Morning Glory Spillway Alternative for Oroville Dam

Redacted Author Names for Privacy
CXX04 S21

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Site Characteristics

- Tallest dam of the country, measuring at 235 m (770 ft)
- Located within the foothills of Sierra Nevada
- Provides flood control and water supply
- The Edward Hyatt Powerplant produces 645 MW of power
- Constructs a reservoir of about 4,300,000,000 cubic meters

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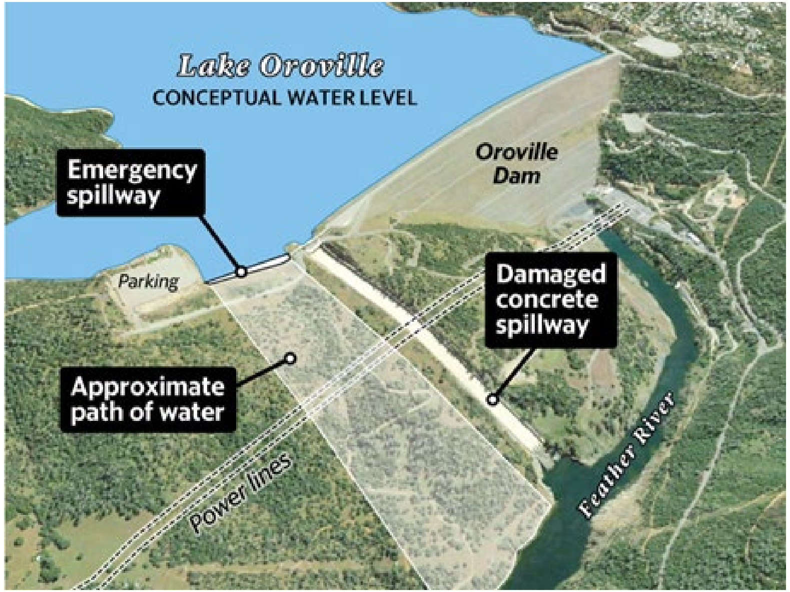
Oroville Dam Hydraulic System

- Two components of spillway system:

1. Service spillway - unlined concrete channel that controls outflow rates down an outlet passage, a headworks structure, and a lined concrete chute
2. Emergency spillway - 15 meter high weir. Water runs down the hillside into the river below.



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Project Need

Source: Ye Tian and Sonja Jankowfsky

Objective

- Current status: repairments and rebuilding of the main and emergency spillways were completed in 2018.
- Only difference is the addition of a concrete buttress, underground secant pile wall and splashpad for the emergency weir.
- This project will approach the dam failure with a new spillway alternative - preferably one that is uncontrolled.
- The goal of this project is to design a hydraulic system for a flow comparable to the max discharge of the existing main spillway.
- The “Morning Glory” spillway will be proposed.

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Oroville Dam 2017 Spillway Incident

- **Early 2005** → environmental groups voiced their concerns about the emergency weir needing concrete protection to avoid heavy erosion
- **2013** → cracks on the main spillway were reported and immediately repaired
- *Complete inspections have not been conducted since Feb. 3, 2015*
- **Jan 2017** → heavy rainfall over Feather Basin
- **Jan 13, 2017** → photographer noticed an unusual wave pattern within the main spillway. Elevations rose due to small rainstorms
- **Feb 3, 2017** → return of flood control limit, in time for large storms
- **Feb 7, 2017** → water discoloration was discovered of main spillway. Outflows ceased, and a large concrete slab was removed
- **Feb 11, 2017** → heavy rains continued and the emergency weir was used for the first time
- **Feb 12, 2017** → evacuation order was issued

