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

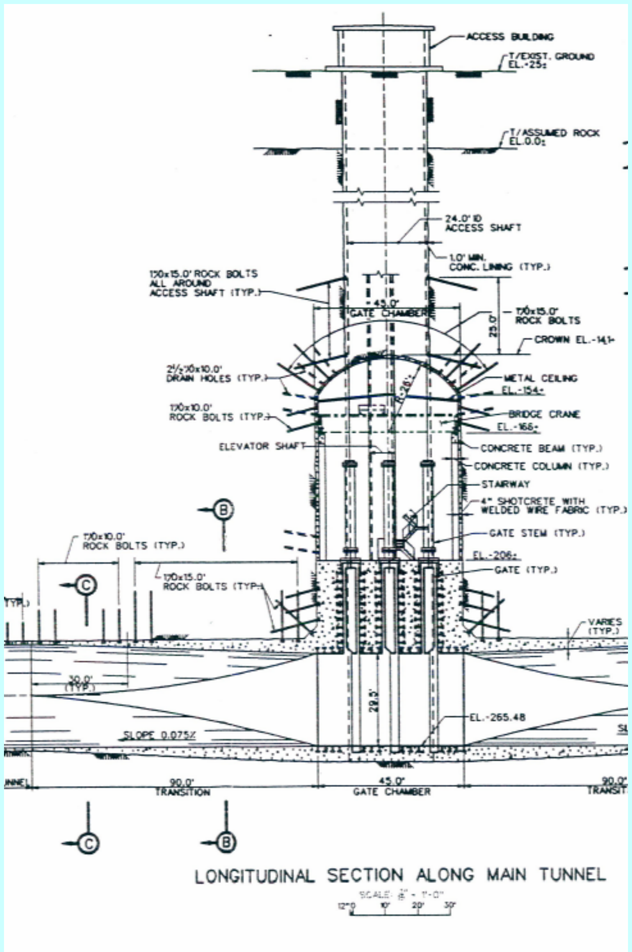
- Except Roosevelt, Arrowrock, Pathfinder, Buffalo Bill & Owyhee dams most gate before Hoover Dam have a capacity less than 150-feet head
- In 1908 5-feet by 10-feet slide gates installed at 220’ head at Roosevelt Dam (Arizona)
- Basic needle valve design invented in 1908 by H.O Ensign used for regulating 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).

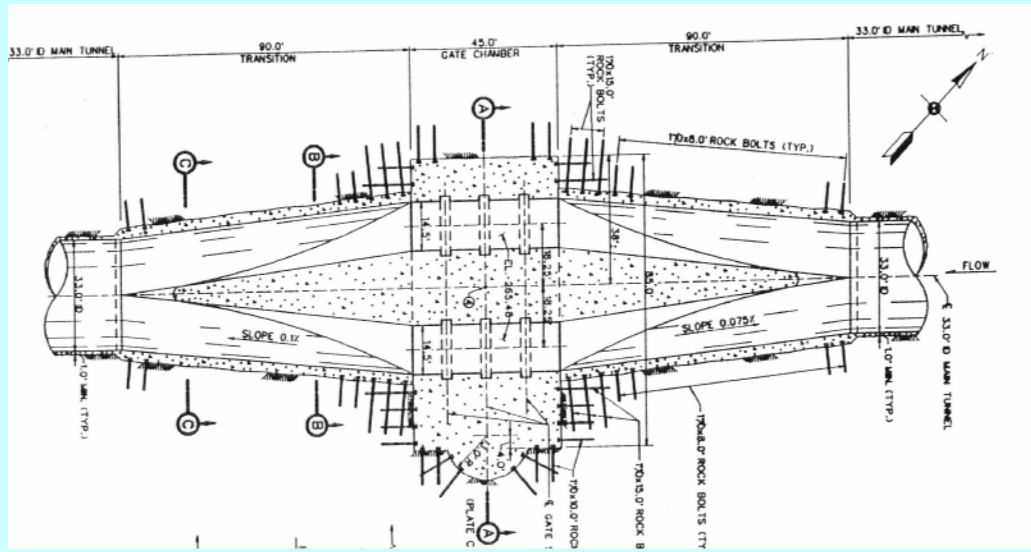
WHEEL GATE DESIGN

DESIGNED BY:

