Grade Control Structures

CIVE 717: River Mechanics
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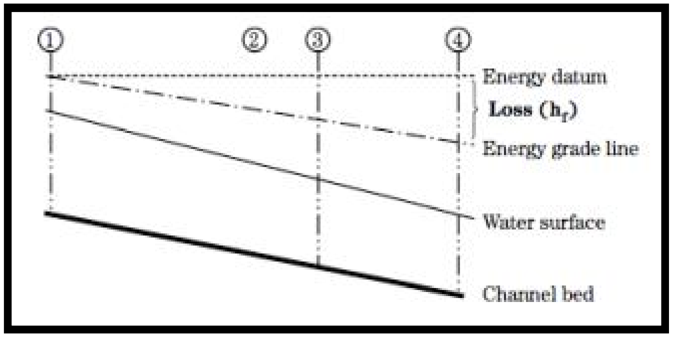
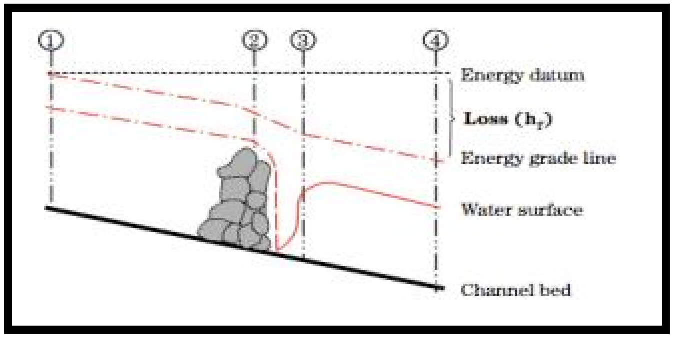
What is a Grade Control Structure (GCS)?

- An earthen, wooden, concrete, or other structure used to prevent gully development and bed erosion
- Typically built on minor streams or part of a dam spillway to pass water to a lower elevation while controlling the energy and velocity of the water as it passes over