Jan 13, 2017

Feb 7, 2017

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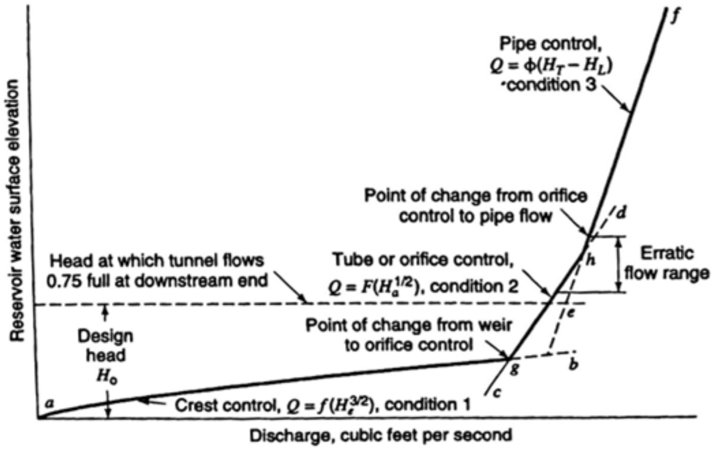
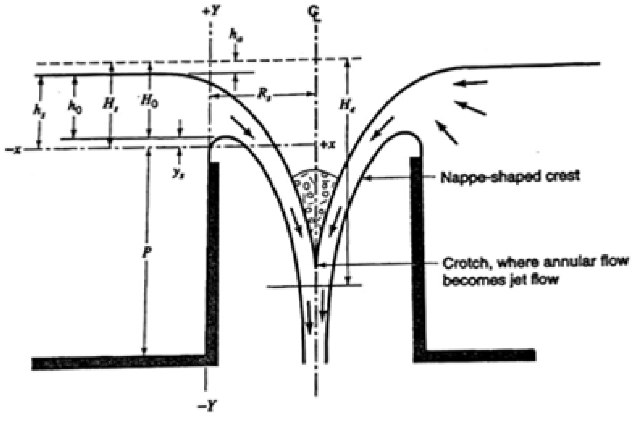
Theory

- Spillway - acts as an additional form of flow release to the riverbed when surface elevations of the reservoir are exceeded
- Morning glory spillway - a drop inlet spillway that allows water to enter through a horizontal lip, into a vertical shaft, and discharged through a horizontal tunnel
- Three types of flow control: crest control, orifice control, and fullpipe flow control
- Flow of water over inlet creates a nappe-shapped profile

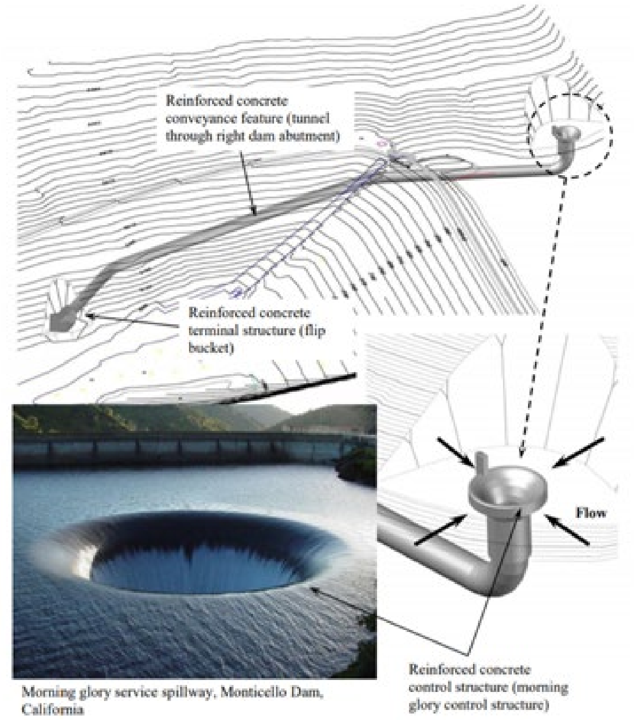




(a)

Monticello Dam's "The Glory Hole"

- Key feature of Monticello Dam, located 100 miles away from Oroville
- Residents call it "The Glory Hole"
- Dam is built between a canyon; limited space for overflow spillway
- Discharges up to 48,800 cfs, 72 ft diameter which narrows to 28 ft