USACE, CHICAGO DISTRICT

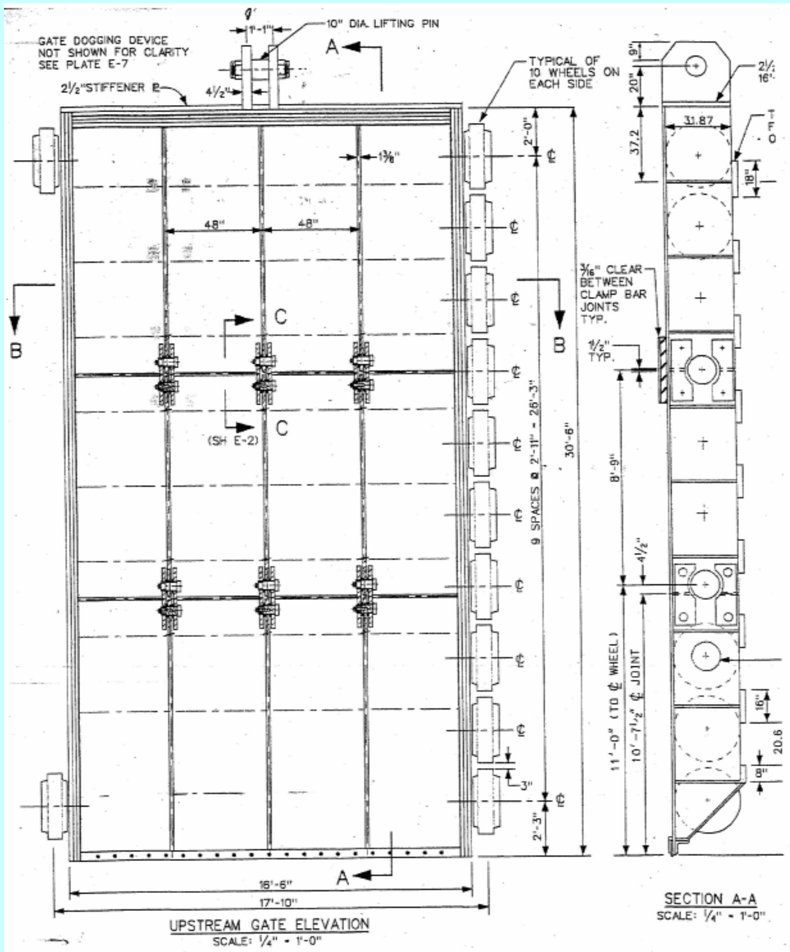
Mc Cook Reservoir Main Gate Chamber Layout



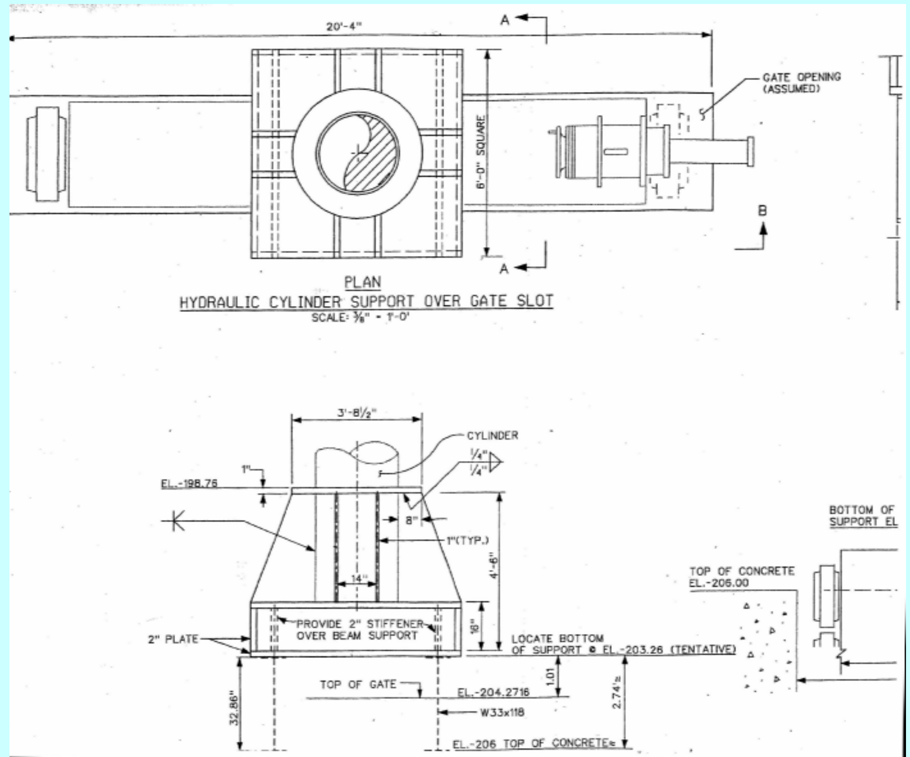


PLAN VIEW OF THE WHEEL GATES (MAIN TUNNEL)

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

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

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:

$$P_{all} = \left[\frac{24.5Bhn - 2200}{2.5(FS)} \right] \quad \textit{Applied Hydraulics Davis}$$

- 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_{max})
- Determine section modulus S_{req}=? (of dogging device)
- Determine deflection Δ=?

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

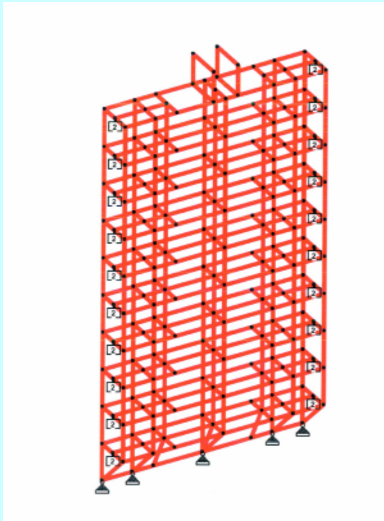


Figure-1 3-D Model of Whole Gate

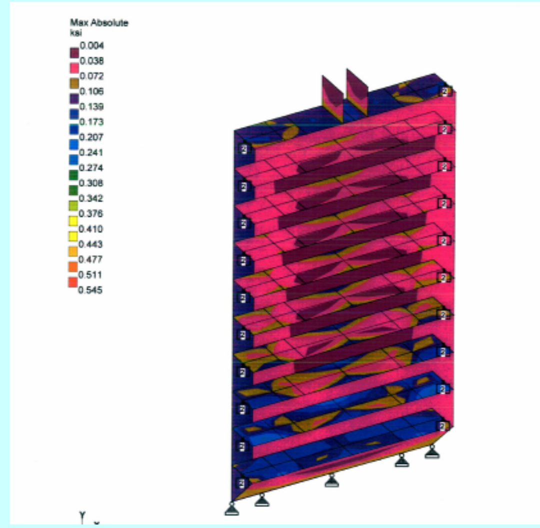


Figure-2 Stress contour (Self Weight)