Preconstruction condition energy diagram



Post construction modified energy diagram

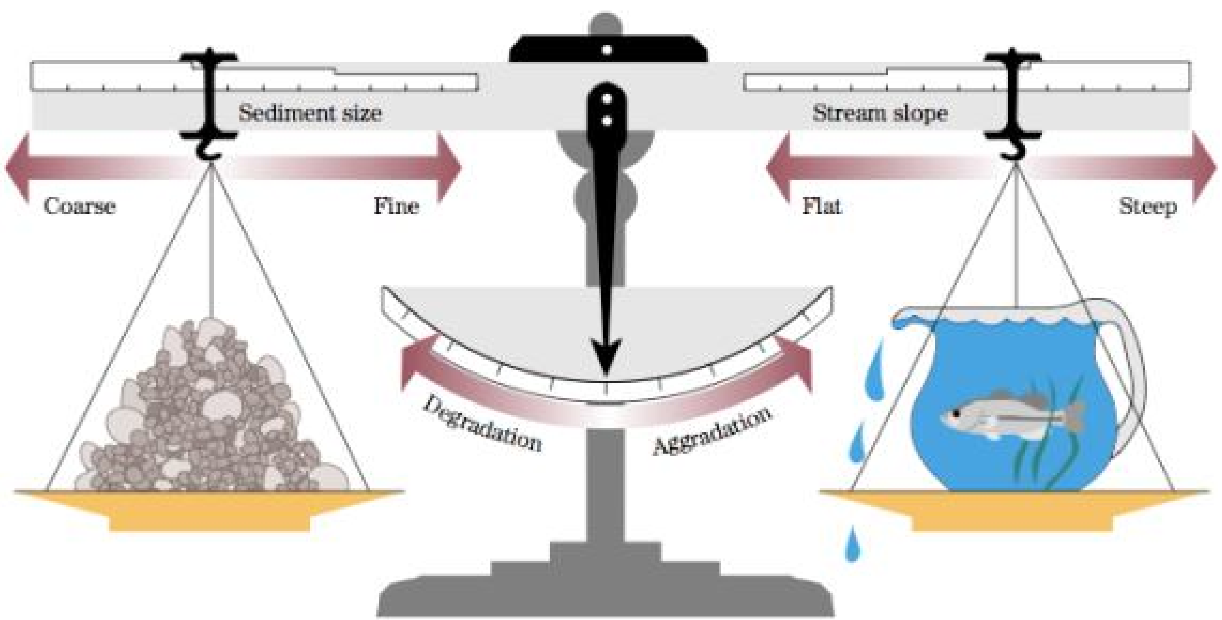
Benefits of Grade Control Structure

- Stabilizes the banks and bed of channel by reducing stream slope and flow velocity → Controls erosion
- Prevents gully head cut formation and channel bed erosion by lowering water in a controlled manner
- Enhances environmental quality and reduces pollution hazards
- Manages channel flow line for non-erosion benefits, including fish passage, water table control, and reduced turbidity
- May provide water source and habitat for wildlife
- Protects existing structures that can be at risk from bed degradation

Grade Control Structure Hydraulics

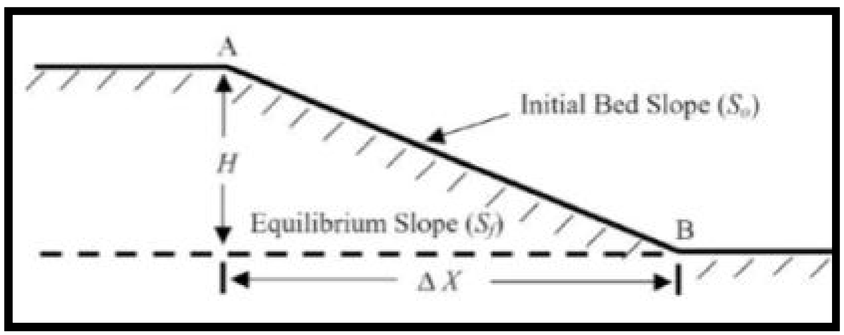
- Continuity of water and sediment through the stream reach promotes channel stability

Lane's Relationship: $QS \propto Q_s D_{50}$

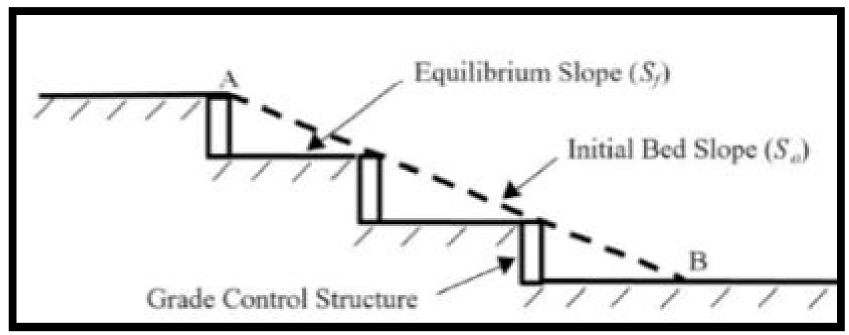


Type 1 GCS: Bed Control Structure

- Provides a hard point in the streambed which resists erosive forces of degradational zone
- Lanes Equation: $QS^{+} \propto Q_s D_{50}^{+}$
- Bed control structure is analogous to locally increasing the size of bed material, thus an increased slope is offset by an increase in bed material size
- Structure is built at grade and does not change upstream or downstream flow conditions



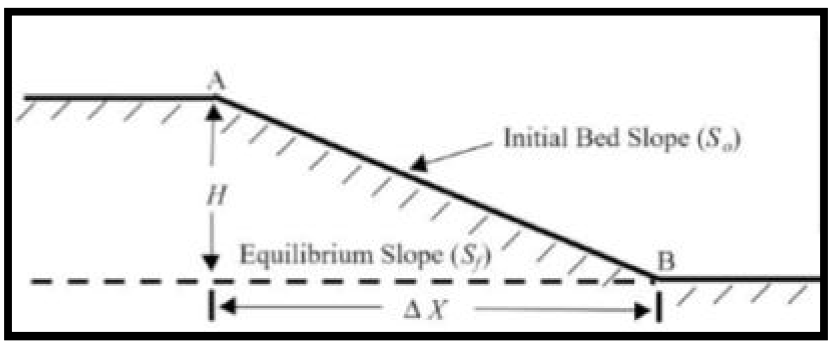
Initial Condition with degradational zone between A and B



