<u>Scale Model of Hydroelectric Gravity Dam</u>

E90 Proposal

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Abstract

We propose to design, analyze, and construct a scale model of a hydroelectric gravity dam, in order to investigate the precision, accuracy, and methods of small-scale models. The project will consist of a 6'-wide, 12" high solid concrete gravity dam, a water reservoir, a working spillway and turbine, all supported on a UNISTRUT® frame. Design work for the dam will include tests and evaluations of construction materials and computerized modeling of stress distributions, and strain measurements at various head levels. The turbine will be designed for low head applications, and tested for efficiency and power generation capability. The design phase of the project has already begun (as of November 2005), and the construction phase will begin in February 2005. A preliminary estimate for total costs for the model construction materials, support structure materials, analysis equipment, water management hardware, and turbine construction materials, is about $1000.

Introduction

Currently, the U.S. Army Corps of Engineers estimates that there are 50,000 small dams in the United States. However, according to the Federal Energy Commission, only 1,400 of these have been developed to produce power. The Public Service Administration predicts that development of current small dams into hydroelectric dams could produce 159.3 billion kWh of power per year, 84.7 billion of which would be at dams producing less than 5000 kW. They also estimate that creating new hydro electric sites could produce up to 396.0 billion kWh of power per year. Even if only 10 percent of these small dams are developed, the United States could save the equivalent of 180 million barrels of oil every. Therefore, the development of small hydro electric sites has the potential to both reduce are dependence on foreign oil and to provide a cleaner source of renewable energy.

Modern dams serve a variety of purposes, including creation of reservoirs for water supply or irrigation, generation of hydroelectric power, flood control, industrial effluent containment, and creation of recreation areas. Multi-purpose dams must often fulfill many of these purposes. This project will focus on designing all aspects of a scale model dam, from basic structural parameters to construction methods. Emphasis will be placed on stability, economy, as well as effective power generation. Standard procedures will be followed for the materials selection and dam design process, and a Kaplan turbine will be designed and built specially for this dam.

The project has four main components: the concrete mix design (which is currently underway), the gravity dam design, the turbine and spillway design, and the structural design of the support frame for the entire system. The main body of this proposal addresses the technical issues and discussion related to these four components. A project schedule and critical path are also included.

Project Qualifications, Responsibilities, and Education Goals

Scott Birney has taken multiple structural and civil engineering courses at Swarthmore College and University of Canterbury, NZ as well as working at a structural engineering firm for three months. He will thus be primarily responsible for the structural design of the support frame and concrete forms as well as the organization and assembly of the hydroelectric system as a whole unit.

Steven Bhardwaj has taken multiple courses in geotechnical and material engineering and will be primarily responsible for the dam design. This will include testing concrete samples for various properties such as compressive strength and coefficient of friction on bedrock surface. Steven will also create an ANSYS model of the stress and strain in a cross-section of the dam of unit width, and perform strain analysis on the dam after construction.

Michael Cullinan is majoring in engineering with a focus in mechanical engineering and will be responsible for the design of the turbine and spillway. He will also be responsible for testing the turbine design to determine efficiency, both actual and theoretical.

All three members of the team will be responsible for the construction and analysis of the dam model as well as the formulation of the final report and presentation.

These tasks require the concerted application of mathematical, scientific, and engineering theory and principles to a series of engineering problems. Experiments are designed, and the data analyzed to create an integrated functioning system. The work environment is bounded by various realistic design constraints including work space, project time-span, available capital, available technology and expertise, and properties and limits of the materials in use. The team members must be able to communicate and coordinate with each other and with multiple faculty members to accomplish these tasks, and produce an effective working project.

Selection of Model Scale and Length/Height Proportion

Gravity dams are the most common type of design used in hydroelectric dams. They can span distances up to 1200 meters with a height of 170 meters. The model dam that will be designed will effectively model a small hydroelectric gravity dam approximately 15’ to 25’ high. In order to accomplish this within the spatial constraints of the available facilities, the length of the dam will be 6.5 feet long by one foot wide at the base (see Figure 1 and Appendix A).

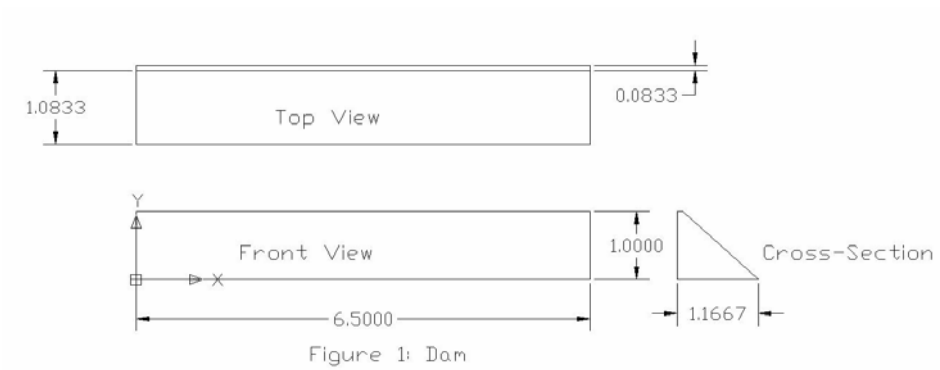


Figure 1: Schematic Drawings of Dam *Units: Feet*

Because strong rivers flowing through steep valleys are quite rare, most dams are much longer than they are tall. Most small gravity dams, and all dams in the Eastern PA area, have a length/height ratio greater than or equal to 6. Since a greater height provides more hydraulic head to the power generation turbine, the maximum height under this ratio was selected. Combined with space constraints on dam length, a height of ~1’ for the dam was chosen.

Design decisions and information in this section is principally from Sources 3, 8, and 9.

Mix Design

Preliminary work is being performed by Steven Bhardwaj and Michael Cullinan as part of their Fall 2005 E082 final project to begin selection of the most appropriate material for the scale model dam. The material should accurately model the behavior of a full-scale dam, and also allow inclusion of a significant factor of safety. Properties of interest include compressive modulus of elasticity, compressive ultimate strength, and the interaction between concrete and reinforcement.

Type III, or high-early cement was selected as the design material because that would allow faster-cycled and more extensive tests. It is chemically and physically the same as Type I, but it is ground finer to allow faster curing.

