Design of High Pressure Vertical Steel Gates
Chicago land Underflow Plan Mc Cook Reservoir

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PRESENTATION OUTLINE

- INTRODUCTION
- SLIDE vs. WHEEL GATE
- HISTORICAL BACKGROUND
- DESIGN PROCEDURE WHEEL GATE
- DESIGN PROCEDURE SLIDE GATE
- DESIGN & MODEL RESULTS
- CONCLUSIONS
- QUESTIONS
INTRODUCTION

• Mc Cook Project overview:
  – Mc Cook Reservoir is (10.5 billion gallon/32,000 acre-foot) reservoir
  – Covers 252-square miles with 3-million people and 1.24-million housing units.
  – Reservoir components: cut off walls, distribution tunnels, main tunnels, hydraulic structures, aeration system, wash down system and various types of gates/valves.

• Definition:
  – Wheel Gate
  – Slide Gate
WHEEL GATE vs. SLIDE GATE

- WHEEL GATE:
  - Adv:
    - Used for large opening and high head
    - Relatively lower friction (Rolling friction)
    - Can maneuver trash clogging and jamming
  - Disadvantage:
    - Needs a higher precision to install
    - Bulky and heavy

- SLIDE GATE:
  - Adv:
    - Can be used in intake/outlet tunnel
  - Disadvantage:
    - Relatively higher friction (static friction)
    - Used only for smaller head and opening
    - Might jam-up with sediment.
HISTORICAL BACKGROUND GATES & VALVES

- Except Roosevelt, Arrowrock, Pathfinder, Buffalo Bill & Owyhee dams most gate before Hoover Dam have a capacity less than 150-feet head.
- In 1908 5-feet by 10-feet slide gates installed at 220’ head at Roosevelt Dam (Arizona).
- Basic needle valve design invented in 1908 by H.O Ensign used for regulating high pressure outlets.
- Similar slide gate installed at Pathfinder Dam in 1909 (Wyoming).
- Further refinement of needle valve resulted in C.H Howell & Howard Bunger fixed cone valve, 1940.
- Slide gate 7-feet by 10-feet with 350’ head of water in 1965 (Glen Canyon).
WHEEL GATE DESIGN

DESIGNED BY:
USACE, CHICAGO DISTRICT
Mc Cook Reservoir Main Gate Chamber Layout

PLAN VIEW OF THE WHEEL GATES (MAIN TUNNEL)
Mc Cook Reservoir Wheel Gate

Wheel Gate Front & Section View

Wheel Gate Hoisting System
Project Design Data

• Wheel Gate Design Data:
  – Size is *16.5-feet wide by 30.5-feet high!!!*
  – Design head is 400-feet (175-psi pressure)
  – Replacement life of the gate = 50 years with 25 years for wheel assemblies
  – Gate overall weight is *94-tons!!*
  – Total of six wheel gates in the main tunnel gate chamber
    (One primary gate sandwiched by two secondary/tertiary gates)
WHEEL GATE DESIGN

HAND COMPUTATION / DESIGN
Design Procedure for Wheel Gate

1. Determine loading & Boundary Condition
2. Check Adequacy of gate section
3. Check gate wheel & shaft
4. Check bottom traing. section
5. Size end plate and diaphragm plate
6. Design lifting bracket
7. Design panel connection
8. Design bumper guide
9. Design dogging bar
Determine loadings & load combo (STEP-1)

- Determine loading & load combo:
  - Hydrostatic & hydrodynamic loads (see cylinder)
    - Cylinder size & internal diameter (3000-psi)
      - Breakaway Force
      - Normal Pull
      - Pull with down pull
      - Max push
  - Boundary conditions and gate support system
  - Determine the load transfer through 1st and 2nd stage concrete
Determine gate cross sectional properties (STEP-2)

- Determine initial gate cross section (based on loading)
- Check flexural stress, shear stress and deflection
- Do iteration till selected cross section is enough.
Determine gate wheel and shaft sizes (STEP-3)

- Determine allowable load on the wheel:
  \[ P_{all} = \left[ \frac{24.5Bhn - 2200}{2.5(FS)} \right] \]  
  *Applied Hydraulics Davis*

- Determine required projected wheel area
- Determine net wheel tread width required
- Design wheel shaft
- Check wheel bearing
  - Radial Rating \((RR)\)
  - Life span of wheel bearing \(L_{10}\) (for intermittent service)
- Check wheel contact pressure
Check bottom triangular gate portion (STEP-4)

- Compute C.G of the bottom triangular section
- Compute flexural stresses from applied loading
Determine the size of diaphragm/end plates (STEP-5)

- Determine the end & inner (diaphragm) plates
- Determine weld sizes
Design lifting bracket (STEP-6)

- Determine plate size/thickness
- Determine weld size
Design Gate Panel Connections (STEP-7)

- Check PIN failure
- Bearing failure of linking plate
- Shear tear-out
Design bumper guide (STEP-8)

- Determine the loading (kinetic energy)
- Compute the maximum (axial Euler load) $P_{all}$
Design of dogging device (STEP-9)

- Weight of the gate + Impact
- Determine the flexural moment ($M_{\text{max}}$)
- Determine section modulus $S_{\text{req}}=?$ (of dogging device)
- Determine deflection $\Delta=?$
WHEEL GATE DESIGN

