permeable groynes are most often fabricated from piles or timbers while rock, gravel or gabions are used to construct impermeable groynes. Permeable groynes are most effective on alluvial streams with considerable bed load and high sediment concentration, which favor rapid deposition around the groynes. This sedimentation is achieved by obstructing the flow and reducing velocities. However, they also may be used in comparatively clear streams where the damping of the erosive strength of the current is sufficient to prevent local bank erosion. FIGURE No. 2 shows a permeable groyne constructed from timber, and commonly known as a "Pile and Waling" groyne (30). (Very little information has been obtained on design parameters for permeable groynes. Readers are referred to Mukhamedov (24) in which the kinematic structure of flow through spur-dykes or permeable groynes is studied).

Impermeable or solid groynes are primarily used to protect sections of eroding bank and to push the river towards a more suitable alignment. In so doing, sedimentation between the groynes is encouraged. As scour at the heads of impermeable groynes is induced by rapidly changing flow patterns, they are especially useful for maintaining navigable depths in streams.
b) Groynes may be either submerged or non-submerged. Such a classification generally refers to the design conditions.

In most instances, impermeable groynes are designed to be non-submerged. Under submerged conditions, solid groynes are susceptible to severe erosion along the shanks, (FIGURE No. 1), resulting from flow over the top of the groyne.

Permeable groynes, on the other hand, are best suited to submerged conditions as they do not create as severe flow disturbances as solid groynes. Anderson and Davenport (5) give design curves for submerged groynes.

c) Groynes vary depending on their action on the stream flow. They may be classified as attracting, deflecting or repelling groynes, (FIGURES No. 3 and 4).

(i) An attracting groyne points downstream and attracts the stream flow towards itself. This type of groyne does not repel the flow towards the opposite bank, and therefore should never be placed on a concave bank.

(ii) A deflecting groyne, usually of short length, changes only the direction of flow without repelling it, and gives only local protection.

(iii) A repelling groyne points upstream and has the property of repelling the river flow away from it.

d) Groynes may be further classified according to their appearance in plan. Among the types illustrated in FIGURE No. 5 are:

- straight round nose
- inverted hockey
- T-head
- L-head
- hockey
- hooked
- Wing or trail
2.0 DESIGN CONSIDERATIONS

The design of a groyne installation is a function of the following factors:

I. Flow Variables
   i) Flood depths and flows;
   ii) Amount of suspended load in relation to bed load;

II. Channel Parameters
   i) Slope and velocity of the river;
   ii) Character of the bed material, (clay, silt, sand, gravel, cobbles, boulders);
   iii) General channel size, width, high and low water depths;

III. Miscellaneous Factors
   i) Debris (logs) flowing down the stream during floods;
   ii) Possible damage due to ice;
   iii) Available materials and funds;

With these considerations in mind, decisions must be made on a number of design parameters. The designer must decide:

- whether to build permeable or impermeable groynes
- the height of the groyne as related to streamflow
- the number of groynes to be built and the spacing to be provided between each groyne
- the shape (in plan) of the groynes
- the projection of the groynes into the stream, and
- the orientation of the groynes to the flow
- the scour to be expected so that adequate apron protection may be provided.

In the following sections, design parameters are discussed with an emphasis on how flow and channel variables affect design decisions.

2.1 **Permeability**

The decision whether to build permeable or impermeable groynes is influenced by many factors. Primarily, of course, the amount of suspended material carried by the stream will govern the choice. Ease of construction must always be considered. Certainly in gravel streams where stone is plentiful and pile driving for most types of permeable groynes is difficult, solid groynes will be favoured. In streams which carry considerable bed load, solid groynes may be best suited. If minor protection is to be provided, or where the stream carried a large portion of suspended load, and the more forceful action of solid groynes is not warranted, permeable groynes should be chosen.

2.2 **Height**

The height of the groynes is dependent on the nature of the stream in which they are to be placed, and the function desired. On wide braided channels, where the flood plain level may only be a few feet above normal flow levels, the groynes should be built to a height no higher than the flood plain elevation. Otherwise, expensive protection against outflanking would have to be provided. And if the stream is subject to frequent flooding above the flood plain level, a decision based largely on economics will have to be made whether or not the groynes should be built above maximum
flood level and connected to high ground or an over-bank longitudinal
dyke or whether adequate protection should be provided against over-
topping. Most often the height may be set by a design criterion based
on providing protection for a specific frequency of return; i.e., if groynes
are to be built to flood plain level, the frequency of bankfull flow may
be established.

Groynes are often designed to be submerged during high flow, especially
when they are intended to improve flow depths for navigation at low flows(5).
For navigation purposes in the Netherlands, the height of groynes is usually
placed between 0.3 m and 1.3 m above the mean yearly water level.

For streams with considerable depth, groynes sloping from root to head
may provide considerable savings in construction.

2.3 Spacing

One of the most important considerations involved in groyne design
is the spacing provided between individual groynes. If groynes are
spaced too far apart the stream current may return to the bank being
protected before the next groyne in the system starts to influence the
flow direction. This may result in bank erosion or even the loss of the
next downstream groyne. In the case where groynes are spaced too close
together, best use is not made of the individual structures. Such a
system would work less efficiently in controlling river flow, and would be
considerably more expensive than a correctly designed system (with larger
spacing).

In general, the literature gives guides on groyne spacing that varies
over a wide range, (TABLE No. 2.1). Ahmad's(2) model studies give spacing
ratios (ratio of the spacing length between two consecutive groynes and the
effective length of the upstream groyne, where the effective length is the
distance normal to the flow from the head to the bank of the stream at the root) of 4.29 for straight reaches and about 5 for curved channels. These results are questionable as general practice is to place groynes closer together on concave banks than along convex banks.

An Indian design manual\(^{(8)}\) recommends a spacing of 2 to 2\(\frac{1}{2}\) times the length of the upstream groyne.

In North America, spacing ratios of about 1\(\frac{1}{2}\) are usually provided. Analysis of U.S. Army Corps of Engineers installations show that a ratio of 2.0 was used in many instances on the Mississippi River.