The test procedure uses a series of batches of concrete, upon which are performed slump tests, as well as compression tests and pullout tests after curing. The concrete mixes consist of varying proportions of cement, selectively graded sand and sandy fines, and water. A standard amount of super-plasticizer (GLENIUM 3030 NS) is added to all mixes, of 10% by weight of the water added. GLENIUM is a polycarboxylate admixture that provides a reduced water content for a given slump.

The water to cement (w/c) weight proportion, grading of aggregate (sand), and curing time (7 to 14 days) are being explored in preliminary tests. These properties may be explored further during the spring semester, and vibration techniques will be tested to attempt to reach the lower w/c ratios, higher densities, and resulting higher strengths associated with roller-compacted concrete.

An aggregate to cement volume ratio of .4 were taken from Sabnis and Harris' work on scale modeling on concrete (Source 2). Admixtures used by Mirza quoted in Sabnis and Harris' work include a zero percentage of non-cementatious fines and mostly mid-grade sand. This mixture allows a very low w/c mixture to retain significant workability. However it is yet to be seen whether the resulting decrease in water content will translate into greater strength.

To understand the effect of roller compaction on the concrete, relationships between the concrete's density and its strength and stiffness will be derived from preliminary as well as subsequent tests on cylinders. A tension reinforcement material will also be selected based on critical pullout length, ultimate strength, and elastic modulus of the reinforcement.

The combination of materials that allows the most efficient and effective dam design, with a focus on modeling the strains of full-scale dams, will be selected. RCC in dams in the United States constructed in the 1980s and 90s have 7-day strengths ranging from 300 psi to 2000 psi, and 1-year strengths from 1250 psi to 7300 psi.

Literature reviewed in this section principally draws from sources 1, 2, and 5.

Design for Sliding Stability

The dam must be designed to resist slip in the horizontal direction. Forces of cohesion and friction between the dam base and bedrock resist the horizontal water pressure load from the upstream dam face, combining to make a coefficient of static friction. A material will be chosen to model the bedrock based on this interfacial quality.

Tests will be performed to find the shear resistance parameters between concrete and a series of candidate bedrock surfaces. Samples of the concrete mix will be cured onto samples of model bedrock, tested in shear, and (shear stress)/(strain) relationships will be derived. Potential bedrock surfaces could include slate, concrete, or other materials. Research on this design criteria is drawn principally from Source 2.

Design and Measurement of Internal Stresses in Dam Cross-Section

Compressive, tensile, and shear stresses within the concrete and reinforcement must also be accounted for when designing the dam. An ANSYS model for the dam cross-section will be programmed based on measured data in the design concrete mix. This will allow prediction of stresses at different locations within the cross-section.

Strains will be monitored on the dam after construction. Results of the ANSYS modeling will determine the magnitude of the expected strains, and these values will be used to determine the appropriate type of strain gage necessary. Electrical strain gages are cheaper and simpler to install and monitor, but are limited to analysis of the dam surface. Past experimentation with electrical strain gages by the student on an aluminum surface allowed measurement of up to +/- 1 microstrain, although deviation from theoretical value was +/- 10 microstrain (1% error for the test).

Fiber optic strain gages are rated at +/- .5 microstrain, which is not significantly different from the electrical gages. However, the potential for embedding fiber optic sensors in the concrete may be an interesting aspect to be investigated. Preliminary discussions with Professor Lynne Molter showed that the Swarthmore Optics lab has the required equipment for signal analysis of the fiber optic sensors. If feasible, it would be possible to observe internal stresses within the dam and correlate these values with the ANSYS model. Unfortunately, the fiber optics are quite expensive. Necessity of using these sensors will depend on preliminary results from ANSYS modeling.

Preliminary Dam Design Calculations

A series of preliminary calculations were performed using Matlab to inform preliminary design decisions. These decisions allow design to continue in parallel on the table support structure and on the turbine. Two calculations were performed to roughly describe the properties of a dam with the given dimensions. Results of this calculation procedure will act as design constraints, describing the stability of the dam when more parameters are available. See Appendix 1 for the results of the calculations, and Appendix 2 for the Matlab code used. The results were:

1. *Necessary Frictional Coefficient to Resist Slip*
2. *Intersection of Resultant of Forces with the Dam Base*

The resultant of forces on sections of the dam, from the top of the dam down to different elevations, was calculated. These resultant net forces and shown to intersect with the center third of the dam base. This design criteria protects the dam against shear failure on planes within the dam, as well as toppling failure.

The necessary frictional coefficient to resist slip was also calculated. The coefficient of friction for a concrete-rock interface depends on both adhesion and physical friction. Values quoted in the literature range from 1.2 to 1.6, showing a large safety factor allowed for the preliminary design. But, experiments must be performed on the materials to be used to ensure safety and design appropriateness.

Other important results of these calculations include total weight of the dam, estimated weight of water in a triangular reservoir, and the effect of uplift pressure. The weight of the dam and the water allows calculation of the table structure. Results of these calculations are shown on the attached spreadsheet. Dimensions of this preliminary dam design are described in the Matlab code, and in schematic drawings on page 5.

The design procedures in this section were drawn from source 3.

Structural Design

An important portion of the project is the design and construction of a structure to support the dam, reservoir, and turbine unit. Due to the large size and weight of the total model, this structure requires specific analysis and design in order to guarantee satisfactory performance and safety during the entirety of the project. The total weight of the dam and water reservoir is estimated to be 11.5 kips.

The structure will be an open box frame (see Figure 1) constructed using UNISTRUT members and connections. The primary element of the frame is the uppermost level (the bottom line of the shaded area in Figure 1a), which will serve as the platform for the dam model. This level will consist of a sheet of 3/4-in. plywood covered with a rubber membrane bolted to four UNISTRUT members running along all four edges of the plywood. These four channels, or channel box, will be modeled as simply supported beams under various distributed loads from the weight of the water and concrete dam. There will be another additional channel at the midpoint of the longer span to add stiffness to the frame and allow attachment of a column-leg. Five column members will function as legs to elevate the table to a height of 3.5 feet using various fittings available from UNISTRUT to attach to the channel box, one at each corner and one at the aforementioned center of the channel box. These column members will be modeled as simple pinned-pinned columns with an axial load applied. A small plate can be attached to provide additional stability at the base of the column legs, if needed.