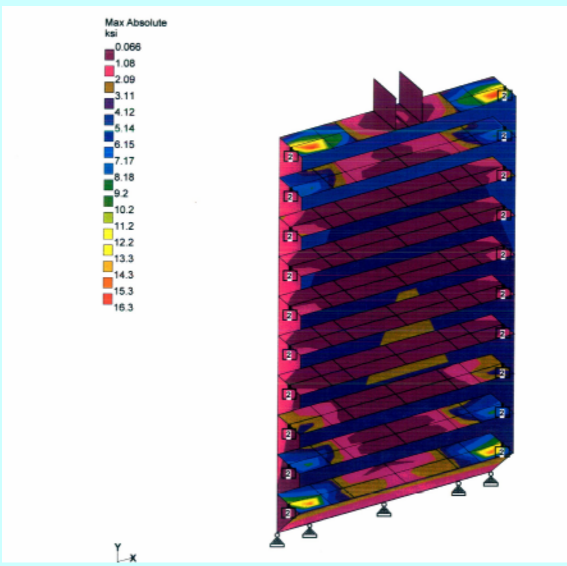


Figure-3 Stress contour (Hydrostatic load)

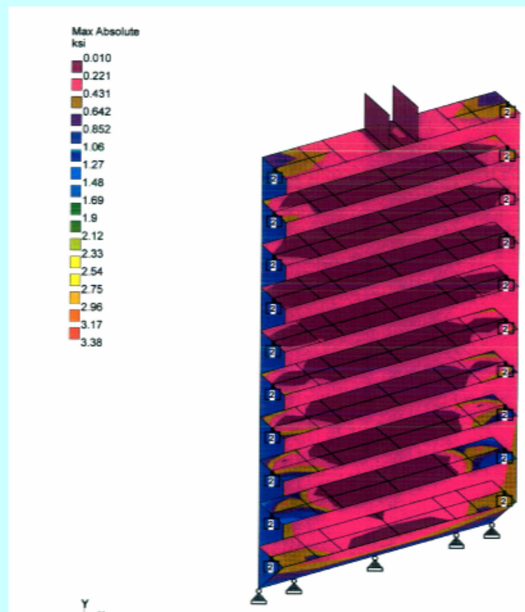


Figure-4 Stress Contour Seal load

STAAD/PRO MODEL RESULTS

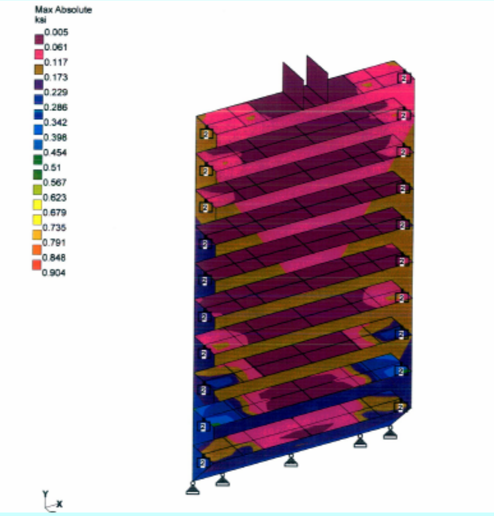


Figure-5 Stress Contour (Down pull load)

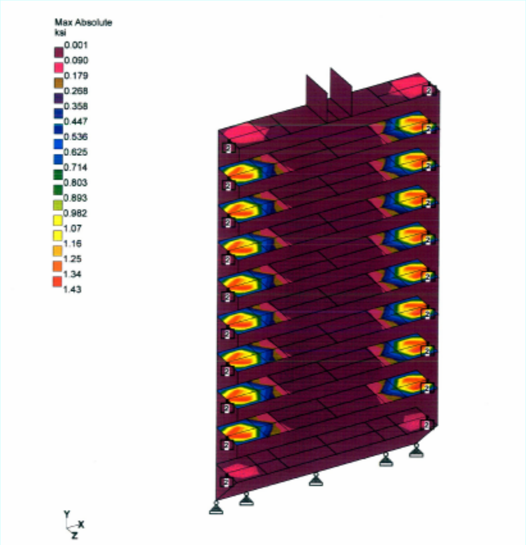


Figure-6 Stress Contour (Wheel load)

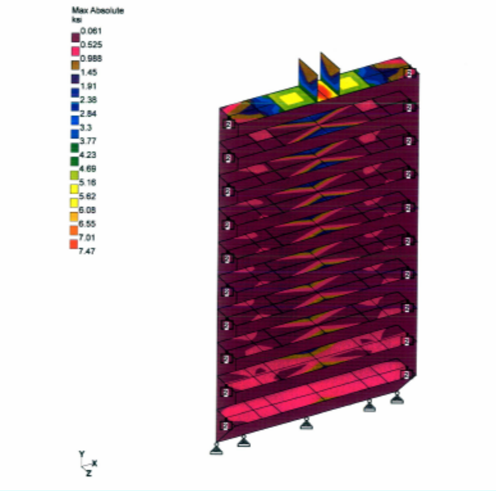


Figure-7 Stress Contour (Machinery load)