**TABLE 2.1**

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>RECOMMENDED SPACING RATIO</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahmad</td>
<td>4.29</td>
<td>Straight Reaches</td>
</tr>
<tr>
<td></td>
<td>= 5</td>
<td>Curved Channels</td>
</tr>
<tr>
<td>Central Board of Irrigation &amp; Power</td>
<td>2 ~ 2(\frac{1}{2})</td>
<td></td>
</tr>
<tr>
<td>U.S. Army</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Mathes</td>
<td>1(\frac{1}{2})</td>
<td></td>
</tr>
<tr>
<td>Strom</td>
<td>3 ~ 5</td>
<td></td>
</tr>
<tr>
<td>Acheson</td>
<td>3 ~ 4</td>
<td>Varies depending on curvature and stream slope</td>
</tr>
<tr>
<td>Bendegom</td>
<td>2 ~ 2(\frac{1}{2})</td>
<td>Convex banks</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td>Concave banks</td>
</tr>
</tbody>
</table>
Mathes (23) states that a spacing ratio of 1½ should be used, and that on European rivers, values from 3/4 to 2 are generally adopted.

Referring to current practice in New Zealand and Australia, Strom (31) states that as a rough rule, a groyne will protect from 3 to 5 times its own length of bank, having little if any effect outside this. Acheson (1) also of New Zealand, gives spacing ratios of 3 or 4 depending on the degree of curvature and river gradient. The sharper the curvature and the steeper the stream gradient, the closer the groynes should be.

Some authors recommend that the spacing not exceed the regulation width, i.e. the open channel remaining between the head of the groyne and the opposite bank. Van Ornum (34) states that European practice is to fix the spacing somewhere between the width of the contracted channel and half this width. Within this range, typical spacing is about half the channel width on the concave margin, seven tenths of this in straight portions, and approximately equal to the width of the contracted channel on the convex side.

One should always keep in mind that longer groynes at wider spacing are cheaper than short groynes at closer spacing, due to the major cost being in the construction of the groyne heads.

It is interesting to note the spacing to length ratios of a system of four groynes on the Pembina River near Manola, Alberta (11), (TABLE No. 2.2). These groynes, (FIGURE No. 5) were installed in late 1963 or early 1964, and have worked very successfully. Three floods of at least 15 year return period have occurred since construction, but no problems have developed with the groynes or the bank they protect.
TABLE 2.2
TIMBER GROYNES - PEMBINA RIVER NEAR MANOLA

<table>
<thead>
<tr>
<th>GROYNE LENGTH</th>
<th>SPACING</th>
<th>Length Between Groynes</th>
<th>Spacing Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ft.</td>
<td>m.</td>
<td>ft.</td>
<td>m.</td>
</tr>
<tr>
<td>75</td>
<td>22.9</td>
<td>285</td>
<td>86.9</td>
</tr>
<tr>
<td>90</td>
<td>27.9</td>
<td>300</td>
<td>91.4</td>
</tr>
<tr>
<td>82</td>
<td>25.0</td>
<td>230</td>
<td>70.1</td>
</tr>
<tr>
<td>50</td>
<td>15.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It appears that no definite spacing ratio was used in the design of these groynes. However, if the ratio of the spacing to the average of the upstream and downstream groyne lengths is considered, an almost constant value of 3.47 results. The spacing does not exceed the regulation channel width of approximately 330 feet (101 m).

2.4 Shape in Plan

No guidelines appear in the literature regarding what shape of groyne is preferred for various situations. The choice of a particular shape is likely a matter of personal preference, (see FIGURE No. 7). Complex designs such as hooked or T-Head groynes are probably justifiable only under special circumstances, e.g., on braided streams where a bank may be attacked by the stream current from many varying angles. For most situations, a properly designed system of straight round nose groynes should provide adequate protection, and induce sedimentation. In addition, construction costs for the straight round nose groyne should be considerably less than other, more complex shapes (L-Head, hockey, hooked, etc).
Special mention should be made of the T-Head groyne (FIGURE No. 8). This shape is preferable in situations where rapid shifting of the stream channel is possible, as in a braided stream. The armoured head portion of the groyne can withstand attack from a number of directions.

2.5 Projection into the Stream

The heads of groynes in a system of such structures should always be aligned to define a bank of the new stream channel. As such, they should define a smooth curve and should guide the flow from the upstream reach into the downstream reach by providing an orderly transition between these two channel lengths. However, care should be taken at all times to ensure that an adequate channel area remains for the development of a stable channel beyond the heads of the groynes. Such a channel should have a regulation width that conforms to regime dimensions.

These restrictions on a smooth channel of sufficient width ultimately define the projection of the groynes into the stream.

2.6 Orientation to Flow

Groynes may be positioned facing upstream, normal to the flow, or facing downstream. Each orientation to the flow affects the river current in a different way. Consequently, the deposition in the vicinity of the groyne is directly affected by the orientation of the groyne to the sediment carrying flow.

In most of our river engineering work, groynes are designed as a means of bank protection. Therefore, our prime interest is in maximizing the amount of deposition between groynes. Tests have shown that a repelling
groyne causes more deposition adjacent to the downstream bank than a
groyne inclined at 90° to the flow, (FIGURE No. 9). In addition, a
still-water pocket (or reverse eddy) is formed upstream of the repelling
groyne, and the suspended load brought down by the stream is deposited in
this area. The principle of the action of these two types of groynes has
been excellently illustrated by Strom \(^{31}\), and is shown in FIGURE No. 4.
The action of a series of repelling groynes is shown in FIGURE No. 10.

Successful protection of an eroding section of a stream bank also
depends on how well the current is directed away from the bank. Groynes
facing downstream, or attracting groynes, due to their intrinsic effects
on the flow, are not suitable for bank protection purposes. The current
which flows towards the root of the next downstream groyne (FIGURE No. 4)
not only endangers the root of the groyne and the surrounding bank area
but the whole groyne itself. Groynes placed normal to the flow may only
protect a small area. Groynes facing upstream deflect the river flow away
from the eroding bank. In sustaining the bulk of the erosive power of the
stream, they are able to protect stream bank areas upstream and downstream
of themselves.

Qualitatively then, deflecting groynes, or groynes pointing upstream
appear to be best suited for bank protection or sedimentation purposes.

References vary in their recommendations for groyne inclination,
(TABLE 2.3). Design guidelines in the literature \(^{22,8,34}\) recommend an
inclination of 100° - 120° (1.75 radians - 2.09 radians) to the flow for
repelling groynes used for bank protection purposes. This design guideline
may be refined somewhat by placing the groynes so as to form an angle to the
flow of 100° or less on the concave side and 100° - 110° on the convex side
of the channel in order to minimize the disturbance to the axial direction
of the currents and so favour the deposition of sediment between them. Often
groynes may be pointed upstream as much as $105^\circ$ to $110^\circ$ in straight reaches. Sometimes, the alignment and spacing of the groynes on opposite sides is fixed so that their axes intersect in the middle of the channel.