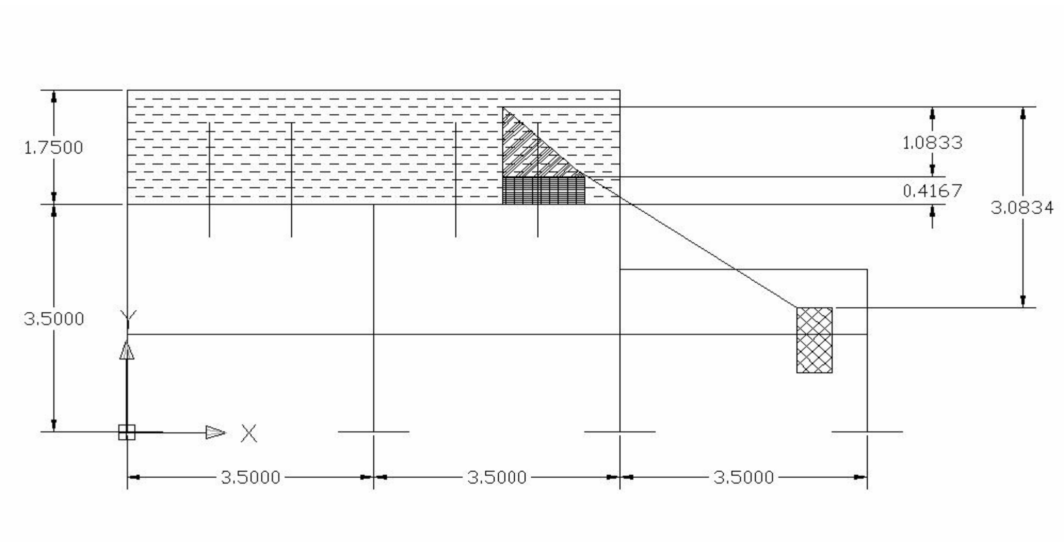


Figure 2a: Side view of structure *Units: Feet*

If necessary, additional bracing will be added to the legs to provide the required stiffness to achieve stability and safety (shown in Figure 1a as horizontal bracing). A similar but smaller structure will be designed to support the turbine unit (see Figure 1) at approximately 3 feet below the water level in the dam in order to acquire the needed pressure head.

In order to contain the reservoir, a retaining wall must be designed to extend above the platform level by 1.5 feet. The wall will be comprised of a 3/4-in plywood sheet covered in rubber membrane and supported by cantilevered channels bolted to the primary channel box at regular intervals around the perimeter of the wall (see Figure 1a).