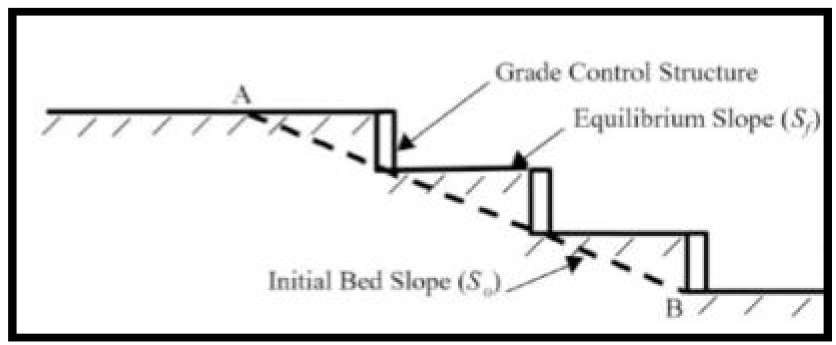
Stabilization with 3 bed control structures

Type 2 GCS: Hydraulic Control Structure

- Reduces the energy slope along the degradational zone so that the stream is no longer capable of scouring the bed
- Lanes Equation: $QS^{-} \propto Q_s D_{50}$
- Structure is built above grade and causes a backwater effect to the upstream flow



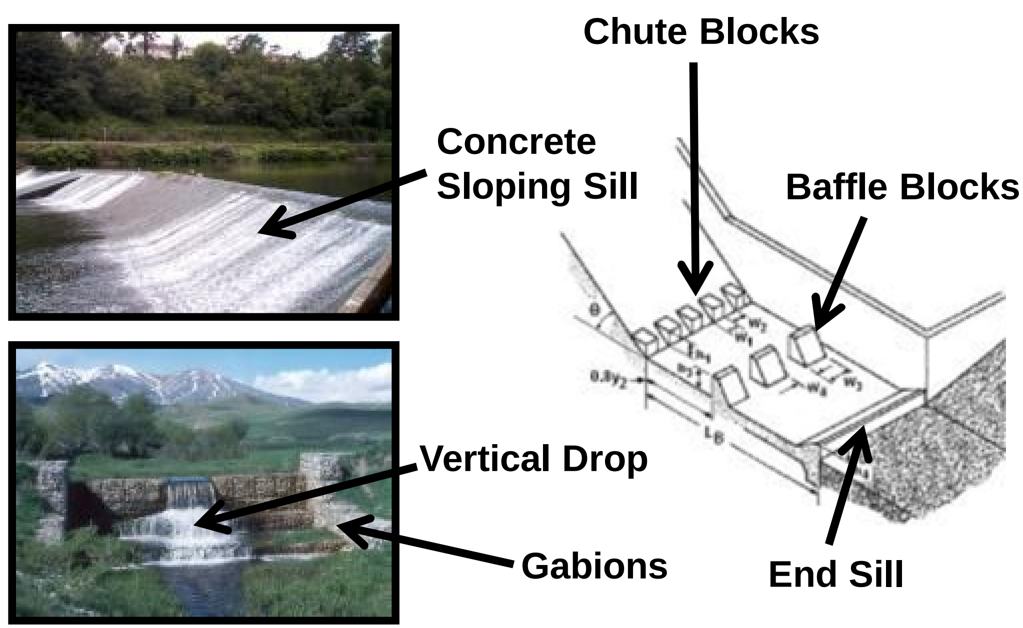
Initial Condition with degradational zone between A and B



Stabilization with 3 hydraulic control structures

Variations of Grade Control Structures

- **Material**
  - Riprap, concrete, sheet piling, treated lumber, soil cement, gabions, compacted earth fill, ect.
- **Shape**
  - Sloping
  - Vertical drop
- **Appurtenances**
  - Chute Blocks
  - Baffle Blocks
  - End Sills