**TABLE 2.3**

**GROYNE INCLINATION TO FLOW**

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>RECOMMENDED INCLINATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Board of Irrigation &amp; Power</td>
<td>$100^\circ$ - $120^\circ$</td>
<td>repelling</td>
</tr>
<tr>
<td></td>
<td>$30^\circ$ - $60^\circ$</td>
<td>attracting</td>
</tr>
<tr>
<td>Mamak</td>
<td>$100^\circ$ - $120^\circ$</td>
<td></td>
</tr>
<tr>
<td>Van Ornum</td>
<td>$&lt; 100^\circ$</td>
<td>on concave bank</td>
</tr>
<tr>
<td></td>
<td>$100^\circ$ - $110^\circ$</td>
<td>on convex bank</td>
</tr>
<tr>
<td></td>
<td>$105^\circ$ - $110^\circ$</td>
<td>on straight channel</td>
</tr>
</tbody>
</table>

2.7 **Scour**

To have a good idea of what scour to expect at the head of a groyne is of paramount importance as the safety of the entire structure and the groyne system as a whole ultimately depends on the head withstanding the local scour. As a result, a considerable amount of investigation has been done in this area including laboratory model tests and field measurements. Unfortunately, no all-inclusive standard design guideline has resulted from this work to aid the engineer in the estimation of scour at the head of the groyne.

2.7.1 **Definitions**

Before proceeding with a discussion of estimates of local groyne scour, an explanation should be given for the nomenclature that applies to this phenomena. As presented by Neill (26) the following terms and
descriptions will be used in this report.

1. General or Regional Scour - scour over a substantial area or across a channel, generally resulting from enhanced velocity of flow, as below a spillway or in a contraction.

2. Local Scour - scour confined to a small area around an obstruction or geometric anomaly, as at a pier, spur or sharp bend; generally associated with three-dimensional flow and vortices.

3. Depth of Scour - depth of scour to which material is removed below its original or normal level.

4. Scoured Depth - depth from water surface to bottom of scour; equal to depth of scour plus normal depth of flow.

2.7.2 Scour Estimation

To determine maximum scour, many parameters describing the groyne and its positioning with respect to the stream and banks must be considered. The relationship between scour and these parameters may be described by the following equation:

\[ d_s = f(h, D_{50}, \rho_s, \rho_w, v, \theta, \beta, b, c, g, \sigma_{gd}, \nu) \]  \hspace{1cm} (2.1)

where

- \( d_s \) = limiting depth of scour below original bed level,
- \( h \) = average depth of normal (approach) flow,
- \( D_{50} \) = grain size of which 50% of the bed material is finer,
- \( \rho_s \) = specific density of bed material,
- \( \rho_w \) = specific density of water,
- \( v \) = mean velocity of the normal approach flow,
- \( \theta \) = angle between the center line of the groyne and the band or thalweg,
- \( \beta \) = angle between the side slope of the groyne and the vertical plane.
B = average width of the approach channel,

b = average width of the contracted channel,

C = sediment concentration by weight,

g = acceleration due to gravity,

σ_{gd} = term describing the size gradation of the bed material,

ν = kinematic viscosity

Clearly, numerous factors affect the scour to be expected at the nose of a groyne. Model tests generally consider only a few of these parameters which makes a comparison of different authors work difficult.

These model tests, together with field observations, have identified the qualitative effects of many of these variables on the depth of scour. For some, studies have provided quantitative data on how scour is affected.

FIGURE No. 10 illustrates these prime factors related to scour at the head of a groyne.

2.7.3 **Dimensional Analysis**

A clearer presentation of the factors affecting the local scour at the head of a groyne may be achieved by performing a dimensional analysis of the parameters.

As stated in equation (2.1), the local scour may be represented by:

\[ d_s = f(h, D_{50}, \rho_s, \rho_w, \nu, \theta, B, b, C, g, \sigma_{gd}, \nu) \] (2.2)

As local scour at the head of a groyne usually occurs under fully rough turbulent flow, the effects of viscosity, \( \nu \), on the depth of scour becomes negligible, and may be neglected, resulting in:

\[ d_s = f_2(h, D_{50}, \rho_s, \rho_w, \nu, \theta, B, b, C, g, \sigma_{gd} ) \] (2.3)
Assuming three repeating variables, \( h, v, \rho_w \), which contain the 3 fundamental dimensions, a dimensional analysis yields 10 \( \pi \)-terms i.e.

\[
\frac{d_s}{h} = f_3 \left( \frac{\rho_s}{\rho_w}, \frac{B}{h}, \frac{b}{h}, \frac{gh}{v^2}, \frac{D_{50}}{h}, \theta, \beta, c, \sigma_{gd} \right) \quad (2.4)
\]

An equivalent form of this equation may be obtained by modifying terms under the rules of dimensional analysis to yield:

\[
\frac{d_s}{h} = f_4 \left( \frac{v}{\sqrt{gh}}, \frac{B-b}{B}, \frac{b}{h}, \frac{D_{50}}{h}, \theta, \beta, c, \sigma_{gd}, \frac{\rho_s}{\rho_w} \right) \quad (2.5)
\]

This analysis clearly illustrates that the relative depth of scour, \( d_s/h \), is directly related to the kinematics of the approach flow, (Froude number), \( v/\sqrt{gh} \), the contraction ratio, \( m = (B-b)/B \), as well as sediment and sediment flow characteristics, \( (D_{50}/h, \sigma_{gd}, \rho_s/\rho_w, c) \), stream geometry, \( (b/h) \), and the other factors directly related to the groyne itself, \( (\theta, \beta) \).

2.7.4 Orientation to Flow (\( \theta \))

The local scour hole generally occurs at the tip of the head of the groyne where the local acceleration of the water around the structure is most pronounced. This applies to groynes facing upstream or normal to the flow direction. As the orientation changes to that of an attracting type, (facing downstream) the scour hole moves downstream and may be positioned some distance below the tip of the groyne. In other words, the scour hole moves upstream relative to the groyne as the angle of inclination to the flow, \( \theta \), increases.

With respect to the actual magnitude of the scour, it may be said that a groyne inclined upstream causes more scour than one inclined
downstream. Conclusive evidence of this fact is provided in tests conducted by Tison (33) as shown in Figure 8.