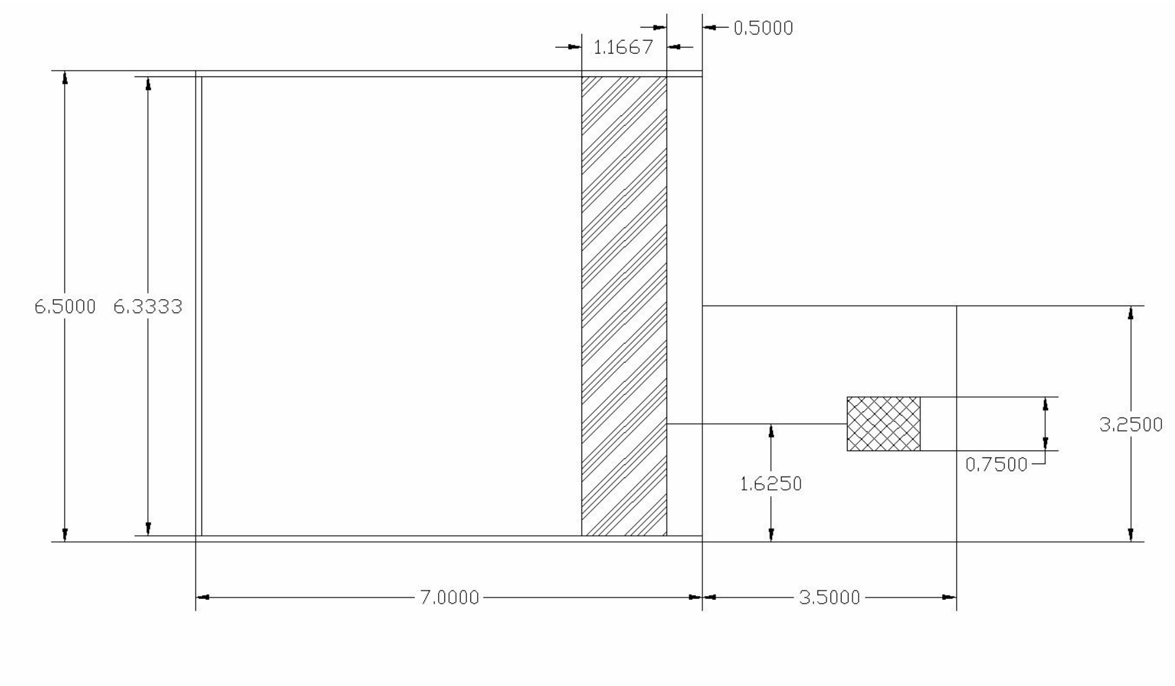


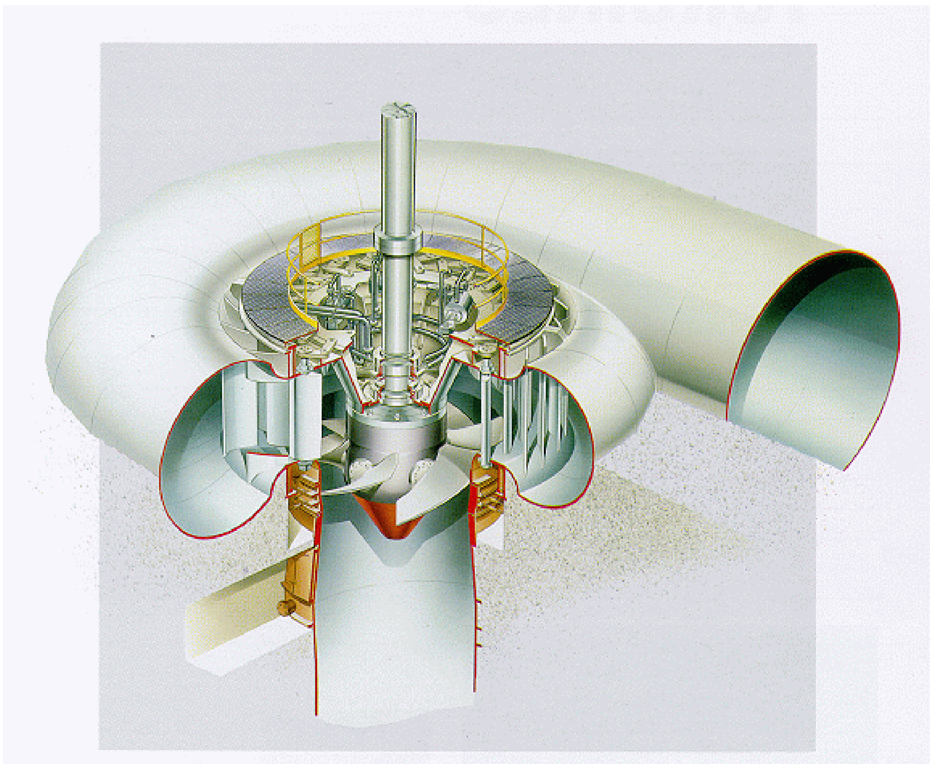
Figure 2b: Top view of structure *Units: Feet*

In order to analyze the structural behavior of the frame, an ANSYS model of the structure will be run based on dead loads calculated from the concrete, water, and material weights. A more intricate model could be run including live loads calculated from water flows.

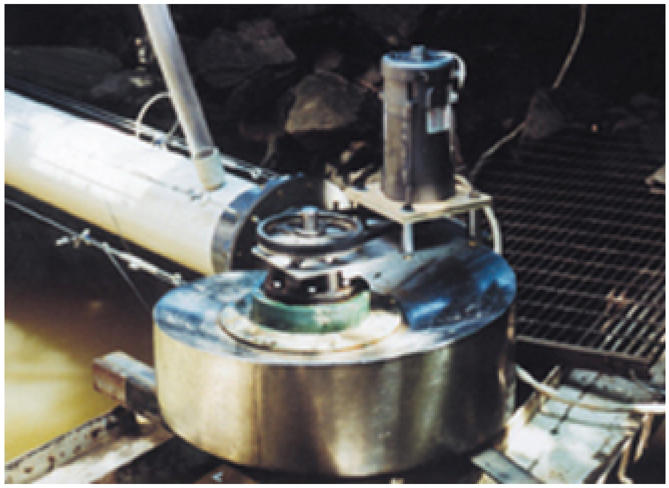
Turbine Design Decisions

The turbine for this project will be a small Kaplan turbine with an inlet about 4 inches in diameter. The Kaplan turbine is an inward flow reaction turbine. Overall, the turbine will be surrounded by a spiral casing that is used to direct the water flow tangentially and to maintain the water velocity even as the flow rate is reduced due to some of the water getting redirected onto the turbine blades. Guide veins will be constructed and placed inside the spiral casing in order to redirect the water flow from the casing through the wick gate and onto the turbine blades at the appropriate angle. The water will then spiral onto the propeller shaped runner causing the turbine to spin. The water will then flow out of the turbine through a draft tube.

Schematic of Kaplan Turbine

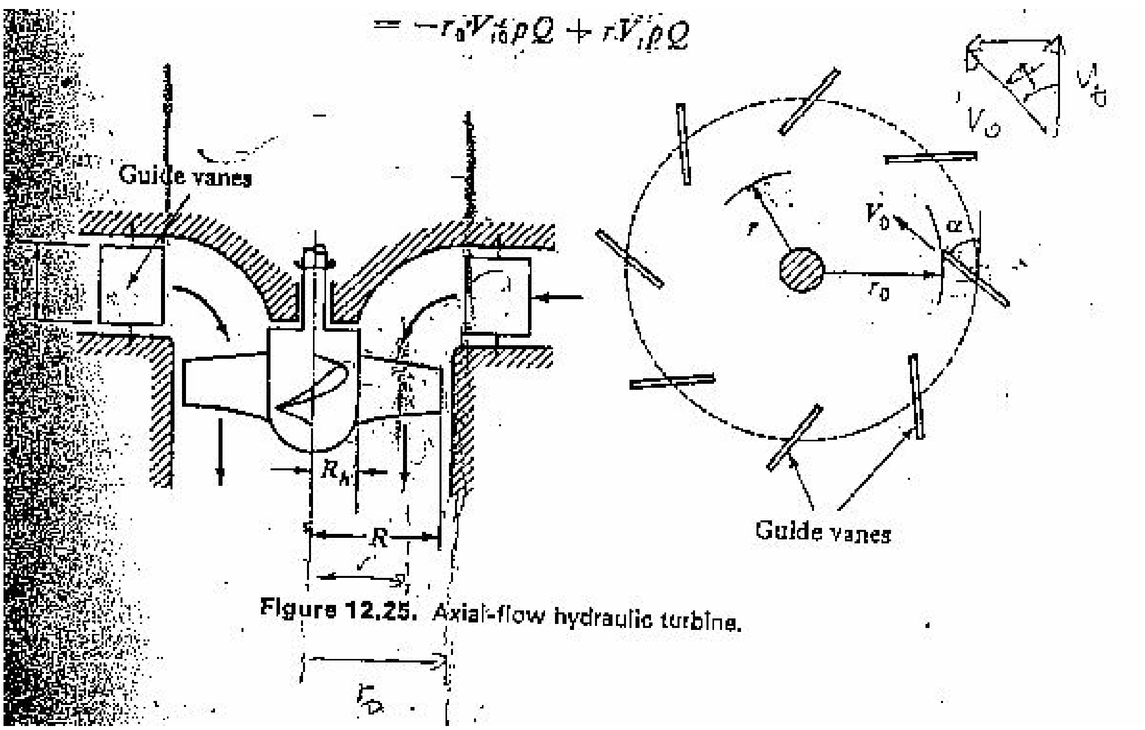


Source: http://www.tfd.chalmers.se/~hani/phdproject/kaplanfoto.gif



Source: http://www.waterturbine.com/index.html

Schematic of Inside of Turbine



As the water moves through the turbine, it gives up its pressure and converts its energy into the rotation of the turbine. This rotation then turns a generator shaft, which is attached to a rotor. Overall, the generator will consist of a rotor, a stator, and the rotating generator shaft. The rotor consists of a couple of magnates attached to the generator shaft designed to produce an electric field. A stator, which will be a coil of copper wire, surrounds the rotor and remains stationary. As the rotor rotates, changes in the magnetic field induce a current in the stator. This action, therefore, generates power.