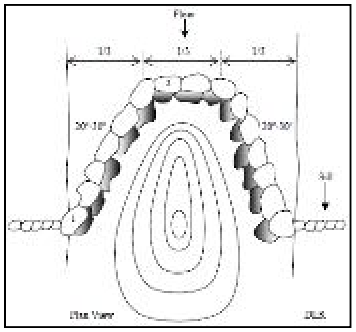


Boulder Weir

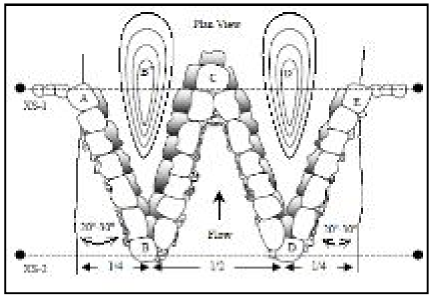
- Imitates natural steps
- Concentrates energy at the crest and dissipates it through turbulence and bed scour
- Bed scour can undermine the structure and outflanking is the most common mode of failure

Boulder Weir Formations

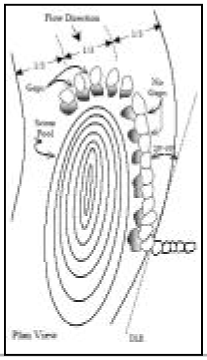
- **Cross-Vane**
  - Decreases the energy near the bank but increases the energy in the center of the channel



- **W-Weir**
  - Prevents bed and bank scour on large rivers by concentrating the spill at ¼ and ¾ channel widths
  - Enhances fish habitat



- **J-Hook Vane**
  - Reduces bank erosion but increases bed erosion in the center of the channel
  - Directed upstream and on the outside of stream bends



Rigid Weir (log)

- Creates drops to raise the downstream water surface to the elevation of a culvert
- Used on narrow channels with moderate gradients
- Provides fish passage

Rigid Weir (sheet piling and concrete)

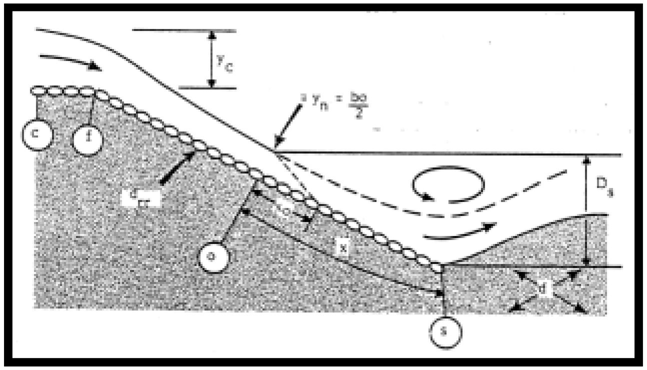
- Can be custom manufactured precisely for the site and fish passage
- Tends to create trapezoidal channels that have very uniform cross sections
- Can become barrier to fish passage following downstream scour

Steel Sheet-Pile Weir

Precast Concrete Weir

Sloping Sill

- Riprap is placed in the channel and on the banks to dissipate energy and prevent erosion
- Rocks can be grouted to resist the flow of water, ice, and debris