This general trend is also indicated quantitatively by Ahmad (3) in Equation (3), and is shown by Garde (14) in FIGURE No. A1-111 giving the relationships between angle of inclination, $\theta$, and the scour coefficient $n_4$.

Mukhamedov (24) makes use of a factor, $K_\beta = (\sin \theta)^{-\frac{1}{2}}$ to modify the scour depending on the inclination of the groyne to the flow. The use of such a trigonometric function is valid for attracting groynes, ($\theta < 90^\circ$), but breaks down for angles of $\theta > 90^\circ$.

The effect of groyne inclination on scour gives rise to design recommendations given by Ahmad (3) on the length of protection required along the sides of a groyne shank. Although the length ratios given are rather large (FIGURE No. 12), these relationships for the length of protection required as a function of spur inclination are valid, and should be useful as a design aid.

2.7.5 Side Slope of the Head

The side slope of the head directly affects the scour near the head of the groyne. The flatter the head slope, the more distant the scour hole from the head, and the longer and shallower the hole.

An Indian design manual (8) states that the scoured depth may vary from 3.8 times Lacey's regime depth for a 1:1 side slope to 2.25 times the depth for a 20:1 slope.

Tison (33) has done model tests on the effect of the slope of the nose on scour. A pair of trapezium shaped groynes were tested (FIGURE No. 13),
and it was found that a sloped head reduced the diving motion of the water near the upstream face. The tests showed a reduction in depth of scour from 35 - 40 mm for vertical faced groynes to 20 mm for the ones with sloped heads. Note also in FIGURE No. 13, that the bed contours indicate a greater deposition of material between the trapezium shaped groynes than for groynes with a vertical face. The results of these experiments may be affected by the non-uniform projected lengths of the two sets of groynes. Mamak\(^{(22)}\) suggests giving the head slope an inclination of 3:1 or even 5:1.

Mukhamedov\(^{(24)}\) uses a factor, \(k_B = (\cos \theta)^{1/2}\) which takes into account the effects of varying head slope on scour, where \(\theta\) is the angle between the side slope of the groyne and the vertical plane.

2.7.6 Contraction

Much of the testing carried out on the scour experienced at groynes has used a parameter known as the contraction ratio, \(m\), where \(m = (B-b)/B=1/B\). (Often the opening ratio is given, \(\alpha = b/B = 1-m\).

Most of the work has failed to differentiate between that general scour due to the contraction of the total flow width, and that local scour caused by pronounced acceleration and horseshoe vortex action at the nose of the groyne. Although the use of \(m\) may be very meaningful for excessive contractions, its use is certainly not valid when analyzing the effects of, say, a small abutment at the edge of a very wide river. This is in agreement with the findings of Cunha\(^{(9)}\) who has proved that, "for flow without continuous sediment motion, local scour does not depend on the contraction ratio and is only affected by local phenomena providing \(m < 0.1\); for flow with continuous
sediment motion, local scour begins to be influenced by the contraction ratio only when the scour hole reaches the opposite bank \(^{(9)}\).

Using this argument, one would expect, therefore, that for \(m > 0.1\), the effects of contraction of the flow section and concentration of vorticity would both influence the depth of scour.

In view of the above findings, the designer should be cautious in using design equations or charts based on contraction ratios for values of \(m\) less than 0.1.

2.7.7 Summary

Scour at the head of a groyne is affected by a multitude of factors, some more important than others. While the qualitative effects of many parameters are known, very little quantitative relationships exist to be of use as a design aid. Scour estimation techniques discussed and compared in Appendices A and B, respectively, illustrate that the kinematics of the flow, and the orientation of the groyne to the flow are the most important parameters to consider. Knowledge of the qualitative effects of other less important factors will help in producing a safe design for a groyne from a scour standpoint.

2.8 Location within the River Reach

Tests and studies have produced guidelines on the orientation and location of groynes in a river reach. In their extensive literature review, Varshney and Mathur \(^{(35)}\) present design recommendations on the positioning of groynes along the outside of a meander loop. They suggest that the groynes be placed at 0.55 of a meander length for one groyne, 0.5 and 0.6 for 2 groynes,
and 0.4, 0.5 and 0.65 of a meander length for a system of 3 groynes, (FIGURE No. 14). Naturally, these recommendations should not be followed blindly, as the spacing and location within the reach should ultimately be determined by appropriate spacing ratios and the location of the problem area respectively. Velocity and shear distributions within the stream should also be considered when placing groynes.

As another guide, Blench (7) offers some suggestions on the location of the lowest groyne when a system of structures is to be placed above a bridge crossing. The first groyne upstream of a bridge should be placed 0.4 meander lengths or about 4 flood breadths above the crossing, measured along the trace of the meander; (Blench (7) considers meander length equal to 10 flood breadths). This is to prevent outflanking of a bridge by the meandering tendency of the stream.

2.9 Groyne Roots

Wiktor Mamak (22) makes mention of the root formed by embedding the shank of the dyke into the bank to be protected (FIGURE No. 15). This should provide protection against flood waters cutting into the bank around the groyne shanks. He recommends a root of 4 to 10 meters deep, into the bank and suggests that short bank revetments each side of the root also be constructed. This protective measure need only be included in the design when anticipated flow conditions appear to threaten the groyne near the bank.
2.10 Side Slopes

In most cases, groynes are designed with the elevations of the top of the shanks equivalent to bankfull level. To avoid excessive damage to the structure from overflowing flood waters, scour on the downstream sides of the shanks should be minimized. In general, the upstream face should be inclined at from 1.5:1 to 3:1; and the downstream from 2:1 to 4:1, with lower portions at even gentler grades. Head slopes in the order of 5:1 should be followed as a general design guide.
3.0 DESIGN RECOMMENDATIONS

The conclusion of this literature review of the publications concerning stream groynes is that the following procedure be used in designing groynes:

1. Select the type of groyne to be placed in the stream based on
   i) sediment load in the stream, ii) construction conditions at the site,
   (alluvium, bedrock, etc). and iii) availability of construction materials.
   - a) permeable, or
   - b) impermeable

2. Should groynes be submerged or non-submerged? Recall that permeable groynes are best if the structure is to act primarily under submerged conditions. If impermeable groynes are expected to be overtopped, downstream side slopes should be flattened and/or armoured.

3. Choose the angle of inclination to the flow. Usually repelling groynes, i.e. groynes pointing upstream, will give the best results. For repelling groynes use an angle of inclination of the order: $100^\circ < \theta < 120^\circ$. Smaller angles should be used along concave banks, and larger angles along convex banks and straight reaches.