A Kaplan turbine will be used because it is capable of producing power at very low heads (as low as 2 feet). This is important because the dam is a scale model and, therefore, will not have a very large head. Water will be taken from the reservoir at the base of the dam and will flow through a penstock to the turbine. The overall, head including the height of the water in the dam and the change in height of the penstock will be about three feet. The other option would be to use a Francis turbine because it can also be used in low head application. However, the Francis turbine is a slightly more complicated design and would probably be harder to construct.

Research in this section is based on source 10.

Turbine Design and Construction Plan

Overall, the major constraint on the turbine is the amount of head that is available to produce power. In order to produce an accurate model of a real dam, the ratio of the height to the length of the dam must be about 1 to 6. Therefore, in the amount of space we have available, it is not possible to construct a dam with a height greater than about a foot. Therefore, in order to increase the amount of head, the turbine will be placed about 2 feet below the level of the dam. A penstock going through the dam will connect the turbine to water reservoir.

A major component of this project will be the construction of the actual turbine. First, the blades will have to be designed and constructed which will not be a trivial task. The next step will be to construct the spiral outer casing of the turbine and to add the wick gate. A draft tube will also have to be added to the casing in order for the water to flow out of the turbine. The next major design component will be to add the generator so that electrical power can be produced. Finally, all of the components must be put together and tested.

Preliminary Turbine Calculations

I first calculated the flow through the turbine using Bernoulli's equation with losses. I assumed a 4 inch diameter pipe and that was 4 feet long and was smooth. I also include entrance losses as well as the losses in the two 45 degree angles. Overall, I found that the velocity of the water entering the turbine would be about 8.33 feet per second and the volume flow rate would be about 0.7269 ft^3/s. I then used this velocity to determine the angles of the blades necessary to produce a rotor speed of 30 radians per second or about 286.5 rpm. I made each of the guide veins 3 inches long and placed down stream veins increasingly closer to the spiral casing in order to maintain the same flow velocity even as the volume flow is decreased due to some of the water flowing through the turbine. The guide veins will be place at a 30 degree angle in order to redirect the flow tangentially on the to turbine blades. Also, I plan to make the casing of the turbine about 2 feet wide and the rotor shaft 2 inches wide. Therefore, each of the turbine blades will be about 6.5 inches long. From these parameters, I calculated that the angle of the turbine blades at the hub would have to be about 2.629 radians or about 150 degrees. At the tip, the turbine blade angle would have to be about 0.406 radians or 23.3 degrees (See Appendix 3 for more details). I have talked to professor Orthlieb about obtaining turbine blades, and he feels that I will be able to find some that will work in my turbine.

Turbine Testing

Testing will consist of measuring the electrical power output of the generator using a multimeter. The power will be found at different heads and flow rates in order to determine the most efficient configuration. The power output will also be compared to the theoretical maximum power output in order to determine the efficiency of the turbine. Finally, the turbine will be connected to the dam and measurements will be taken of the power produced by the hydroelectric dam. These results will then be compared to the maximum turbine efficiency from testing and to the theoretical maximum power output of the dam.

Spillway

The spillway will be a simple steel gate that can be manually removed from the dam in order to model an emergency situation where the water level needs to be drastically reduced and the turbine flow is not adequate. This situation happens very frequently with most dams, most notably in flood conditions. In order to avoid overtopping the dam, the level of water must be drastically reduced. However, allowing too much water to exit the dam at once can cause problems with the dam as well. Therefore, care must be taken when lowering the water level, and appropriate methods should be investigated. The spillway opening will be cast into the concrete dam with a width of 6-10 inches.

Sources

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3. United States Bureau of Reclamation. Design of Small Dams. United States Government Printing Office. Denver, 1987.

4. Hassoun, M. Nadim and Al-Manaseer, Akthem. Structural Concrete: Theory and Design. John Wiley and Sons, Inc. Hoboken, 2005.

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6. Merzbacher, C. I.; Kersey, A. D.; Friebele, E. J. "Fiber optic sensors in concrete structures: a review." Smart Materials and Structures Vol 5, (1996) p196-208. http://ej.iop.org/links/q80/GphEoEY545WZa1es0tH9nA/sm6208.pdf

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8. Pennsylvania Fish and Boat Commission. "Pensylvania Run of the River Dams." http://sites.state.pa.us/PA_Exec/Fish_Boat/rrdam.htm

9. US Army Corps of Engineers. "Gravity Dam Design." EM 1110-2-2200. 30 June 1995.

10. Lyon-Allen, Mary. “Developing a Small Hydroelectric Dam Potential.” Community Service Administration. Washington D.C.: 1979.