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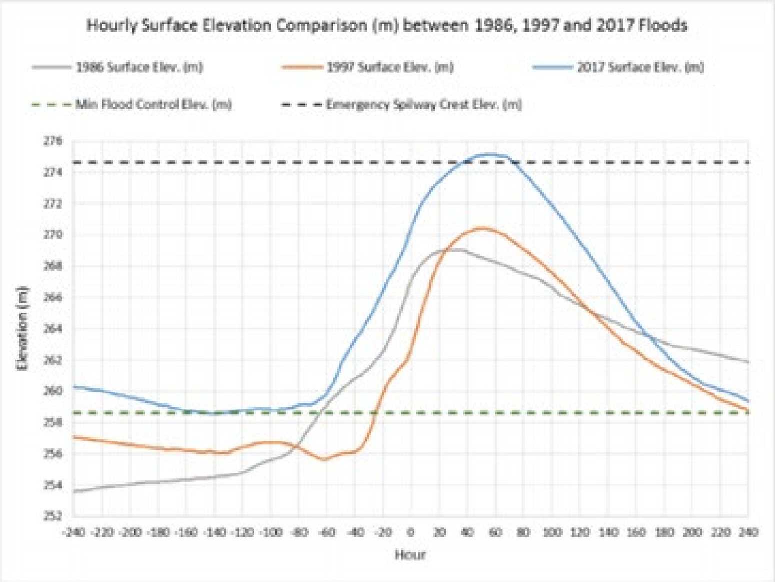
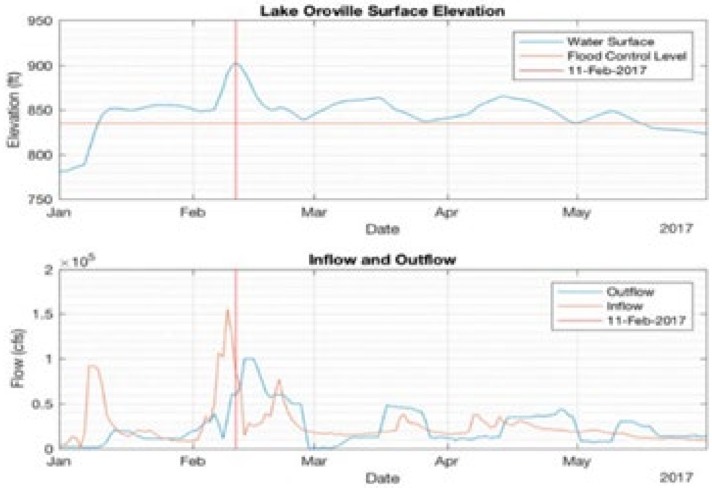
Methodology

1. Gathered data following the Oroville Dam crisis and performed analysis on the experienced flood events
2. Find information on the maximum discharge rates for Oroville's existing main and emergency spillways
3. Using the discharge values, calculations were conducted to compute the design parameters of the proposed morning glory spillway
4. A schematic diagram was created.
5. Discussion of flow control, pressure changes, and other mechanisms of the water flow was executed.

Oroville Dam Data



(Koskinas et. al., 2019)



(Hollins et.al, 2018)

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Mechanism	Function	Max Flowrate
Main Spillway	Primary removal of water when high flowrate is needed	4,246 m^3/s (150,000 cfs) under normal conditions
Emergency Spillway	Earthen weir. Last resort removal of water when reservoir elevations exceed weir height	11,327 to 16,990 m^3/s (400,000 to 600,000 cfs)
Hyatt Powerhouse	Powerplant removes water in controlled flow. Operates 5-6 turbines	396 m^3/s (14,000 cfs)
River Valve Outlet System	Used when water is at low water levels	68 m^3/s (2,400 cfs)

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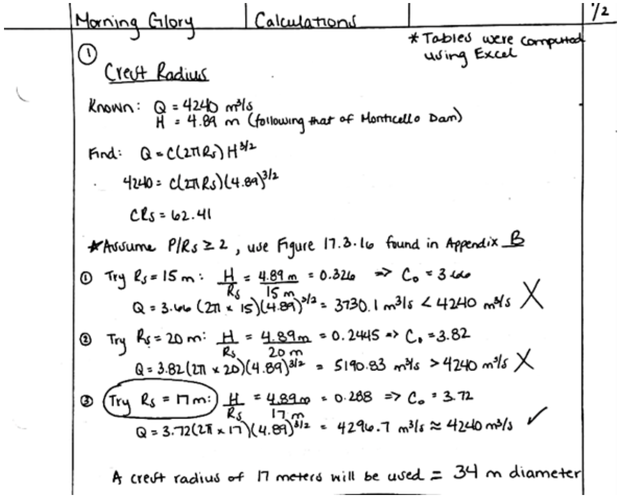
Design Parameters

$$Q = CLH_e^{3/2} \quad (1)$$

$$Q = C_0(2\pi R_s)H_0^{3/2} \quad (2)$$

$$Q = C_0\left(2\pi R^2\sqrt{2gH_a}\right) \quad (3)$$

Design Parameters of Morning Glory Spillway	Value
Maximum flowrate	4240 m3/s
Maximum surcharge head	4.89 m
Crest diameter	34 m
Drop shaft diameter	20 m
Tunnel diameter	11 m


Morning Glory | Calculations | 1/2

*Tables were computed using Excel

(1) Crest Radius

Known: $Q = 4240\ m^3/s$
$H = 4.89\ m$ (following that of Monticello Dam)