4. Station the first (upstream) at an appropriate location with respect to the river reach to be protected or controlled. A suitable regime width should be left between the groyne and the opposite bank.

   Where groynes are meant to control the approach to a hydraulic structure on a meandering stream, such as a bridge, canal intake, etc., the further downstream groyne should be placed 0.4 of a meander length upstream of the structure.
5. Using the general guideline for a spacing ratio of about 1.0 to 2.0 for concave banks, and $2\frac{1}{2} - 3$ for convex banks, establish the rest of the groynes downstream from the upstream groyne.

When moving upstream from an initial groyne, check that the spacing does not exceed the multiplicative product of the spacing ratio times the projection of the upstream groyne into the flow.

6. **Impermeable Groynes:** With an appropriate design flow, (based on bankfull discharge or frequency of return), estimate the scour to be expected at the nose of the groyne. Methods advisable for use include Karaki and Blench (1 and II).

For sand bed channels, scour estimates should be compared with the Inglis/Lacey scour ratio of $d_s/h = 1.75$.

For coarse-bed streams, a scour ratio of not more than 2.0 should be used as a guideline.

**Permeable Groynes:** As no information was found in the literature on the design of permeable groynes, design guidelines or recommendations cannot be given.

7. When scour depths have been decided, appropriate riprap/gabion slope protection and apron material should be designed. Ahmad's (3) design curve, (FIGURE NO. 12) may be used as a guideline for the length of protection required.

8. For impermeable groynes, slopes at the head should be constructed at a grade of 5:1. Until further evidence is available as to the quantitative effects of scour reduction due to flat nose slopes, no changes in the design of the apron, Step 7, is recommended.
9. Upstream sideslopes of impermeable groyne shanks should be that of the angle of repose of the construction material, or about 2:1. Flatter slopes of about 3:1 to 5:1 are recommended for the downstream face. Where frequent overtopping of the groyne is expected, a compound slope on the downstream side may be required.
4.0 RECOMMENDATIONS

The work that has been done to the present in the field and in the laboratory on groynes and related structures can provide the design engineer with only a general idea of how various design parameters affect the operation of groynes. In most cases, only qualitative aspects are available. Very little quantitative information exists to guide the design engineer. In some instances, there is a definite lack of information on how various parameters affect the action of groynes on the streamflow and vice versa.

With this in mind, the following recommendations for further investigation and research are given:

1. A continuing review of the literature on groynes, scour, sedimentation, etc. should be undertaken by the River Engineering Branch.

2. Field measurements of scour near groynes be taken in Alberta for use in improving design relationships.

3. Laboratory studies be carried out to establish the quantitative effects of the following parameters on scour:
   i) length and angle of the groyne
   ii) head slope and various head configurations
   iii) size of the bed material (with scaling of material to include the sand range), and
   iv) self-armouring of scour holes, i.e., the effect of bed material size gradation on scour.

4. Field and laboratory measurement of local velocities around the head of the groyne to improve riprap design criteria for aprons and side slopes.

5. Assessment of in-place groynes, noting:
i) different types and locations,

ii) design aspects

iii) the scour experienced, and

iv) failures (if any)

A study of this nature should provide valuable guidelines for groyne design.

6. Laboratory study of the action of permeable groynes and the design aspects of these structures.
REFERENCES


2. Ahmad, Mushtaq "Spacing and Projection of Spurs for Bank Protection". Civil Engineering and Public Works Review, London; March, 1951 (pp.172-174) April (pp.256-258).


12. Engineering News-Record

13. Franco, J.J.,


22. Mamak, Wiktor "River Regulation". Arkady, Poland, 1964 (415 pp)


FIGURE No. 1
General Drawing
Impermeable Round-Head Gravel Groyne
FIGURE No. 2
Permeable Timber Groyne
Reference No. 31
A. Deflecting Groyne

B. Attracting Groyne

C. Repelling Groyne

FIGURE No. 3
Types of Groynes
FIGURE No. 4
The Principle of Groynes
Reference No. 31
Flow

Straight Round Head  T-Head  L-Head

Flow

Hockey  Inverted Hockey  Wing or Tail

FIGURE No. 5
Forms of Groynes
FIGURE No. 6
Pembina River
Groynes near Manola
Reference No. 11

Top of Bank, April, 1963
Top of Bank, April, 1959
Top of Bank
1959 & 1963 (April)

Scale in Feet

Scale in Feet
FIGURE No. 7
Impermeable Hooked Groyne
Reference No. 1
FIGURE No. 8
Water Movement Associated with T-Head Groyne
Reference # 29
Maximum scour depth: 69mm

A. Contour map for Groynes Facing Downstream (\( \theta = 72^\circ 30' \))

Maximum scour depth: 82mm

B. Contour map for Groynes Facing Upstream (\( \theta = 107^\circ 30' \))

Maximum scour depth: 73mm

C. Contour map for Groynes Perpendicular (\( \theta = 90^\circ \))

FIGURE No. 9
Reference No. 33
A. Flow lines between Groynes in Series with Uneven Spacing

B. Flow lines between Groynes in Series with Uniform Spacing

FIGURE No. 10
Group Groyne Action
Reference No. 8
FIGURE No. 11
Illustration of Key Parameters
FIGURE No. 12
Length Requiring Protection
as a Function of Spur Inclination

Reference No. 3
A. Contour Map with Vertical-Faced Groynes

B. Contour Map with Trapezium Shaped Groynes

FIGURE No. 13
Contour Maps with Groynes
Reference No. 33
FIGURE No. 14

Idealized Location of Three Groynes

Reference No. 35
FIGURE No. 15
Tying in Groyne to Bank
Reference No. 22
APPENDIX A

SCOUR ESTIMATION METHODS

Laboratory research and field measurements have yielded numerous formulae and methods for the estimation of maximum scour at the head of a groyne. Conditions under which field and laboratory measurements were taken vary widely, so comparison of various methods is difficult.

Each method is presented below, together with the conditions under which experiments or measurements were conducted. No attempt has been made to complete in the presentation of each investigator's work. Readers were recommended to refer to the original article for additional information, and to consult the section, "Nomenclature" at the end of this report for an explanation of the terms used in the following discussions.