Sloping Sill

Sloping Grouted Boulder Drop

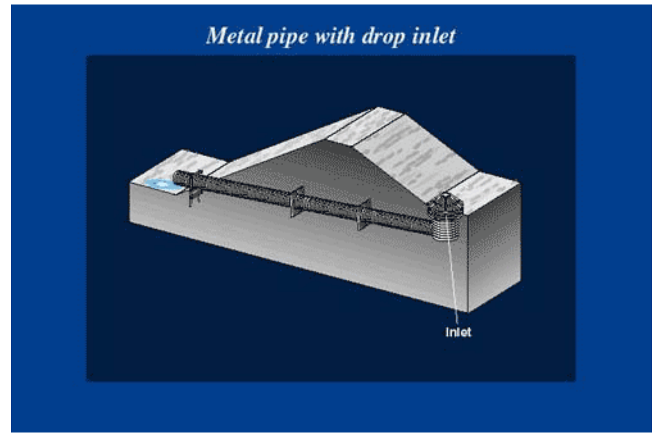
Roughened Channel

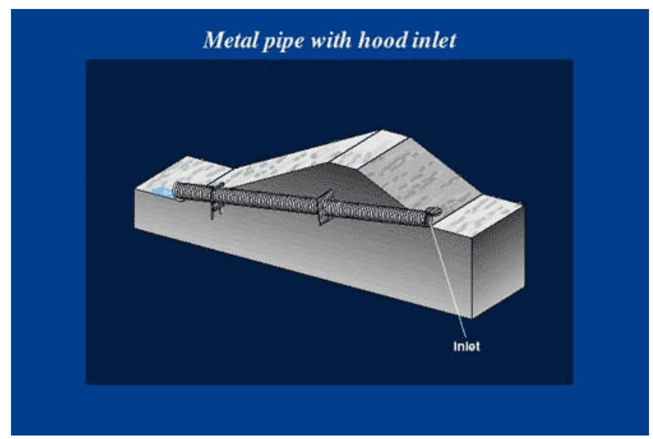
- Creates high bed-roughness on steep channels
  - Limits water velocity to allow the passage of a target fish
  - Bed material is sized to be immobile at the design flow
- Maintains steep gradients in a naturalistic manner

Rock Riffle

Corrugated pipe

- Effective in conveying water through or under an earth embankment when the drop in grade is dramatic
- Types of inlets
  - *Drop inlet* – water drops down into the inlet
  - *Hood inlet* – water flows directly into the inlet while a hood prevents the air above the water's surface from entering the pipe

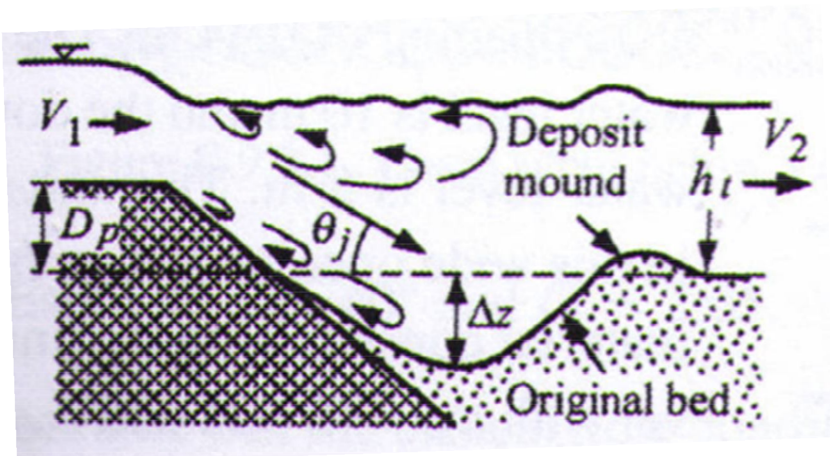




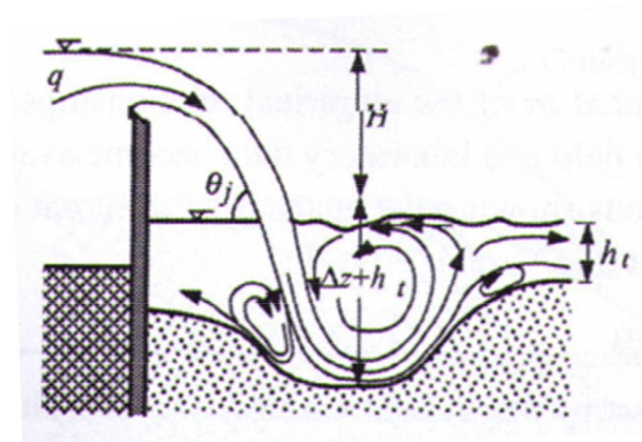
Sloping Sill and Drop Structure Scour

- The scour depth below sills and drop structures can be estimated by the method of Bormann and Julien (1991)

$$\Delta z = \left\{1.8\left[\frac{\sin\phi}{\sin(\theta_j + \phi)}\right]^{0.8} \frac{q^{0.6} V_1 \sin\theta_j}{[(G-1)g]^{0.8} d_s^{0.4}}\right\} - D_p$$



