Geneva Dam

Design of a Steep, Temporary, Riprap Ramp
A Run-of-River Dam Analysis
for Geneva Dam

Credit to:

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Presentation Purpose –

- History of the Geneva Dam
- Problems with the dam
- Potential Solutions
- Modeling Hydraulic Characteristics of the Dam
- Rock ramp sizing
Fox River Dams
History of Geneva Dam
Built in 1837 for Sterling Sawmill

c. 1890
Several mills operational along 2 raceways by the 1870’s

1871 Atlas Map of Geneva:
Popular Swimming Hole

Down at the Mill-Race.
Geneva, Ill.
And Popular Fishing Hole
1950’s: Problems with the dam
1960 – New Ogee Spillway Dam
Geneva Dam Basic information

- **Type** - ogee
- **Material** - concrete
- **Weir Length** - 441 ft
- **Height** - 13 ft
- **Spillway crest elevation** - 675.40 ft
- **Length of pool** - 1.98 miles
- **Area of Pool** - 89 acres
Public Safety

- Hydraulic Roller causes safety concerns

- Several dams on the Fox River have had recorded deaths

![Diagram of Hydraulic Roller causing safety concerns](image1)

![Plaque in memory of Michael J. Deutsch](image2)
IDNR Requirements for Dams

Which we own or are likely to own and
For which State funds are to be expended

- Public Safety
- Ecological improvements to the river
- Development of recreational opportunities
Potential Dam Alternatives

* Dam Removal
* Dam Modification
  (Spillway Steps & Fish Ladder)
* Rock Ramp
  (Temporary or permanent)
Criteria for Design of Replacement Structure

- Fish Passage
- Flood Conveyance
- Long Term City Planning
- Cost Effectiveness
- River Trails

- Boat Passage
- Safety
- Healthy Ecosystem
- Sediment Transport
- Predictable Results
Objectives of Geneva Dam Study

• Identify suitable methodologies to define hydraulic characteristics and alternatives to minimize roller problem

• Development of methodologies to support the sizing of a temporary rock ramp downstream of Geneva Dam:
  – To minimize existing “roller“ for up to or over a 5-year frequency flow event
  – Rock ramp stable up to 100-year frequency flow
  – 20-year expected project life
MISSION:

Find a computer model that:

1. Will simulate the hydraulics of a submerged hydraulic jump;
2. Will run easily on existing IDNR desk top computers;
3. Will require minimal training to use; and
4. Is inexpensive.
Use of 1-D (HEC-RAS) Model

• Conditions suitable for 1-D (HEC-RAS) modeling:
  – A design unit discharge along dam crest can be assumed.
  – Approaching flows are generally perpendicular to the weir.
  – Design water velocities have insignificant lateral component along riprap slope.

• Conditions requiring 2D/3D modeling:
  – Alternatives involving significant lateral or vertical variations in flow field, such as notches or unusual upstream flow alignment.
  – Physical conditions (bathymetry/geometry) resulting in 2D/3D flow field.
Rock Ramp Sizing Evaluation
Flow

Fill Distance Below Crest

Run-of-river Dam

Dam Crest Elevation

Top of Fill Elevation

D$_{30}$ stone size, where 30% of stone is less than the specified diameter

Slope of Fill

Bed profile will vary

Fill Length (varies depending on bed profile)

Scour hole will vary in size and shape
Geneva Dam Rock Ramp Sizing Approach

- **Select design flow:**
  - Minimize roller at 5-year frequency
  - Stable ramp at 10-, 25-, and 100-year frequencies

- **Obtain design velocities and water depth:**
  - HEC-RAS modeling.
  - Using 5% and 10% rock ramp slopes.
  - Using two Manning’s n: 0.035 and 0.07.
  - Mixed flow turned on.

- **Compare riprap sizes via four methodologies:**
  - Rock ramp sizing spreadsheets.

- **Recommend final sizes and gradation.**
Riprap Sizing Methods Examined

• Four Methods Evaluated:
  – U.S. Army Corps of Engineers' (COE) method for steep slopes (from EM 1110-2-1601).
  – Isbash Method, high turbulence (from EM 1110-2-1601).
  – Frizell, Ruff and Mishra method for overtopping flows.
U.S Army Corps of Engineers
Method for Steep Slopes
(EM 111-2-1601)

\[ D_{30} = \frac{1.95 \, S^{0.555} \, q^{2/3}}{g^{1/3}} \]

Where: \( S \) = Slope of bed, \( q \) = unit discharge

- Thickness = \( 1.5 \times D_{100} \)
- Slope can range from 2 to 20%
- Assumes no tailwater but horizontal extension of the ramp will minimize this limitation
Isbash Method

\[ D_{50} = \frac{V_a^2}{2gC^2(G_s - 1)} \]

- \( D_{50} \) = stone size, ft
- \( V_a \) = average Channel Velocity, ft/s
- \( G_s \) = specific gravity of stone \((\gamma_s / \gamma_w)\)
- \( g \) = acceleration of gravity, ft/s\(^2\)
- \( C \) = 0.86 for high turbulence zones
  = 1.20 for low turbulence zones
Frizell, Ruff, and Mishra

\[ \frac{V_i}{\sqrt{gD_{50}}} \cdot 2.48S^{0.58}C_u^{2.22} \]