1. Garde et al

A "Study of Scour Around Spur-Dykes" by Garde, Subramanya, and Nambudripad (14,15) gives the following relationships:

\[
\frac{h+d_s}{h} = 4.0 \eta_1 \eta_2 \eta_3 \eta_4 \frac{1}{(1-m)} F^n
\]  

(1)

FIGURE No. A1 shows the relationship between \( \eta \) and \( \eta_1 \). The coefficient 4.0 and the value of \( \eta_1 \) were obtained by taking 0.29 mm diameter sediment as the standard sediment size and expressing K values (FIGURE No. A1-i) of other sediment sizes as \( \eta_1 = K/K_{0.29\text{mm}} \). Variation of \( \eta_2 \) with \( w/l \), (groyne width to length ratio) and \( F \), and the variation of \( \eta_4 \) with \( \theta \) are shown in FIGURES A1-ii and A1-iii, respectively. The authors quote only 2 experimental values for \( \eta_3 \), namely, for semi-circular ends, \( \eta_3 = 0.90 \) and for a Joukowky aerofoil section (\( w/l = 5.0 \)), \( \eta_3 = 0.82 \).
Test conditions were:

- a single vertical-faced groyne normal to the flow; (tests were done later with groynes inclined to flow);
- contraction ratios of 0.10, 0.165, 0.33 and 0.470;
- bed material of median diameters 0.20 mm, 0.45 mm, 1.00 mm, and 2.25 mm. and of average specific gravity 2.70.

The authors concluded that the maximum scour depth is affected significantly by the size of the sediment, and that the Froude Number of the approach flow adequately describes flow conditions. Following Neill's discussion (25) they agreed that the use of $C_D$ (drag coefficient) was not valid, and stated that more work needed to be done over a large range of sediment sizes. They cautioned against using the relationships for field conditions.

II. Gill

Gill (16,17), in "Erosion of Sand Beds Around Spur-Dykes", gives this equation for maximum scour depth:

$$\left(\frac{h+d_s}{h}\right)_{\text{max}} = 8.375 \left(\frac{D_{50}}{h}\right)^{1/2} \left(\frac{1}{1-m}\right)^{6/7}$$

(2)

and recommends its use for design. This equation is for the 'worst case' i.e. where $\tau_c = \tau^*$, (tractive force in approach channel equals critical tractive force.

Test conditions were:

- a single vertical - faced groyne normal to the flow;
- contraction ratios of 0.13, 0.27 and 0.40
- mean bed material sizes of 1.52 mm and 0.914 mm.
The author concluded that the depth of equilibrium scour is affected by the size of the bed material, and the depth of the approach flow.

III. Ahmad

Ahmad\(^{(3)}\) has found the following simple relationships to apply:

\[
\frac{h + d_s}{q^{2/3}} = 1.616 - .908 \left(\frac{2}{3}\right)^{\theta/15}
\]  

(3)

His tests show that \(\frac{h + d_s}{h}\) may increase from about 1.5 for \(\theta = 30^\circ\) to about 3.0 for \(\theta = 150^\circ\).

Test conditions were:
- groynes at various angles to the approach flow, (facing downstream and upstream).
- mean bed material sizes of 0.289 mm, 0.354 mm and 0.695 mm.
- contraction ratio of 0.33

The author's conclusions were that an estimate of the maximum scour to be found at the nose of a groyne is of the form, \(h + d_s = Kq^{2/3}\) where \(K\) depends on the flow concentration, and angle of groyne inclination.

IV. Liu, et al

Liu, Chang and Skinner\(^{(21)}\) conducted extensive laboratory studies on scour at bridge abutments of different shapes, (vertical wall, wing wall and spill-through). For the case of sediment transporting flow and a vertical wall model they found:
\[
\frac{(h+d_s)}{h} \max = 0.3 + 2.15 \left( \frac{B-b}{h} \right)^{0.4} F^{1/3}
\] (4)

For the clear water scour the equation given was:

\[
\frac{(h+d_s)}{h} \text{limiting} = 12.5 \left( \frac{F}{1-m} \right)
\] (5)

Only two sizes of sand of 0.56 mm and 0.65 mm were used.

They found that the scour depth for wing wall and spill through type abutments were lower than those for the vertical wall models, for the same values of F and m.

V. Das

In his work on the hydraulics of end-dump closure, Das\(^{(10)}\) recommended the use of the curves shown in FIGURES No. A2, A3, and A4 for determining maximum scour depth.

His data indicated F, m, \(\rho_s/\rho_w\), d/h and \((d_s+h)\) to be the essential inter-related non-dimensional variables describing scour. He found that the size of the bed material appears to have significant influence on both the depth and rate of scour for clear water flows. For sediment transporting flow, however, bed material size has less influence on the depth of scour. It is important to note that the lower limit of h/d values that agree with the design curves is about 10.

Experimental conditions were:
- end dump closures, (headslopes having non-vertical faces)
- mean bed material size of 1.2 mm, 0.60 mm, 0.25 mm, 6.6 mm (pebbles), and 1.6 mm (coal)
- contraction ratios from 0.23 to 0.93
VI. Karaki et al

Karaki\(^2\) discusses scour prediction formula obtained by laboratory tests and prototype measurements.

He states that "According to the studies of Liu et al. (1961) the equilibrium scour depth for local scour in sand at a spill slope when the flow is subcritical is determined by the expression:

\[
\frac{d_s}{h} = 1.1 \frac{a}{h} 0.40F^{0.33} \tag{6}
\]

For vertical-walled embankments, he quotes:

\[
\frac{d_s}{h} = 2.15 \frac{a}{h} 0.40F^{0.33} \tag{7}
\]

indicating that the scour hole depth in sand is nearly double that for the spill slope.

Field data for scour at rock dykes on the Mississippi indicates the following relationships:

\[
\frac{d_s}{h} = 4F^{0.33} \tag{8}
\]

He recommends the use of (6) for short groynes or embankments, where \( \theta < a/h < 25 \), and (8) for \( a/h > 25 \), (FIGURE No. A5).

These formulae give the equilibrium depth of scour. These values should be increased by about 30% to yield the maximum depth of scour.

Also, the relationships shown above are for groynes placed perpendicular to the flow, (where \( a = \lambda \)). Scour depths found by using (6) or (8) should be modified by multiplying the suitable coefficient \( n_{x} \) given in FIGURE No. A1-iii to take into account the effects of inclination to the flow.
A general design equation for estimating local scour of the form
\[ h + d_s = A \cdot K_c \cdot K_\xi \cdot K_p \cdot h \cdot F^x \] (9)
has been proposed by Mukhamedov\(^{(24)}\).