Project Costs Estimate

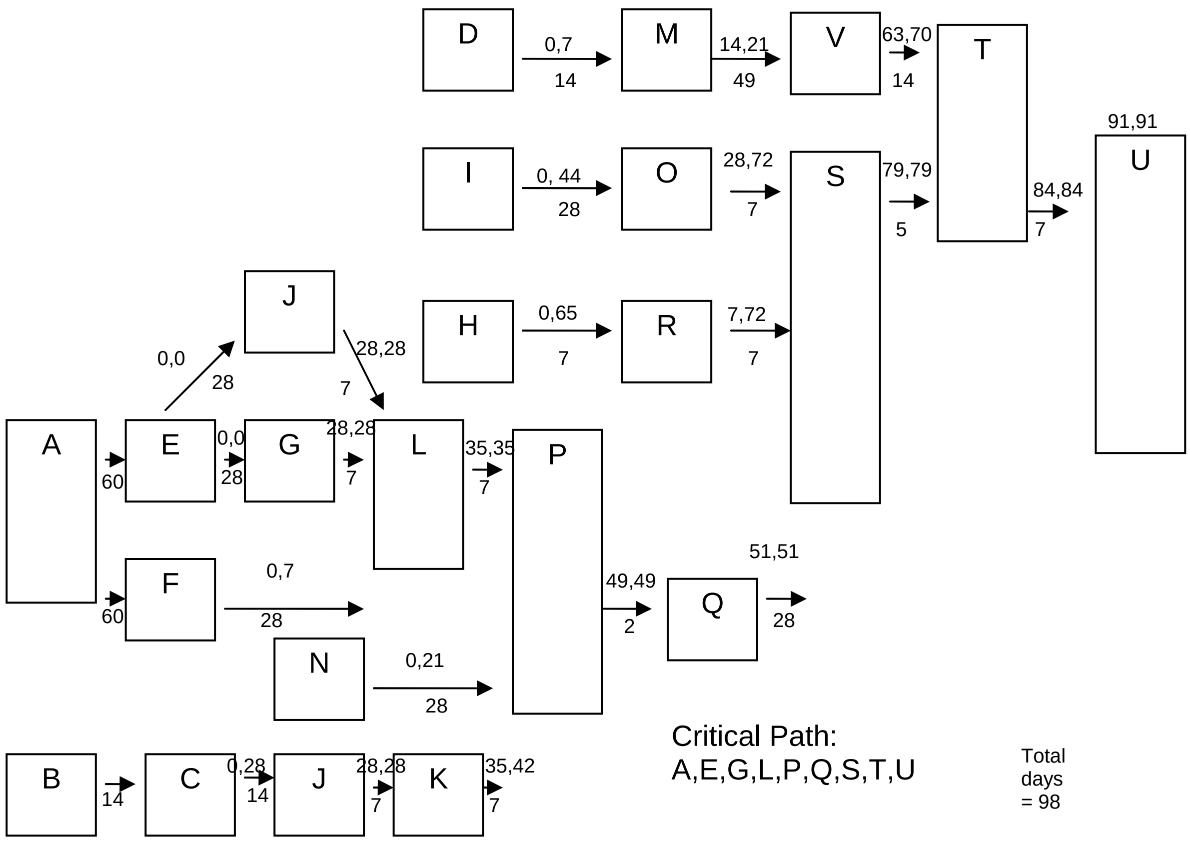
Category	*Item*	*Unit Cost*	*Unit*	*Amt Needed*	
Dam Construction Materials	High-Early Portland Cement Mix	$20.0	80 lbs	2	$40.0
	Sand	$2.0	80 lbs	8	$16.0
	Model Bedrock Material	$20.0	80 lbs	1	$20.0
	Awl Thread for Reinforcement	$10.0	6 ft	2	$20.0
Support Materials	Unistrut®	-	-	-	$250.0
	Plywood for Reservoir Support	$26.3	4x8x3/4	4	$105.3
	Wood for forms	$2.3	8 ft 2x4	12	$28.0
	Steel for forms	-	-	-	
Analysis Materials	Concrete Test Specimen Molds	$2.0	1	20	$40.0
	Strain Gages	$15.0	1	10	$150.0
	Fiber Optic?	$100.0	1	2	$200.0
Water Management	Rubber Membrane	$3.0	5'x1'x1/4"	20	$60.0
	Water Pump	$50.0	1	1	$50.0
Turbine					$250.0