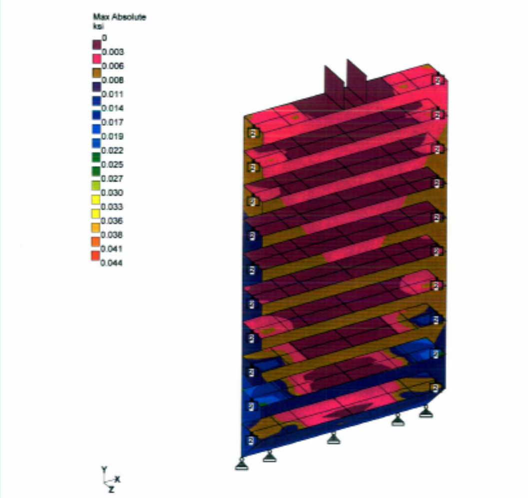


Figure-8 Stress Contour (Bouyancy load)

STAAD/PRO MODEL RESULTS

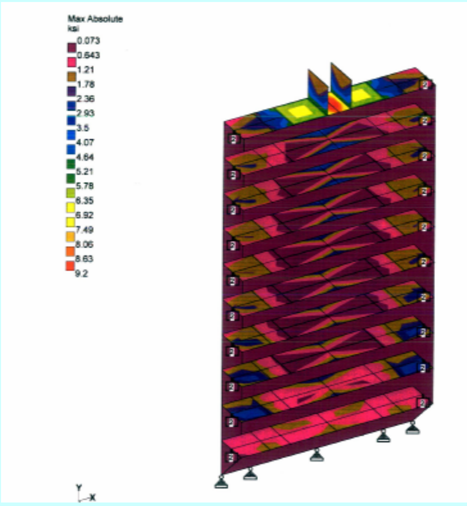


Figure-9 Stress Contour (Load combo-1)

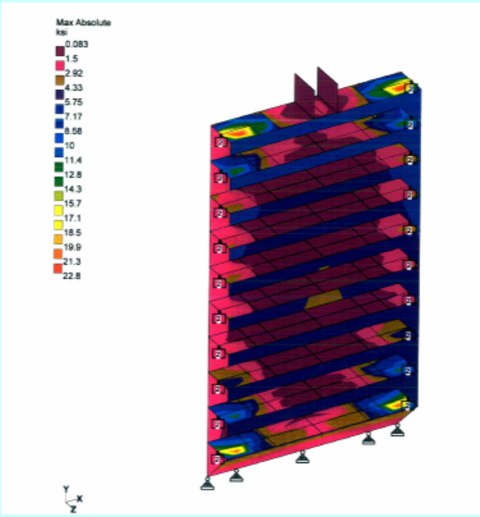


Figure-10 Stress Contour (Load combo-2)

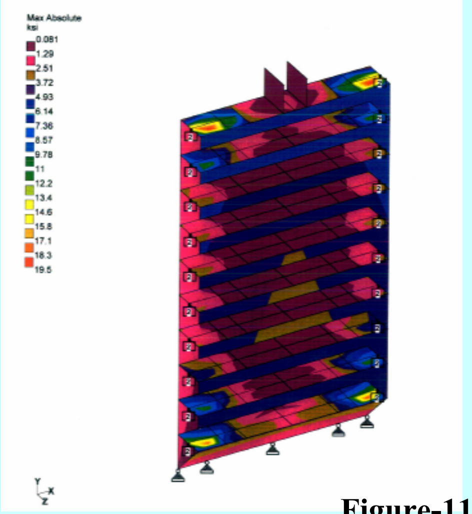


Figure-11 Stress Contour (Load combo-3)

STAAD/PRO Model Result Discussion

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

- Stress & Deflec (LRFD)
  - Allowable Stress:
    - S_{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 super structure 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