Sloping Sill Scour

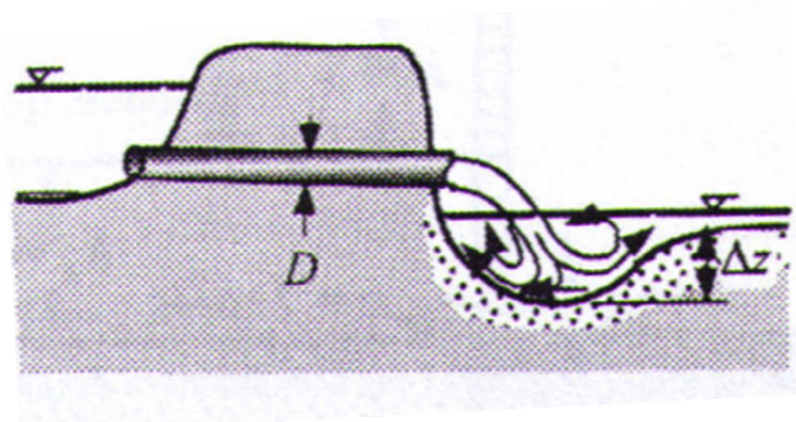


Drop Structure Scour

Circular Culvert Outlet Scour

- The scour depth below circular culvert outlets in cohesive material can be estimated by the method of Ruff et al. (1982)

$$\Delta z = 2.07D\left(\frac{Q}{\sqrt{gD^5}}\right)^{0.45}$$



Design Process: Spacing of Structures

$$\boldsymbol{H = (S_o - S_F)X}$$

- H is the total vertical drop in bed elevation
- S_o is the original slope
- S_f is the final or equilibrium (desired) slope
- X is the length of the reach

