Stilling Basins

CIVE 401 – HYDRAULIC ENGINEERING
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Stilling Basin Overview

- Stilling basins are used to dissipate the energy of water exiting the spillway of a dam
- Their purpose is to prevent scouring that occurs when high-velocity water enters the downstream reach of the dam
- This scouring can damage the foundation of the dam, leading to overtopping, and also causes severe erosion downstream
- The primary method of dissipating energy is to generate a hydraulic jump to transition flow from supercritical to subcritical
Stilling Basin

Overview

- Stilling basins are placed at the ends of dam spillways and at the ends of steep-sloped canal sections where elevation change has generated high kinetic energy.
- Stilling come in a variety of types and can either contain a straight drop to a lower elevation or an inclined chute.
- Inclined chutes are the most common design for stilling basins and the most used inclined chutes are:
  - USBR Stilling Basins Type II-IV
  - SAF Stilling Basins
- The designs are selected based off of the Froude Number of the flow and the flow velocity.
The Froude Number is the ratio of the fluid’s velocity to flow depth, given by:

\[ F = \frac{V}{\sqrt{gD}} \]

- For open-channel flow:
  - *Fr<1 is subcritical* (low velocity and high depth)
  - *Fr>1 is supercritical* (high velocity and low depth)
  - *Fr=1 generates a hydraulic jump, dissipating energy by:

\[ \Delta E = \frac{(y_2 - y_1)^3}{4y_1y_2} \]

The turbulence generated by the hydraulic jump causes significant energy loss and the reduced speed reduces the potential for scouring and erosion.
Stilling Basin Elements

- The different types of stilling basins typically have the following common elements:
  - Chute blocks - concrete blocks built into the inclined sections of the spillway. These features are commonly placed at the head of the stilling basin to create turbulence prior to the hydraulic jump.
  - Baffle blocks - freestanding concrete blocks built in the main basin. These blocks are only used for flows <20m/s due to the high force they are subjected to and the potential for cavitation.
  - End sills - a built-up lip at the tail of the basin, with or without blocks. The sill height has the most significant impact on energy dissipation and taller sills are used to reduce the overall length of the stilling basin.

Stilling basin diagram with chute blocks, baffle blocks and end sill
Chute Blocks/Baffle Piers

- Generate turbulence in the stilling basin in order to cause a hydraulic jump
- Not used for flows greater than 20m/s
  - Flows >20m/s typically cause cavitation behind the blocks, damaging the stilling basin

The force on baffle blocks is:

\[ F = 2\gamma A(d + hv) \]

- \( F \) = force in lbs
- \( \gamma \) = unit weight of water (lb/ft\(^3\))
- \( (d + hv) \) = specific energy of flow entering basin (ft)
Straight Drop Stilling Basins

- In straight drop stilling basins, water flows over the spillway crest and falls onto a flat apron, often with blocks or other energy dissipating features.
- Straight drop basins are typically used for low-flow spillways because high flows can cause the nappe to submerge, reducing energy dissipation and increasing potential for scouring.
- For intermediate flows, longer basins are required, with baffle-blocks and sills, in order to dissipate the energy further.
USBR Type II Stilling Basins

- Developed by the U.S Bureau of Reclamation

- Utilizes chute blocks and a dentated end sill to dissipate energy

- Does not utilize baffle blocks

- Chute blocks lift flow and dissipate energy through eddies

USBR Type II Stilling Basins
Design Recommendations

- Froude number of 4 to 14
- The height of the chute blocks should be equal to the depth of the incoming flow
- The width of the chute blocks should be equal to the depth of the incoming flow
- The spacing between each chute block should be equal to the height of the incoming flow
- A spacing equal to half of the incoming flow height is recommended between the chute blocks and the outside walls
- The height of the dentated sill should be equal to 0.2 times the depth of incoming flow depth
- The maximum width and maximum spacing of the dentated sill is 0.15 times the incoming flow depth
- Length of basin is dependent on Froude number and incoming flow depth

Retrieved from the Federal Highway Administration
USBR Type III Stilling Basins

- Developed by the U.S Bureau of Reclamation
- Utilizes chute blocks, baffle blocks, and an end sill to dissipate energy
- Creates a steep hydraulic jump with minimal wave action downstream
- The position of the baffle blocks are key in the success of type II stilling basins