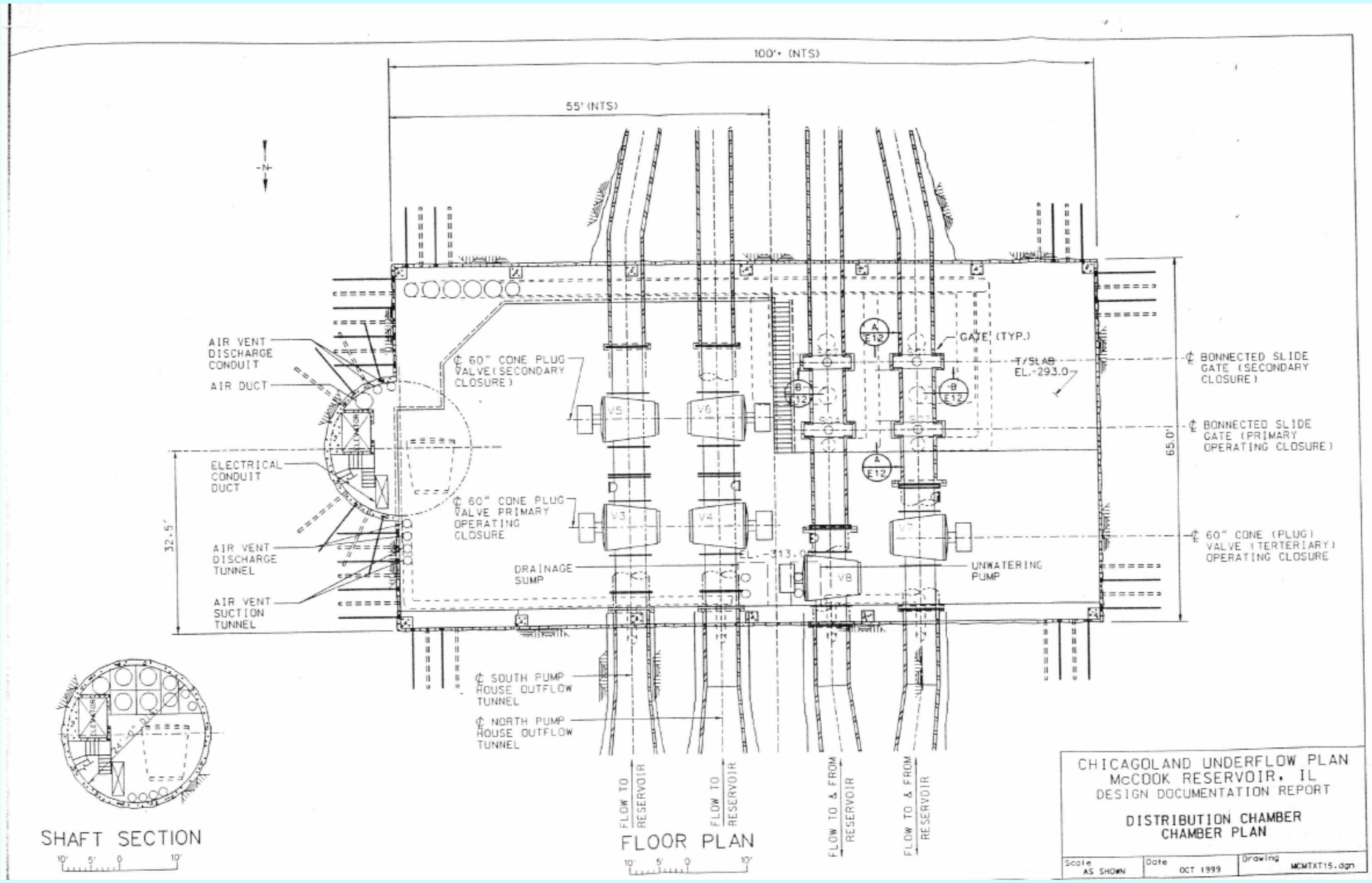
- Vertical lift gate should be designed as horizontally framed than vertical ones
- Design by hand and check with software based model simulation
- Consider fabrication issues early on the design phase
- Carefully select materials for various gate components

SLIDE GATE DESIGN

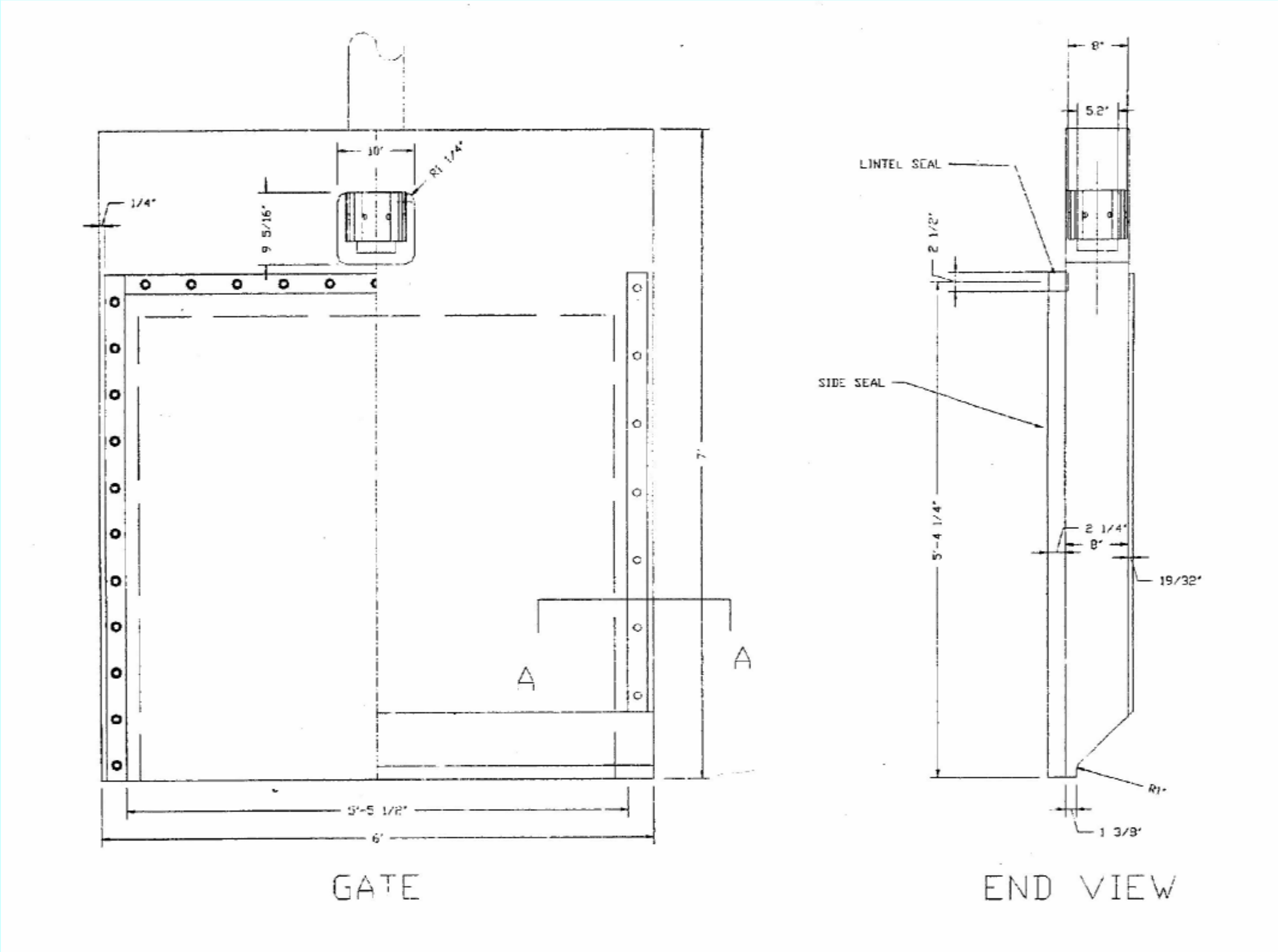
DESIGNED BY:

