Gardiner Dam’s Historic Movement and Ongoing Stability Evaluation

Director, Dam Safety and Major Structures
Outline

• South Saskatchewan River Project Introduction
• Lake Diefenbaker Reservoir
• Gardiner Dam
  – Foundation Conditions
  – Major Components
  – Movements
  – Previous Stability Evaluations
• Grant Devine Dam Stability Evaluation
• Expected Results
  – Not expected results
SSRP Introduction

Gardiner Dam

Qu’Appelle River Dam
SSRP Introduction

- 1894 first consideration for large irrigation
- 1968 completed
- Total cost $120 million (1968 value)
- Replacement value $2.41 Billion
- Owned and operated by Water Security Agency
- Operation, maintenance and monitoring complete by 8 onsite staff
Lake Diefenbaker Reservoir
Reservoir Drainage Basin

- Three Regions
  - Eastern Rockies
  - Foothills
  - Prairies

- 60% Snowmelt
- 38% Rainfall runoff
- 2% Glacier melt

- Effective Distribution
  50% Area / 80% Flow
  50% Area / 20% Flow
Reservoir Operation

- Runoff patterns
  - Low winter flow
  - Spring peak, April
  - Summer peak, May/June
  - Recession, Aug/Sept
Reservoir

- Lake Diefenbaker
- 225 km long (near Eston, SK)
- 760 km shoreline
- Volume $9.25 \times 10^9$ m$^3$
- Usable Storage $3.95 \times 10^9$ m$^3$
- Up to 58 m deep
2013 Release

- Largest flow released
- 1600 m$^3$/s spillway
- 2000 m$^3$/s total
Gardiner Dam
Gardiner Dam
Major Components

- Plateau Embankment
- Coteau Creek Embankment
- Spillway
- Tunnels
- Main (River) Embankment
Gardiner Dam Embankments

- Three zoned compacted-earth filled embankments
- Total Length 5000 m
- Crest Elevation 562.4 m
- Max height 64 m
- Upper Slopes 2H:1V
- Lower Slopes 85H:1V
Gardiner Dam
Foundation
Gardiner Dam Foundation

- Till
  - Eroded except on abutments

- River Sand
  - In valley bottom

- Bedrock
  - Bearpaw Formation
    - Snakebite Shale
    - Ardkenneth Sandstone
Gardiner Dam Foundation

- Snakebite Shale Description
  - Upper Cretaceous Origin
  - Marine Deposited
  - Dark Grey Shale, flat horizontal lying strata
  - Jointed, Slickensided, and Bentonite seams
  - Highly Plastic
  - Presheared
Gardiner Dam Foundation
Gardiner Dam Foundation
Gardiner Dam
Movement
Gardiner Dam
Horizontal Movement

- Occurring since start of construction
- Shear plane located in shale foundation near the contact with the underlying sandstone
  - Approximately 114 m below the crest of the dam El. 448 m
Gardiner Dam
Horizontal Movement

- Movement rates and magnitude vary by position from the dam crest
- Maximum movement rate and magnitude is occurring at toe of main embankment
Historic Instrumentation

Horizontal Movement

- The movement is occurring on a defined shear plane in the shale
Gardiner Dam
Horizontal Movement

- Movement rate generally slowing
- On an annual frequency the movement rates indicate a trend with the reservoir
Historic Instrumentation

Time Comparison

• The piezometric level fluctuates with reservoir
Previous Analysis

- 1948-1953
  - Limit Equilibrium
  - Total Stress Analysis
- 1954-1965
  - Limit Equilibrium
  - Effective Stress Analysis
  - Redesigned as the back analysis of local slopes
- 1979
  - Finite element stress deformation analysis
  - Computational limited
- 1980-2009
  - Simple mechanical model with a spring and damper to predict movement related to historic movement
Previous Analysis

• 2009-2013
• Analytical Model
• Simple sliding block evaluation

• It appeared there is a correlation between total stress loading on the shale and pore water dissipation.
Previous Analysis

What does this all mean

- We don’t understand the movement mechanisms
- The stability of the structure is not fully understood

Next Steps

- Detailed Finite Difference Model (FDM)
- Understand long term deformations and impacts on structures
Detailed FDM Analysis Moving Forward

Grant Devine (Alameda) Dam 2011-2014

• Similar problem as Gardiner but was moving faster
  • Process will be very similar
Detailed FDM Analysis Moving Forward

Grant Devine (Alameda) Dam

- Unanticipated shear displacements during construction
- Stop construction to redesign
- Added toe berms

Glacial Till (Foral/Battleford) Formation

Bedrock – interbedded sandstones, siltstones and clay shales (Ravenscrag Formation)
Detailed FDM Analysis Moving Forward

Detailed Geological Framework

- Need to understand the materials in the foundation
- Develop a representative model
Detailed FDM Analysis Moving Forward
Detailed FDM Analysis Moving Forward

Start with a 2D

- 2D model is required to minimize complications
- Calibrate model
  - Lab tested material properties
  - Actual deformation measurements

- Establish appropriate constitutive model of soil
- Once model behavior is understood then move on to 3D
Detailed FEM Analysis Moving Forward

Move forward with 3D

- Start with properties from calibrated 2D model
- Calibrate again
  - Actual deformation measurements
  - Measured porewater pressure
Expected Results

- Understanding of long term movements
- Understanding of the stability of the structure
- Estimate of total deformation and rate
- Impact on the ancillary structures
  - Spillway
  - Relief Well Drainage Conduit

Limitations
- Not expecting be able to estimate annual displacement
- A traditional Factor of Safety is not possible
Summary

• The dam is performing well
• Monitoring and maintenance activities are ongoing
• The embankment is moving downstream with rates slowing
• With over 50 years of satisfactory performance there is valuable lessons to be learned from this project
• This project is a valuable asset to the province and will remain to be in the future