- \( V_i \): interstitial velocity (m/s)
- \( D_{50} \): initially determined from design curves
- \( g \): gravitational constant (9.81 m/s²)
- \( S \): embankment slope
- \( C_u \): coefficient of uniformity = \( D_{60}/D_{10} \)
FHWA HEC-15 for Steep Slopes

\[ n = \frac{\alpha d_a^{1/6}}{\sqrt{g \ f(\text{Fr}) \ f(\text{REG}) \ f(\text{CG})}} \]

d_a = average flow depth in the channel

g = acceleration due to gravity

Fr = Froude number

REG = roughness element geometry

CG = channel geometry

\( \alpha \) = unit conversion constant, 1.0 (SI) and 1.49 (CU)
FHWA HEC-15 for Steep Slopes

\[ f(Fr) = \left( \frac{0.28Fr}{b} \right)^{\log(0.755/b)} \]

\[ f(REG) = 13.434 \left( \frac{T}{D_{50}} \right)^{0.492} b^{1.025(T/D_{50})^{0.118}} \]

\[ f(CG) = \left( \frac{T}{d_a} \right)^{-b} b = 1.14 \left( \frac{D_{50}}{T} \right)^{0.453} \left( \frac{d_a}{D_{50}} \right)^{0.814} \]

T = channel top width (ft)
## Riprap Ramp Results

<table>
<thead>
<tr>
<th>Return Period</th>
<th>Channel Slope</th>
<th>Manning's n</th>
<th>Methodology</th>
<th>Average D$_{50}$ (ft)</th>
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<tr>
<td></td>
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<td></td>
<td>COE-EM1601-1</td>
<td>COE-EM1601-Ishbach</td>
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<td>5-yr</td>
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<td>0.035</td>
<td>D$_{30}$ (ft)</td>
<td>D$_{50}$ (ft)</td>
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<td>5%</td>
<td></td>
<td></td>
<td>0.72</td>
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<td>10-yr</td>
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<td>10%</td>
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<tr>
<td>100-yr</td>
<td>1.56</td>
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Gradation Determination
Based Upon COE Gradations

<table>
<thead>
<tr>
<th>D_{100}^{(max)} (in.)</th>
<th>Max</th>
<th>Min</th>
<th>Max^2</th>
<th>Min</th>
<th>15 Max^2</th>
<th>Min</th>
<th>D_{30}(min)</th>
<th>D_{50}(min)</th>
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<td>292</td>
<td>117</td>
<td>86</td>
<td>58</td>
<td>43</td>
<td>18</td>
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<td>394</td>
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<td>197</td>
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<td>1.59</td>
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<td>540</td>
<td>400</td>
<td>270</td>
<td>200</td>
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<td>359</td>
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<td>1.96</td>
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<td>1,168</td>
<td>492</td>
<td>2.19</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Specific Weight = 165 pcf
General Comments on Riprap Methods

• All these methods assume that the riprap is at least moderately angular and for temporary conditions only.

• The riprap methods and the ramp do not take into consideration ice or debris impacts.

• Because of the high turbulence, vibration of the riprap would tear filter fabric – recommend granular filter.

• Note that the COE method for steep slopes gives $D_{30}$ for the representative riprap size whereas the others give $D_{50}$.

• To make the methods comparable, the $D_{30}$ result was converted to an equivalent $D_{50}$ using the formula $D_{30} = D_{50} (D_{15} / D_{85})^{0.33}$, which is related to the COE gradation method.
Basis of Method Selection

• Isbash method was developed for the construction of dams by depositing rock into running water. If the dumped rock did not slide or roll under those conditions, the rock size was considered stable - too conservative.

• HEC-15 method uses an arbitrary safety factor of 1.5 – overly conservative.

• For the Frizell et al. method, the unit discharge for the Geneva Dam exceeded those presented in the graph used in determining the $D_{50}$ of the riprap and values had to be extrapolated.

• The COE method shows reasonable results for the full range of ramp slopes and discharges and was therefore recommended for design of the riprap for Geneva Dam.
5% or 10% Slope?

- 5% or 10% slopes will minimize the formation of the dangerous hydraulic rollers for the 5-year flow events and will function properly per design requirements.

- Therefore, recommendations for either a slope of 5% or 10% depend on the costs.

- The 10% ramp slope has a larger gradation ($D_{30}$ of 1.70 feet) than the 5% ramp slope ($D_{30}$ of 1.10 feet) but would have a smaller overall riprap volume.

- Since the costs for riprap is a combination of availability of large sized rock as the volume of riprap, the recommended ramp slope should be based upon local rock supply conditions.
<table>
<thead>
<tr>
<th>Description</th>
<th>Tons</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORPS METHOD 10% SLOPE</strong></td>
<td>19,800</td>
<td>$2,485,000</td>
</tr>
<tr>
<td>Less rock but bigger rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$89/TON</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CORPS METHOD 5% SLOPE</strong></td>
<td>35,700</td>
<td>$3,800,000</td>
</tr>
<tr>
<td>More rock but smaller rock</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$85/TON</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Where are we headed now?
Investigate Temporary Rock Ramp Placement
INVESTIGATE PERMANENT ROCK RAMP DESIGN
ARCH RAPIDS LONGITUDINAL PROFILE
(consider Luther Aadland Design)

Public Safety
Fish Passage
Recreational Boat Passage
Investigate Dam Removal

Source: Emily Stanley, University of Wisconsin
Compare to Stair Step Dam Modification at Yorkville

$2,900,000
Thank you!
Frizell, Ruff, and Mishra

\[ V_{\text{ave}} = V_i \times n_p \]

\[ n_p = \text{porosity of the riprap} \]