USBR Type III Stilling Basins
Design Recommendations

- Froude number of 4.5 to 17
- Maximum velocity of 60 ft/s
- Maximum unit discharge of 200 ft^3/s-ft
- The height, spacing, and width of the chute blocks should be equal to the depth of incoming flow
- The height and spacing of the baffle piers are relative to the Froude number and depth of incoming flow
- The distance from the back of the chute blocks to the front of the baffle piers should be 0.8 times the depth of incoming flow
- The height of the end sill is determined by the Froude number and the depth of incoming flow
- Length of basin is dependent on Froude number and incoming flow depth
- The tailwater depth must be equal to or greater than full conjugate depth

Retrieved from the Federal Highway Administration
USBR Type IV Stilling Basins

- Developed by the U.S Bureau of Reclamation
- Utilizes chute blocks and an optional end sill to dissipate energy
- Does not utilize baffle blocks
- Used for cases with low Froude number
- Since flow is low the hydraulic jump may not fully develop which could result in downstream waves

USBR Type IV Stilling Basins
Design Recommendations

- Froude number of 2.5 to 4
- The maximum width of the chute blocks is equal to the depth of incoming flow
- The spacing between the chute blocks is recommended to be 0.75 times the depth of the incoming flow
- The top of the chute blocks is located at height equal to twice the incoming flow depth above the basin floor
- The tailwater depth should be 110% of the full conjugate depth
- The height of the end sill is determined by the Froude number and the depth of incoming flow
- Length of basin is dependent on Froude number and incoming flow depth

Retrieved from the Federal Highway Administration
Saint Anthony Falls (SAF) Stilling Basin

- Developed by model studies conducted by the Soil Conservation Service at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota

- Utilizes chute blocks, an end sill and either baffle or floor blocks

- Generally used for smaller structures, such as culverts or canals, to implement a more cost-effective approach to energy dissipation

- Effective for Froude numbers between 1.7 and 17

Failure Mechanisms

Stilling Basin Sweepout

- Tailwater is insufficient and does not allow hydraulic jump to form and stabilize in the stilling basin which results in any or all of these failures

1) Erosion in downstream channel
2) Headcutting and progressive failure up spillway chute
3) Erosion of toe of embankment dam
4) Uplift pressure causing the stilling basin to float
5) Erosion of stilling basin foundation
6) Ultimate failure of the stilling basin

- If any of these mechanisms result, the stilling basin needs modification as it is not designed for the correct capacity
Failure Mechanisms

Ball Milling

- Crushed material (sands, gravels, and cobbles) are drawn into stilling basin from downstream and trapped in hydraulic jump
- Trapped material erodes stilling basin concrete through grinding process
- Over time, stilling basin foundation is undermined, headcutting progresses upstream and can eventually cause reservoir breach
- Unlikely to cause complete failure because ball milling takes a very long time and regular inspections will repair damage caused
Case Study - El Guapo Dam

- **Date:** December 16, 1999
- **Location:** Rio Guapo Basin - 3 miles South of El Guapo, Venezuela
- **Events Progression**
  1. Water level of dam reaches 8 in. below dam crest
  2. Overtopping of spillway crest occurs
  3. Overtopping results in stilling basin sweepout
  4. Headcutting progresses upstream of stilling basin as overtopping over spillway causes erosion of spillway backfill
  5. Reinforced concrete chute, stilling basin, and approach channel all fail between 4:30 and 5:00 pm
  6. The combination of these events results in breach of reservoir and ultimate failure of the dam
Case Study - El Guapo Dam

1 - 3 From Left to Right

1) Stilling basin sweepout initiates headcutting upstream
2) Spillway overtopping initiates erosion of spillway backfill
3) Headcutting progresses to breach reservoir
Case Study - El Guapo Dam

What went wrong

- Initial hydrologic studies based on similar basin but not Rio Guapo Basin
- During construction, spillway chute walls were overtopped which prompted addition hydrologic studies and addition of a tunnel spillway
- Basing design calculations on inaccurate data resulted in a stilling basin and spillway system that could not handle the volume of water necessary
References:

- http://nptel.ac.in/courses/105106114/pdfs/Unit32/32_1.pdf