Equation (10) was derived using dimensional analysis and conforms to the results of Garde et al\(^{(19,15)}\).

Following extensive laboratory tests, analysis of the flow kinematics and comparison with field observations on Central Asian Rivers, the following was proposed as a design equation:
\[ h + d_s = 10.4 \frac{(\sin \theta)^{\frac{1}{2}}(\cos \beta)^{\frac{1}{2}}}{(1-m)\xi_{85\%}^{\frac{1}{6}}(1+0.09C)} \cdot \frac{U_m \cdot h_m^{0.5}}{q^{0.5}(1+135 \cdot F)^{1.5}} \] (10)

As the factor \((\sin \theta)^{\frac{1}{2}}\) is useful only for groynes inclined at less than \(\pi/2\) to the flow, it is possible that Mukhamedov's equation (10) might be amended to include the factor \(\eta_4\) proposed by Garde et al\(^{(14,15)}\) as given in FIGURE 5C resulting in:
\[ h + d_s = 10.4 \frac{(\eta_4)(\cos \beta)^{\frac{1}{2}}}{(1-m)\xi_{85\%}^{\frac{1}{6}}(1+0.09C)} \cdot \frac{U_m \cdot h_m^{0.5}}{q^{0.5}(1+135 \cdot F)^{1.5}} \] (11)

Experimental conditions were:
- bed material of uniform sands of five sizes
  \((dm = 0.4-7.4 \text{ mm})\) and of non-uniform sands of 3 different sizes
  \((dm = 0.96-7.67 \text{ mm})\);
- maximum contraction ratio 40% 
- inclination, \(30^\circ < \theta < 90^\circ\)
- groyne slope grading between vertical and 1.75:1
(i) METHOD I: General Scour by Regime Method

This method is one of two techniques based on recommendations by Blench which appeared in (27).

Using details of average channel geometry for a relatively straight "incised" reach, (in which no spilling occurs except in very high flows), compute average incised discharge intensity:

\[ q_i = \frac{Q_i}{b_i} \]  \hspace{1cm} (12)

Next, compute average design discharge intensity in the proposed opening at the groyne:

\[ q_f = \frac{Q_f}{b_w} \]  \hspace{1cm} (13)

In order to determine \( b_w \), \( d_f \) should first be determined by trial, and later adjusted if necessary after equation (14). Now compute the average 'flood depth' in the controlled waterway opening:

\[ d_f = d_i \left( \frac{q_f}{q_i} \right)^s \]  \hspace{1cm} (14)

where \( s \) is an exponent dependent on the bed material, ranging from 0.67 for sand to 0.85 for coarse gravel. To obtain general maximum scoured depths at the head of the groyne, \( d_f \) should be multiplied by a factor of 2.0 - 2.75 as given in (7).
(ii) METHOD II: Zero Flood Depth Method

The second technique in (27) is based on Blench's 'zero flood depth', and follows this procedure:

1. Estimate the flood discharge intensity $q_f (q_f = Q_f/b_w)$ immediately adjacent to the groyne, in cfs/ft.

2. Calculate the corresponding regime depth in feet (assuming no bed sediment supply):

$$d_{fo} = 3\sqrt{q_f^2/F_{bo}}$$

where $F_{bo}$ is Blench's 'zero bed factor', by FIGURE No. A6.

3. Estimate the maximum scoured depth, $h+d_s = z \cdot d_{fo}$, where $z = 2.0$ to 2.75 for the head of a groyne.

IX. Awazu

Awazu (6) performed laboratory studies on the maximum scour depth around a groyne of the non-overflow type below sub-critical flow.

The formula for local scour defined by the upper limit of the experimental data is:

$$\frac{d_s}{h} = 0.30 + 1.60 \log_{10} \frac{\tau_{ns/N_{ns}}}{\tau_{ns/N_{ns}}}$$

where

$$\frac{\tau_{ns/N_{ns}}}{\tau_{ns/N_{ns}}} = \frac{82.6 \cdot \tau_c}{(3.69 \cdot m + .840)^2}$$

Experimental conditions were:

- groynes on the same and opposite sides of the flume,
- contraction ratios varying from 0.1 to 0.4
- approach Froude number 0.49 to 0.53
- sand of mean diameters 1.79 mm, 13.58 mm, 2.50 mm, and 3.50 mm
The terms \( N_{ns} \) and \( N_{ns'} \), denoting a dimensionless term of roughness may be found by either:

\[
N = n^2 g/h^{1/3} \quad (18)
\]

or

\[
1/N = (5.94 + 5.75 \log(h/D_{50}))^2 \quad (19)
\]

where, as for all terms, the subscripts \( ns \) and \( * \) denote hydraulic quantities corresponding to the normal approach flow, and those corresponding to the beginning of scouring motion, respectively.
A. Variation of $n$ & $K$ with $C_d$

B. Variation of $n_2$ with $F$

C. Variation of $n_4$ with $\theta$

FIGURE No. A1

Reference No.'s 14 & 15
FIGURE No. A2
Design Curve for Maximum Depth of Scour in Clear-Water Flow
Reference No. 10

\[ \log_{10} \left( \frac{1.44 (h+t_s)_s}{h} \right) = 0.29 \left( \frac{m_0}{m_{0_w}} \right)^{0.43} / 0.85 \]
FIGURE No. A3
Design Curve for Maximum Scour Depth for Clearwater Flow

Reference No. 10
FIGURE No. A4
Design Curve for Maximum Scour Depth in Sediment-Transporting Flow
Reference No. 10
Karaki's Scour Prediction Equation

Reference No. 20
FIGURE No. A6
Relationship of Blench's 'Zero Bed Factor' to the Size of Bed Material.
APPENDIX B

COMPARISON OF SCOUR ESTIMATION METHODS

1. Comparison

To see how the scour estimation methods presented in Appendix A compare, a sample design situation was set up. A site on the St. Mary River at Woolford Provincial Park was chosen as the writer had done some design work on groynes in the area previously.

For a 10-year return flood discharge of 9000 cfs (bankfull), regime formulae give a stream width and depth of 180 feet and 5.9 feet, respectively. Mean bed material size is approximately 0.312 feet. It was assumed that groynes placed in a 300 foot wide braided channel area, and at an angle of 110° to the flow would constrict the channel to regime width.

Table A1 gives the results obtained by using the various methods described in Appendix A under 10-year return and 100-year return flood conditions.