Find: $Q = C(2\pi R_s)H^{3/2}$

$4240 = C(2\pi R_s)(4.89)^{3/2}$

$CR_s = 62.41$

*Assume $P/R_s \geq 2$, use Figure 17.3.16 found in Appendix B

(1) Try $R_s = 15\ m$: $\frac{H}{R_s} = \frac{4.89\ m}{15\ m} = 0.326 \Rightarrow C_0 = 3.66$
$Q = 3.66(2\pi \times 15)(4.89)^{3/2} = 3730.1\ m^3/s < 4240\ m^3/s$ X

(2) Try $R_s = 20\ m$: $\frac{H}{R_s} = \frac{4.89\ m}{20\ m} = 0.2445 \Rightarrow C_0 = 3.82$
$Q = 3.82(2\pi \times 20)(4.89)^{3/2} = 5190.83\ m^3/s > 4240\ m^3/s$ X

(3) Try $R_s = 17\ m$: $\frac{H}{R_s} = \frac{4.89\ m}{17\ m} = 0.288 \Rightarrow C_0 = 3.72$
$Q = 3.72(2\pi \times 17)(4.89)^{3/2} = 4296.7\ m^3/s \approx 4240\ m^3/s$ ✓

A crest radius of 17 meters will be used = 34 m diameter

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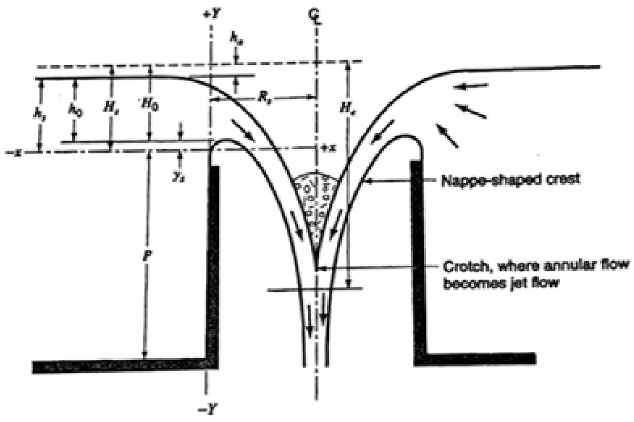
X/H_s	Y/H_s	$X = (X/H_s)*H_S$	$Y = (Y/H_s)*H_S$
0.000	0.000	0.000	0.000
0.010	0.032	0.053	0.170
0.020	0.064	0.106	0.340
0.030	0.096	0.159	0.511
0.040	0.128	0.212	0.681
0.050	0.160	0.266	0.851
0.060	0.192	0.319	1.021
0.070	0.224	0.372	1.191
0.080	0.256	0.425	1.362
0.090	0.288	0.478	1.532
0.100	0.321	0.531	1.702
0.110	0.353	0.584	1.872
0.120	0.385	0.637	2.042
0.130	0.417	0.690	2.213
0.140	0.449	0.743	2.383
0.150	0.481	0.797	2.553
0.160	0.513	0.850	2.723
0.170	0.545	0.903	2.893
0.180	0.577	0.956	3.063
0.190	0.609	1.009	3.234
0.200	0.641	1.062	3.404

Sample of X-Y coordinates of the crest profile above the weir crest



(a)

② Shape of Crest

Known: $\frac{P}{R_s} = 2$, $\frac{H_0}{R_s} = 0.288$

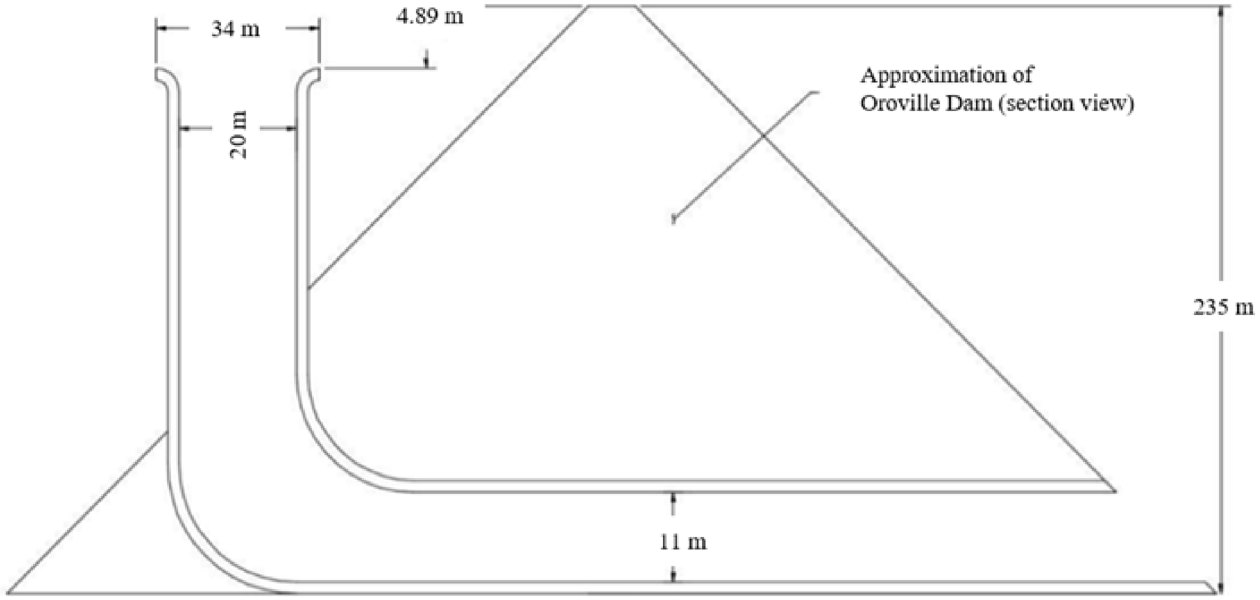
Using Figure 17.3.15b, $\frac{H_s}{H_0} = 1.0856$ => $H_s = 5.31$ m