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

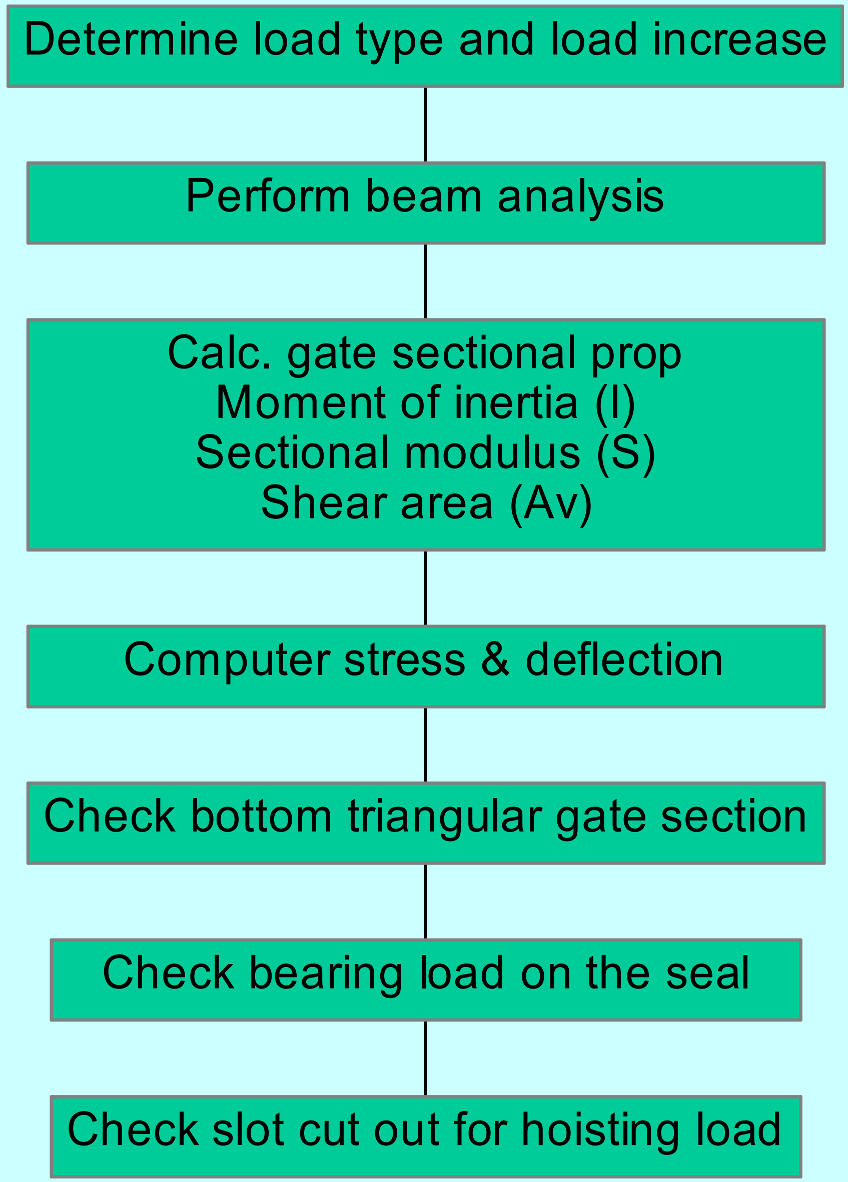
Project Design Data

- 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

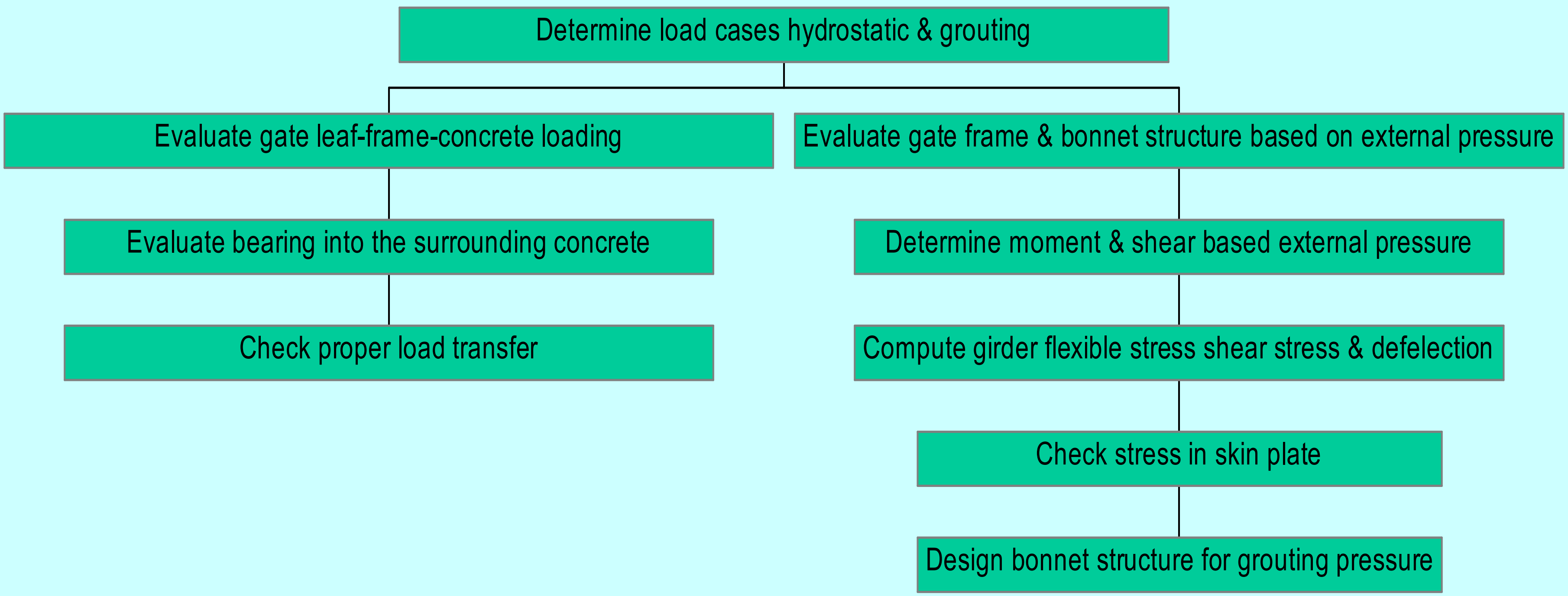
DESIGN OF SLIDE GATE