This comparison of the various scour estimation methods illustrates that the estimates of local scour cover a wide range, varying from less than 8 feet to almost 45 feet for the 100-year return flow (ignoring the clear water case of Liu). This is because the methodology for estimating scour for each investigator varies widely as well as the conditions under which tests were conducted, and the applicability of test results to various practical situations.

Concurrently, the scour ratios, $d_s/h$, similar to Blench's scour factor, \( z \), cover a wide range as well. These values, ranging from less than one to almost five for the 100-year return flood, should be compared...
to the values given by Blench (7) for head of groynes of 1.0 to 1.75 times the "zero flood depth", and Lacey's scour ratio of 1.75.

One interesting trend noted in the comparison is that for a larger discharge, many of the scour estimation methods give a smaller scour ratio value than that for a lesser flow.

The formula provided by Mukhamedov (24) predicted aggradation in the contracted channel section, so its results are not given in Table A1.

---

**TABLE A1**

GROYNE SCOUR ESTIMATION COMPARISON

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>ds/h</th>
<th>ds(ft)</th>
<th>ds/h</th>
<th>ds(ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu</td>
<td>5.99</td>
<td>35.4</td>
<td>4.95</td>
<td>44.5</td>
</tr>
<tr>
<td>(Maximum)</td>
<td>5.29</td>
<td>31.2</td>
<td>4.25</td>
<td>38.3</td>
</tr>
<tr>
<td>(Clearwater)</td>
<td>11.15</td>
<td>65.8</td>
<td>10.33</td>
<td>93.0</td>
</tr>
<tr>
<td>Gill</td>
<td>5.22</td>
<td>30.8</td>
<td>4.60</td>
<td>41.4</td>
</tr>
<tr>
<td>Karaki</td>
<td>4.07</td>
<td>24.0</td>
<td>3.38</td>
<td>30.7</td>
</tr>
<tr>
<td>Garde</td>
<td>3.45</td>
<td>20.4</td>
<td>3.33</td>
<td>29.9</td>
</tr>
<tr>
<td>Ahmad</td>
<td>2.61</td>
<td>15.4</td>
<td>2.33</td>
<td>21.0</td>
</tr>
<tr>
<td>Blench (I)</td>
<td>1.70</td>
<td>10.0</td>
<td>1.70</td>
<td>15.5</td>
</tr>
<tr>
<td>(II)</td>
<td>1.70-1.75t</td>
<td>6.9-12.1</td>
<td>1.70-1.75t</td>
<td>10.8-18.9</td>
</tr>
<tr>
<td>Awazu</td>
<td>1.29</td>
<td>7.6</td>
<td>1.68</td>
<td>15.2</td>
</tr>
<tr>
<td>Das</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Clearwater-1)</td>
<td>.86</td>
<td>5.1</td>
<td>.98</td>
<td>8.8</td>
</tr>
<tr>
<td>(Clearwater-2)</td>
<td>.64</td>
<td>3.8</td>
<td>.86</td>
<td>7.7</td>
</tr>
<tr>
<td>(Sediment Transporting)</td>
<td>1.67</td>
<td>9.9</td>
<td>1.53</td>
<td>13.8</td>
</tr>
</tbody>
</table>

\[ d_s = z \cdot d_f \; ; \; 1.0 < z < 1.75 \]
2. Conclusions

Until more field measurements of actual scour at the heads of groynes is available, very little can be said of the accuracy of these scour estimation records. In the meantime, the design engineer must rely on scour estimation techniques that appear in design books. These techniques have been verified to some extent by field measurements. Of the eight authors' techniques presented in TABLE A1, only two have appeared in design publications, namely: Blench, (methods I and II), and Karaki. Sample calculations for these techniques are illustrated in Appendix C. It is recommended that these methods be used to provide an estimate of the scour at the head of a groyne.
APPENDIX C

SAMPLE SCOUR CALCULATIONS

Given

\[ Q_i = 9000 \text{ cfs} \]
\[ b_i = 180 \text{ ft} \]
\[ Q_f = 15,000 \text{ cfs (100-year return)} \]
\[ b_w = 180 \text{ ft} \]
\[ d_i = 5.9 \text{ ft} \]
\[ D_{50} = 80 \text{ mm} \]
\[ \theta = 110^\circ \]
\[ l = 120 \text{ ft} \]
\[ h = 9.1 \text{ ft} \]

1. Blench (1)

\[ q_i = Q_i/b_i = 50 \text{ cfs/ft} \]
\[ q_f = Q_f/b_w = 83.3 \text{ cfs/ft} \]
\[ d_f = d_i \left( \frac{q_f}{q_i} \right)^s \]
\[ d_f = 5.9 \left( \frac{83.3}{50} \right)^{0.85} \approx 9.1 \text{ ft}. \]
\[ d_s = 1.7 \times (9.1) = 15.5 \text{ ft} \]
\[ d_s/h = 1.7 \]
2. Brench (11)

\[ q_f = \frac{15,000}{210} = 83.3 \text{ cfs/ft} \]

\[ F_{bo} = 5.5 \quad \text{(FIGURE No. A6)} \]

\[ d_f = \frac{3 \sqrt{83.3^2 / 5.5}}{} = 10.8 \text{ ft.} \]

\[ d_s = 1.75(10.8) = 18.9 \text{ ft. (high)} \]

\[ d_s = 1.00(10.8) = 10.8 \text{ ft. (low)} \]

\[ d_s/h \text{ (average)} = 1.63 \]

3. Karaki

\[ a = \frac{l}{\cos(\theta-90^\circ)} = \frac{120}{\cos 20^\circ} = 128 \text{ ft.} \]

\[ a/h = \frac{128}{9} = 14.2 \]

\[ \text{since } 14.2 < 25, \text{ use (6) for spill slope} \]

\[ F = \frac{V}{\sqrt{gh}} = \frac{15,000/(9.180)}{\sqrt{32.2}} (9) = .544 \]

\[ d_s/h = 1.1 (14.2)^{0.40} (.544)^{0.33} \]

\[ = 2.60 \]

\[ d_s = 2.6(9) = 23.4 \text{ ft.} \]

But, maximum depth of scour = \( d_s \times 1.3 = 30.4 \text{ ft.} \) For groynes with \( \theta = 110^\circ, \eta_4 = 1.01 \) so finally, \( d_s = 1.01 (30.4) = 30.7 \text{ ft.} \) and

\[ d_s/h = 3.38. \]