STAAD/PRO SOFTWARE BASED DESIGN
STAAD/Pro Design Procedure

- Build up 3-D model for the gate
- Determine the boundary condition (Support type)
- Apply the appropriate loads individually:
  - Dead load
  - Hydrostatic/Hydrodynamic load
  - Seal load
  - Buoyancy load
  - Down pull load
  - Wheel dead weight (analyzed separately)
- Apply the appropriate load combo
  - Three different load combo cases considered.
  - Select/pick the worst case scenario
- Analyze the STAAD/Pro output
STAAD/PRO MODEL RESULTS

Figure-1  3-D Model of Whole Gate

Figure-2 Stress contour (Self Weight)

Figure-3 Stress contour (Hydrostatic load)

Figure-4 Stress Contour Seal load
STAAD/PRO MODEL RESULTS

Figure-5 Stress Contour (Down pull load)

Figure-6 Stress Contour (Wheel load)

Figure-7 Stress Contour (Machinery load)

Figure-8 Stress Contour (Bouyancy load)
STAAD/PRO MODEL RESULTS

Figure-9 Stress Contour (Load combo-1)

Figure-10 Stress Contour (Load combo-2)

Figure-11 Stress Contour (Load combo-3)
STAAD/PRO Model Result Discussion

- Stress & Deflec (LRFD)
  - Actual Stress:
    - $S_{\text{max}} = 22.9$-ksi
    - $S_{\text{min}} = 0.083$-ksi
  - Actual deflection:
    - Def. = 0.143”

- Stress & Deflec (LRFD)
  - Allowable Stress:
    - $S_{\text{allow}} = 40.5$ ksi (Miter Gate)
  - Allow deflection:
    - Def. = 0.4*(thickness of skin plate) = 0.51”
Further Design Work to do (Wheel Gate)

- Design the gate superstructure to fit DDR gate chamber outline
- Detail the fixed & moving parts and connection to complete gate design
- Model simulation design for certain critical gate components
CONCLUSIONS

- Vertical lift gate should be designed as horizontally framed than vertical ones
- Design by hand and check with software based model simulation
- Consider fabrication issues early on the design phase
- Carefully select materials for various gate components
SLIDE GATE DESIGN

DESIGNED BY:
INCA ENGINEERS, INC
Mc Cook Reservoir Distribution Chamber Layout
Mc Cook Reservoir Slide Gate
Design Methodology

- Hand calculation/computation
  - Equation from (EM 1110-2-2105)
- Software computation (ANSYS 7.0)
  - 3-D model simulation
Project Design Data

- Overall Slide Gate Design Data:
  - Gate leaf in 8-inches thick
  - Clear height = 5.00-feet
  - Clear span = 5.00-feet
  - Internal design pressure (Normal operation): 152-psi
  - Internal design pressure (Overload operation): 300-psi
  - Maximum external grouting pressure: 50-psi
  - Maximum time required to open/close gate: 30 min
  - Maximum gate velocity at closing (final 1-foot closure): 0.33fpm
  - Total gate stroke = 5.08-feet
DESIGN OF SLIDE GATE

• Project Design Data
• Gate Leaf Structure
• Gate Frames, Bonnet and Bonnet cover
• Hoisting Requirements
Gate Leaf Structure

1. Determine load type and load increase
2. Perform beam analysis
3. Calc. gate sectional prop
   - Moment of inertia (I)
   - Sectional modulus (S)
   - Shear area (Av)
4. Computer stress & deflection
5. Check bottom triangular gate section
6. Check bearing load on the seal
7. Check slot cut out for hoisting load
Gate Frames, Bonnet and Bonnet cover

- Determine load cases hydrostatic & grouting
  - Evaluate gate leaf-frame-concrete loading
  - Evaluate bearing into the surrounding concrete
  - Check proper load transfer
  - Evaluate gate frame & bonnet structure based on external pressure
    - Determine moment & shear based external pressure
      - Compute girder flexible stress shear stress & deflection
        - Check stress in skin plate
        - Design bonnet structure for grouting pressure
Hoisting Requirements

Performing hoisting requirements

- Compute all type of loads
- Determine load combo
  - Normal pull
  - Normal push
  - Lowering control

**NOTE:** Hoisting requirements are determined to estimate cylinder size and max. push requirements.
ANSYS Model Result (Slide Gate)

Figure-1 Slide Gate ANSYS mesh generation

Figure-2: Gate leaf stress contour (ANSYS)

Figure-3: Gate leaf deflection contour (ANSYS)

Figure-4: Gate slot cut-out close-up view (ANSYS)
DISCUSSION OF ANSYS MODEL RESULTS

• Stress Contour:
  – $S_{\text{max}} = 13.486$-ksi
  – $S_{\text{min}} = 16.395$-ksi

• Deflection Contour:
  – $S_{\text{max}} (-) = 0.079733$
  – $S_{\text{max}} (+) = 0.021756$

• Allowable Stress:
  – $S_{\text{allowable}} = 18$-ksi (For 30-ksi steel)
  – $F_{\text{all}} = 0.75*0.6*F_y*1.33$

• Allowable Deflection:
  – $S_{\text{delta}} = 1/750''$ (0.08'')
QUESTIONS
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