Total	$1,229.3
w/o Fiber Optics	$1,029.3

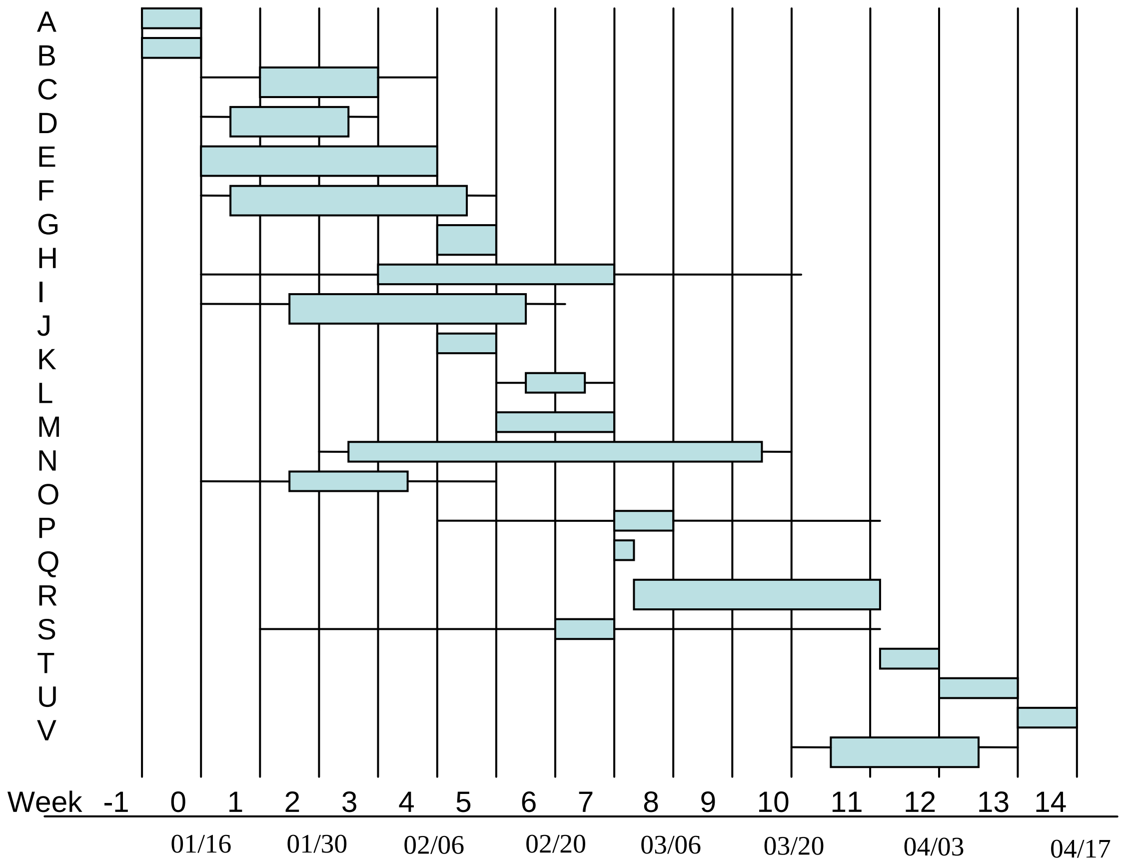
Needs and Feeds Chart

Activity	Needs	Feeds	Duration	Effort	Action
A		E,F	60	70	Find Appropriate Concrete Mix and Reinforcement Wire (Also Part of E82 Project)
B		C	14	15	Determine Appropriate Size and Modeling for Dam
C	B	J	14	50	Design Table
D		M	14	50	Design Turbine
E	A	G,J	28	80	Design Dam
F	A	L	28	20	Design Dam Reinforcement
G	E	L	7	10	Design Forms
H		R	28	5	Design Pumping System
I		O	28	30	Design Spillway
J	C,E	K,L	7	5	Order Materials
K	J	P	7	50	Assemble Table
L	F,G,J	P	14	40	Construct Forms and Reinforcement
M	D	V	49	100	Machine Turbine
N		P	28	50	Design and Installation of Measurement Devices
O	I	S	7	40	Build Spillway
P	L,N,K	Q	2	50	Mix and Pour Concrete
Q	P	S	28	0	Curing
R	H	S	7	30	Build Pumping System
V	M	T	14	40	Test Turbine
S	R,O,Q	T	5	10	Test Spillway
T	V,S	U	7	40	Analyze Data
U	T		7	30	Write Report

Critical Path Diagram

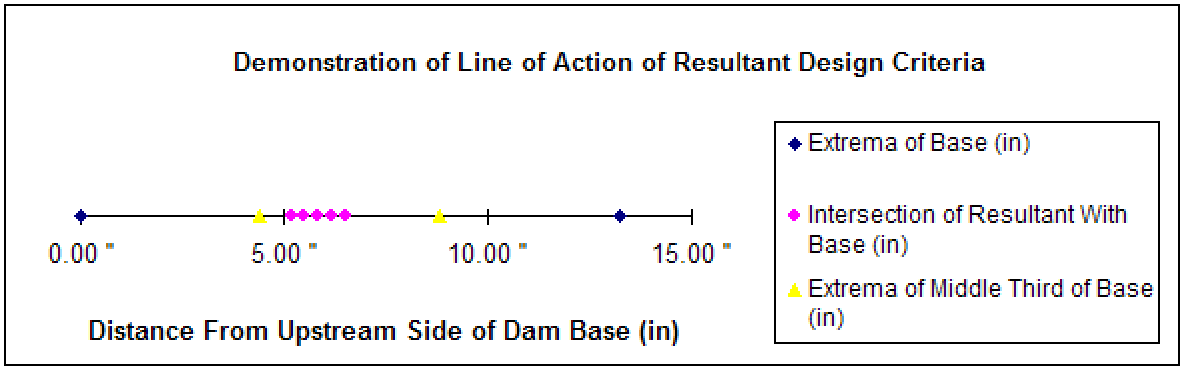


Modified Gantt Chart



(Week 1 begins on Monday, January 16.)

Results of Preliminary Dam Stress Calculations



Elevation Of Base of Partial Section (in)	1.97	3.94	5.91	7.87	9.84
Intersection of Resultant With Base (in)	5.18	5.49	5.83	6.17	6.52

Extrema of Base (in)	0.00	13.21
Extrema of Middle Third of Base (in)	4.40	8.81

(Distances measured from upstream face of dam)

Preliminary Design Statistics

Vtotal =	157.43	Horizontal Force from Upstream Water: (lbs)
Wc =	1368.20	Normal Force Reacting Against Weight of Concrete Dam Structure (lbs)
Uplift =	200.00	Total Uplift Force on Base (linearly decreases Upstream to Downstream) (lbs)
FSoverturn =	2.26	Factor of Safety against overturn failure: (-Mo)/(Mp)
FSoverturnUplift =	1.25	Factor of Safety against overturn failure, acct. for uplift: (-Mo)/(Mp+Mu)
Kstatfric =	0.28	Necessary Friction Coefficient to Resist Shearing Failure at Base (not acct'd for U)
KstatfricU =	0.43	Necessary Friction Coefficient to Resist Shearing Failure at Base (acct for U)
WeightDam =	562.5	(lbs)
MassWater =	157.43	(lbs) (broad estimate - assuming .4m long reservoir to account for future refinements)