From Figure 17.3.15a, $Y_s = H_s - H_0 = 5.31 - 4.89 = 0.42$ m

$\frac{H_s}{R_s} = \frac{5.31}{17} = 0.312$

X-Y coordinate of crest profile is computed in Table 3

Schematic Diagram of Morning Glory



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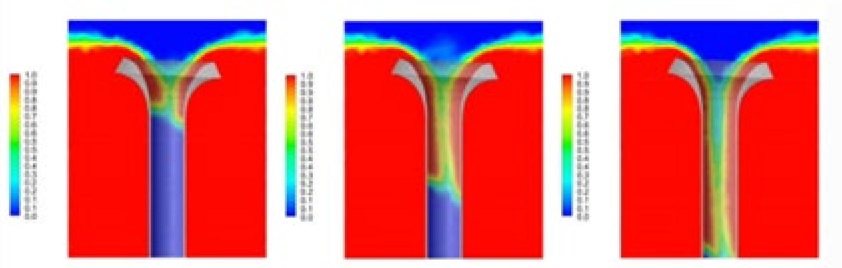
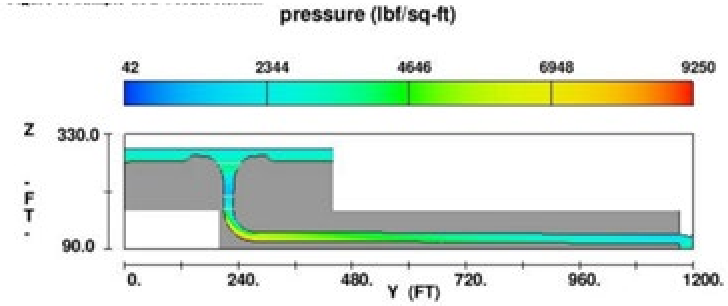
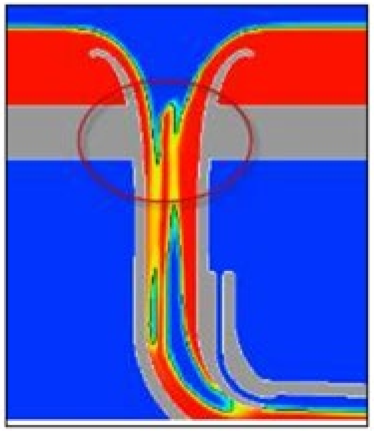
Discussion



Contours of water volume over time frames of 2 seconds, 6 seconds, and 10 seconds (Mirabi et. al., 2021)



Transition from weir flow to full pipe flow (Gomez et. al., 2017)



Interference of water and the crotch point (Razavi & Ahmadi, 2017)

Conclusion

- Oroville Dam experienced an almost catastrophic event in February 2017, resulting in an evacuation of over 180,000 residents.
- Warnings about this failure could've been detected if proper inspections were conducted in the years before the incident.
- The goal of this project was to propose an alternative spillway system from the existing and previously failed Oroville spillway system.
- The morning glory spillway was chosen because of its ability to discharge large volumes of water and its uncontrolled release ability.
- Ensuring that the system is safe, the construction of the spillway must be built on adequate rock foundation.
- Annual inspections must be performed when the morning glory spillway is not in use, usually in summer and fall seasons, to ensure good design operation and maintenance.

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