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

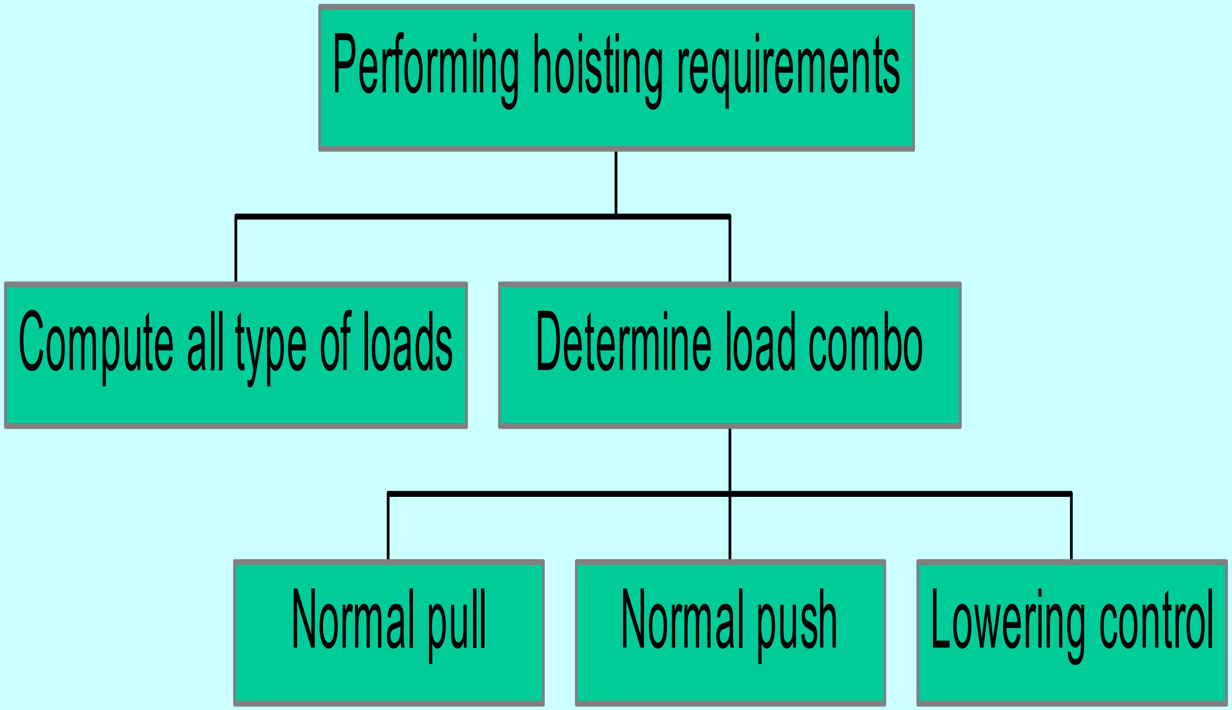
Gate Leaf Structure



Gate Frames, Bonnet and Bonnet cover



Hoisting Requirements



NOTE: Hoisting requirements are determined to estimate cylinder size and max. push requirements.