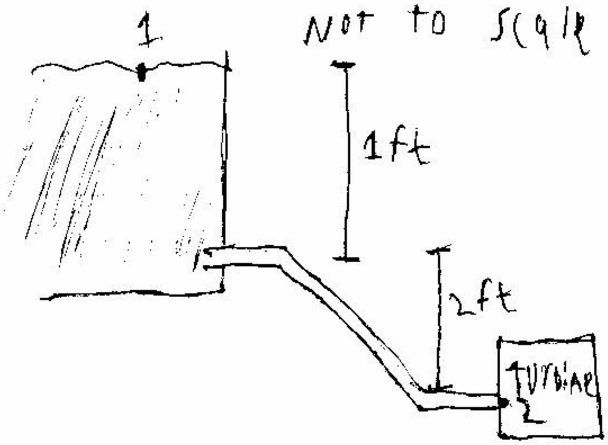
Matlab Code for Preliminary Dam Stress Calculations

```
clear;
Tc = 1 ; %in
hc = 12 ; %in
hw = 11 ; %in
T = 14 ; %in
L = 6*12 ; %in
B = 7*12 ; %in (design length of reservoir)
gammaC = 150 ; %lbf/ft^3
sigCrCmp = 3000 ; %lb/in^2
Estat = 5000000 ; %lb/in^2
Edyn = 6000000 ; %lb/in^2
Esust = 3000000 ; %lb/in^2

Tc = Tc*.0254 ; %m
hc = hc*.0254 ; %m
hw = hw*.0254 ; %m
T = T*.0254 ; %m
L = L*.0254 ; %m
gammaC = gammaC*4.44822162/.3048^3 ; %N/m^3
sigCrCmp = sigCrCmp*4.44822162/0.0254^2 ; %Pa
sigCrTensStat = sigCrCmp*.05 ; %Pa
sigCrTensDyn =  sigCrCmp*.1 ; %Pa
tauCrStat =  sigCrCmp*.1 ; %Pa
Estat = Estat*4.44822162/0.0254^2 ; %Pa
Edyn = Edyn*4.44822162/0.0254^2 ; %Pa
Esust = Esust*4.44822162/0.0254^2 ; %Pa

gammaW = 9.81*1000 ; %N/m^3
g = 9.81 ; %m/s^2
nu = .2 ; %poisson's ratio

%properties for unit section 1 meter thick of dam
V = hw/2 * gammaW * hw;  %Horizontal Force from Upstream Water: N/m
Mp = -V * hw/3;  % Moment of V around COG of dam base (ccw +): N/m/m
Wc = (hc*T - .5*hc*(T - Tc)) * gammaC;  % Normal Force vs Wt of
Concrete
Mo = 0 + (T-Tc)*.5*hc*gammaC * (T*.5 - .333*(T-Tc));  %Mmnt of W COG
base
U = T*.5*hw*gammaW;  % Total Uplift Force on Base (linearly decreases)
Mu = -U * T/6;  % Moment of Uplift About COG of base
%Mo=(moment of big rect around COG of base) + (negative moment of
triangle)

FSoverturn = (-Mo)/(Mp);  %
FSoverturnUplift = (-Mo)/(Mp+Mu);

%Necessary Friction Coefficient - Estimate of Shear on Dam Base
sigPrime = (Wc-U)/T;  %Avg Eff. Stress Under DamBase (acct. for U) (Pa)
KstatfricU = V/(Wc-U); %min coeff of static fric (w/U):  Ffric = Fn * k
Kstatfric = V/(Wc); %min coeff of static fric (w/o U)

%Calculation of Weight of Dam
WeightDam = L*Wc; %Total Weight of Dam (N)
```

```
WeightWater = gammaW*B*hw*L; %Estimate of Total Weight of Water
MassDam = WeightDam/9.81; %(kg)
MassWater = WeightWater/9.81; % (kg)

%Calculation of Resultant
m = -hc/(T-Tc) ; %slope of dam face
count = 1;
hi(count) = count/20;
a = Tc;
while hi(count) < hc
    b = a + hi(count)*(-m);
    cx(count) = (a^2 + a*b + b^2)/(3*a + 3*b);
    cy(count) = hi(count)*(2*a + b)/(3*a + 3*b);
    hci(count) = hi(count) - cy(count);
    Vi(count) = hi(count)/2 * gammaW * hi(count);
    Wi(count) = (hi(count)*b - .5*hi(count)*(b - a)) * gammaC;

    count = count + 1;
    hi(count) = count/20;
end

mi = -Wi/Vi;
ResultantOnBase = cx + (hc - cy)/-mi;
T/3;
2*T/3;

%Convert out of metric
WeightDam = WeightDam/4.44822162 ; %lbf
WeightWater = WeightWater/4.44822162 ; %lbf
Uplift = U*L/4.448;
Vtotal = V*L/4.448;

%Take Outputs
WeightDam
WeightWater
Kstatfric
FSoverturn
Vtotal
```

Turbine Design Calculations

$$P + \tfrac{1}{2}\rho V_1^2 + \gamma Z_1 = P_2 + \tfrac{1}{2}\rho V_2^2 + \gamma Z_2 + \text{losses}$$



$$2 = \frac{V^2}{2g} + \left(f\frac{l}{D} + K_L\right)\frac{V^2}{2g}$$

$$K_L = .8 + .4 + .4 = 1.6$$

$\varepsilon = 0$ if pipe is plastic

$$Re = \frac{\rho V D}{\mu}$$

$$3 = \left(f\frac{4}{1/3} + 2.6\right)\frac{V^2}{2(32.2)}$$

Try $f = 0$

$$V = 8.62 \text{ ft/s}$$

$$Re = \frac{1.94 \cdot 8.62 \cdot 1/3}{2.34 \times 10^{-5}} = 2.38 \times 10^5$$

$$f = .0152$$

Try $f = .0152$

$$V = 8.33 \text{ ft/s}$$

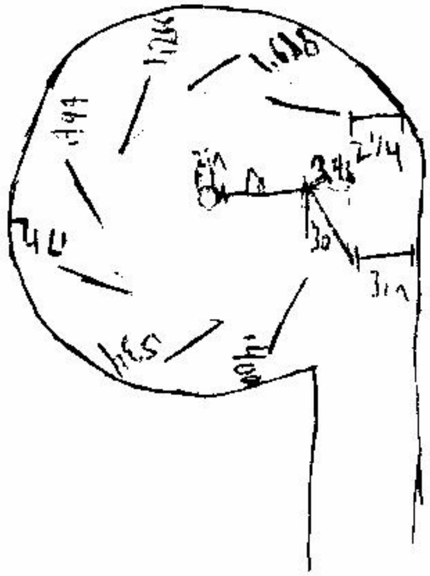
$$Re = \frac{1.94 \cdot 8.33 \cdot 1/3}{2.34 \times 10^{-5}} = 2.38 \times 10^5$$

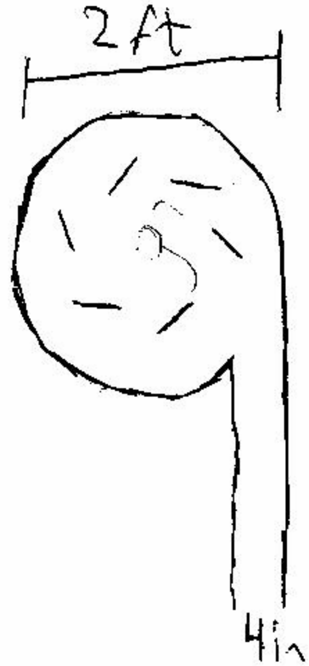
$$f = .0152$$

$$V = 8.33 \text{ ft/s}$$

$$Q = \frac{\pi}{4}(1/3)^2 V = 0.7269 \text{ ft}^3/\text{s}$$

Guite vains are 3 inches long





Blades are 6.5 inches long

$R_H = 2 \quad R_T = 8.5 \quad r_0 = 8.644$

$\alpha = 30^\circ = \pi/6$ radians

In order to get rotor speed of 30 rad/s need;

$\beta_h = 2.629$ rad $= 150.63^\circ$

$\beta_t = .406$ rad $= 23.26^\circ$