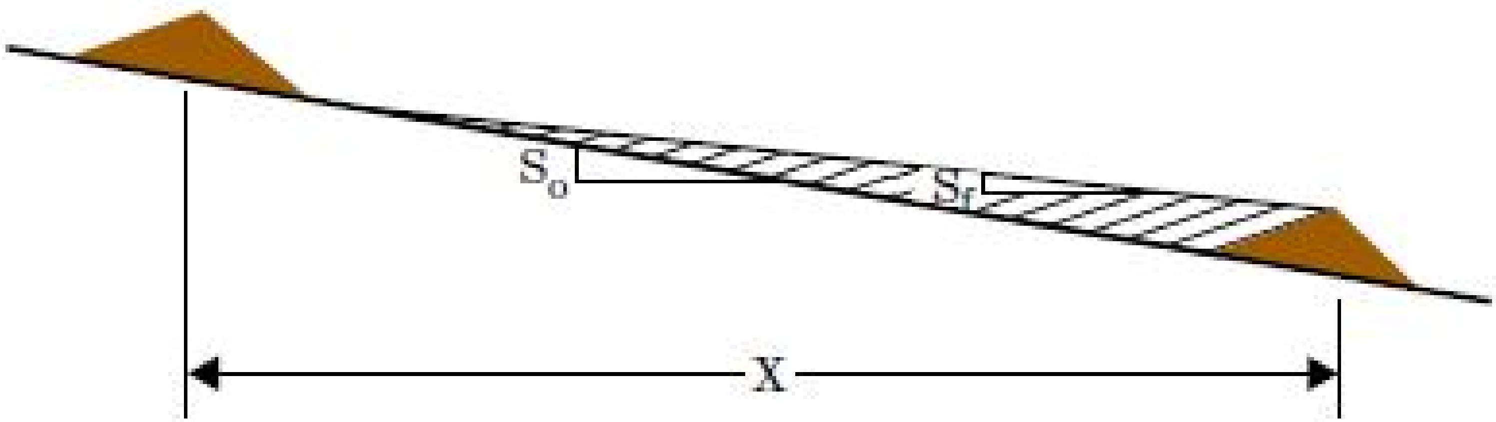
$$\boldsymbol{N = H/h}$$

- N is the number structures required
- h is the vertical drop at each structure

$$\boldsymbol{Spacing\ of\ Structures = L_p/N}$$

- L_p is the length of the project

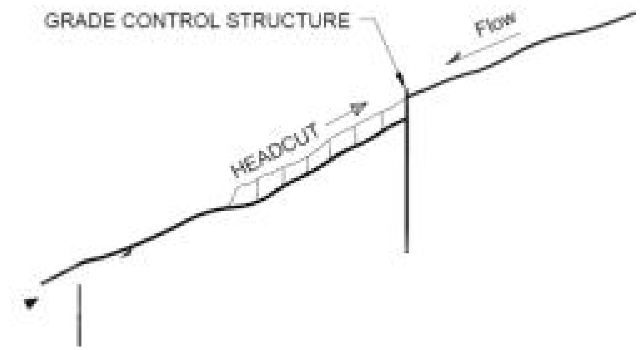
Spacing of Grade Control Structure



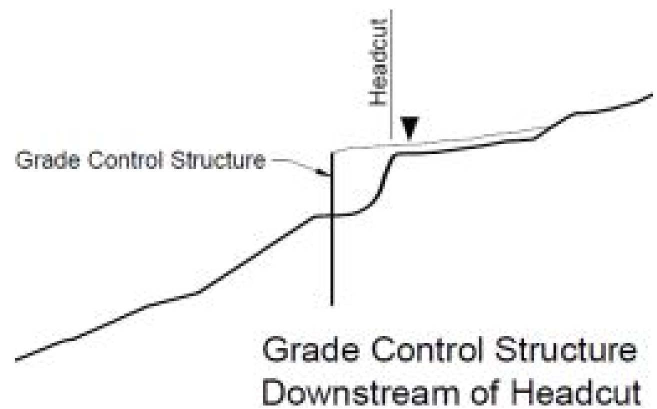
Spacing of GCS (adapted from Mussetter 1982)

Design Considerations: Geotechnical

- Channel degradation can cause severe bank instability due to exceedance of critical bank height
- Grade control structures can enhance bank stability (2 ways)
  - 1) Bed control structures: stabilizes the bed, which reduces the length of bank line that has an unstable height
  - 2) Hydraulic control structures: two advantages
    - Bank heights are reduced due sediment deposition upstream of the structure
    - Creates backwater situation where velocities and scour are reduced → promotes self- healing of the banks



Bed Control Structure



Hydraulic Control Structure

Design Considerations: Flood Impacts

- The objectives of flood control measures and channel stability are often conflicting
  - Constriction at the structure can cause overbank flooding

- Must consider safe return of overbank flows back into channel
  - Overbank flow can cause damage to the structure and severe erosion of channel banks
  - Force water through the structure by use of an earthen dike or berm
  - Control overbank flow by providing an auxiliary high-flow structure → water will re-enter at a specified location downstream

Design Considerations: Environmental Impacts

- Advantages of GCS
  - Provides vertical stability to the stream and reduces amount of sediment eroded from streambed and banks
  - Produces man-made pools which provides greater stability for aquatic habitats
- Disadvantages of GCS
  - Construction of GCS can destroy riparian habitat
  - Obstruction of fish passage: drop heights must be small enough for fish to migrate upstream
    - Openings, fish ladders, smaller structures, or other passageways may need to be incorporated

GCS designed for fish passage

Design Considerations: Existing Structures

- Advantage of GCS
  - Protect bridges, culverts, pipelines utility lines, and other structures by preventing bed degradation
- Disadvantage of GCS
  - Can increase potential flood stages and sediment deposition upstream of hydraulic control structure, thus submerging existing structures
- Design process
  - It is beneficial to integrate a GCS with the repair of existing structures
  - Designer should take advantage of existing structures that could be providing grade control

Damage to infrastructure due to bed degradation

Conclusion

- Grade control structures have been successfully implemented to **reduce erosion** in water resource projects
- Most effective when incorporated in the planning phases of the channel system **before** it has destabilized
- **Many considerations** must be made in the planning of grade control structures in order to provide environmental sustainability as well as erosion control

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