ANSYS Model Result (Slide Gate)

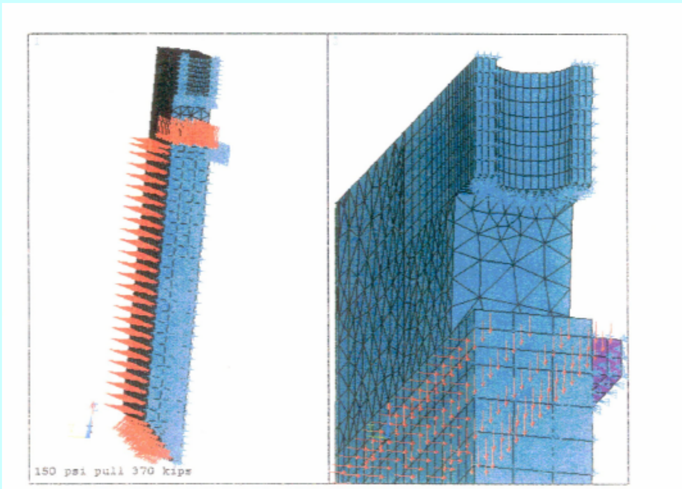


Figure-1 Slide Gate ANSYS mesh generation

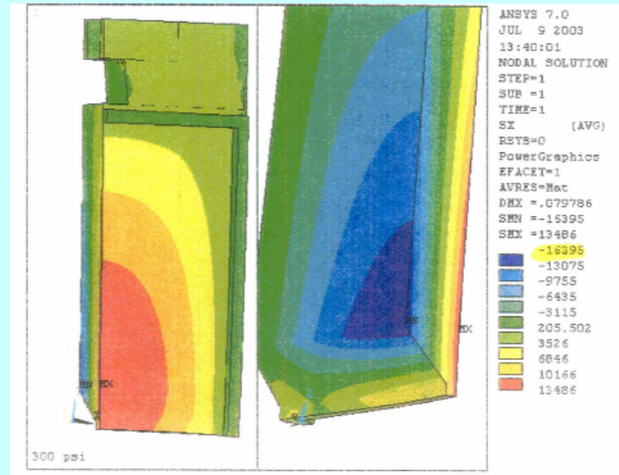


Figure-2: Gate leaf stress contour (ANSYS)

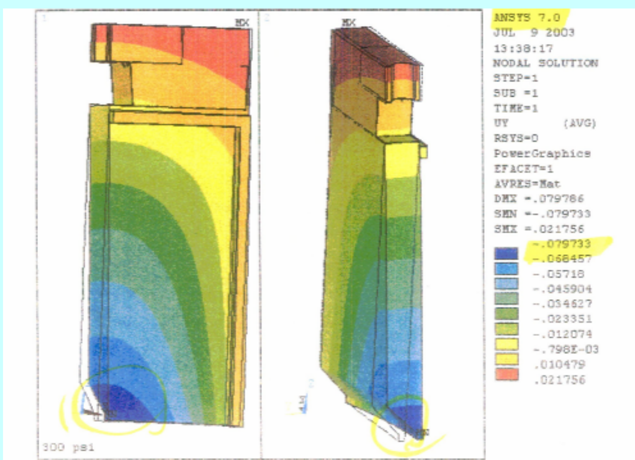


Figure-3: Gate leaf deflection contour (ANSYS)

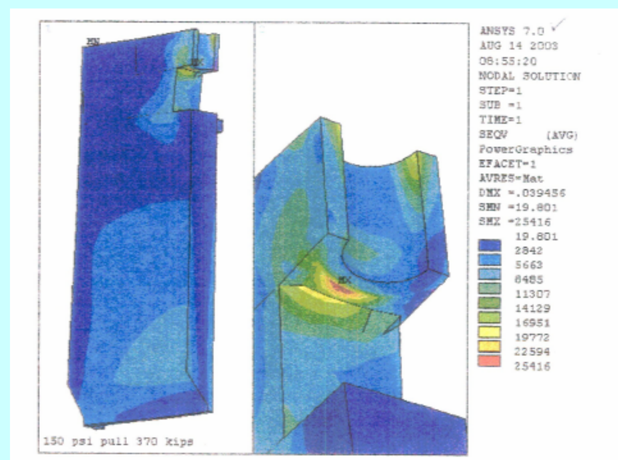


Figure-4: Gate slot cut-out close-up view (ANSYS)

DISCUSSION OF ANSYS MODEL RESULTS

- Stress Contour:
  - S_{max} = 13.486-ksi
  - S_{min} = 16.395-ksi
- Deflection Contour:
  - S_{max} (-) = 0.079733
  - S_{max} (+) = 0.021756
- Allowable Stress :
  - $S_{allowable}$ = 18-ksi (For 30-ksi steel
  - F_{all} = 0.75*0.6*Fy*1.33
- Allowable Deflection:
  - S_{delta} = 1/750’’ (0.08’’)

QUESTIONS

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