A BRIEF STUDY OF ECONOMIC

PENSTOCK DESIGN

Supplimentary to course 800
Department of Civil Engineering

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AN ECONOMIC PENSTOCK FOR KR-3 SOUTHERN CALIFORNIA EDISON CO.

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In order to eliminate certain complications which at this time are inadvisable ~~to involve~~ the following assumptions and basis of study were used.

(1) The plant is to operate continously under a full load of 600 second feet brought in thru two penstocks.

(2) The value of power is taken as that value at the switchboard. This value is estimated as .8cents per kilowatt hour. This ~~value~~ is based on value given by Mr. Heywood of the Edison Co. and advise of Professor Sorenson. Expressed as the annual value of a horse-power ths is $654, assuming capitalization at 8% .

(3) The cost of pipe is 8cents per pound, rivets and overlaps being omitted.

The formula for the economic diameter of a penstock was the one derived by W.L.Butcher, in the Transactions of the A.S.C.E. Vol.LIX The formula is based upon the fundamental assumption that the cost of the pipe line plus the annual value of the power lost should be a minimum.

$$\text{Economic Dia.} = \sqrt[7]{\frac{.0492Q^3d}{ab - fb}}$$

a = head in feet on section under consideration
b = cost of pipe in dollars per pound
d = value of energy of one cu.ft.per sec. with head of one foot
f = total loss by friction in the above section
Q = quantity flowing in second feet.
10000 = tensile stress in steel in pounds per sq. in.
490 = weight of one cu. ft. in pounds.

This assumes a tensile stess allowable of 10,000#/in^2, or an efficiency of riveted joints $\frac{10}{16}$ =62.5%

In order that our diameter, as obtained by the formula, be comprable with the pipe thickness in which we thought it advisable to use 75% efficiency, which is in accordance with good practice, weworked Mr. Butcher's formula thru using 12000 instead of 10000 for the tensile stress. The only change, of course, being the constant. The new constant obtained is .0587

This formula gives a diameter such that the value of the energy lost in frictional resistance equals .4 the cost of the pipe, which according to the original assumption is the most economic diameter. No account is taken of the fact that steel plate is usually rolled to the nearest 1/16" or that a factor for corrosion must be added. The corrosion factor is constant and the change to the nearest 1/16" will not vary much. However in order to make the cost comparison equal 2/5 the exact diameter and exact thickness of pipe for that diameter and pressure must be used.

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The penstock was divided into four eqal parts such that the head first was 0-200 feet, the second 200-400 feet, etc. Diameters were calculated for these sections. For comparison a "cut-and-try" method was used on the first two sections. Curves were plotted with diameter of pipe as abscissa and the sum of the cost of the pipe plus the value of energy lost as ordinates. In calculating these actual thickness of pipe was used and a minimum of 1/32" was allowed for corrosion. The diameters as indicated by the curves check those obtained by the formla within a reasonable limit. The sudden jogs in the curves are caused by the abrupt changes in the thickness of the pipe.

DESIGN OF AN ECONOMIC PENSTOCK

For KR-3 Edison Plant. 800Ft. Head
Maximum 600 Sec. Ft.
Two Pipes

Tabulated results computed by formula based upon the criterion that the cost of the pipe plus the annual value of the energy lost must be a minmum

Section	Thickness of Shell in inches 75% Eff.	Cost of pipe Without corrosion factor	Cost of pipe with corrosion factor	Velocity in Ft/Sec.	Friction head c=100
	Diameter 9.4'=113"				
0-200	7/16	$ 9100	$9780	4.32	.159
	Diameter 8.5'=102"				
200-400	3/4	$ 14500	$ 15200	5.28	.262
	Diameter 8.03'=96"				
400-600	1-1/16	$19850	$ 20200	5.93	.335
	Diameter 7.7'=93"				
600-800	1-3/8	$25200	$ 25600	6.45	.410
Totals		$63560	$70780		1.166

Total value of the energy lost=

1.166×.1134×$654×300= $ 25500

25500 ÷ 63560= .400 Which agrees with the accepted condition.

Method of computing diameter;

$$\text{Dia.} = \sqrt[7]{\frac{.05870Q^3d}{ab - fb}}$$

a = The head in feet on section under consideration
b = The cost of the pipe in dollars per pound
d = The of the energy of one cu. ft. per sec. with a head of one foot
f = The total loss of friction in the above section
Q = The quantity flowing in secon feet
1200 = The tensile stress in the steel in pounds per sq. in.
This considers 75% efficiency at the joint.
490 = The weight of one cu.ft, of steel in pounds

Sample computation

$$\text{Dia.} = \sqrt[7]{\frac{.0587 \times 300^3 \times 654}{300 \times .08 - 1.2 \times .08}}$$

$$= 9.405 \text{ Ft.} = 113 \text{In.}$$

$$\text{Thickness} = \frac{113 \times 62.4 \times 300}{2 \times 16000 \times .75 \times 144} = .409 = 7/16 \text{ Inches}$$

$$\text{Velocity} = 300 \div \frac{9.4^2 \times 3.1416}{4} = 4.32 \text{ ft./sec.}$$

Friction head from table = .069/100ft.

Value of energy lost

$$.069 \times 3.31 \times .1134 \times 654 \times 300 = \$\ 3540$$

Cost of pipe line

$$\frac{113.44 \times 3.14 \times .438 \times 490 \times 231 \times .08}{144} = \$\ 9780$$

Solution by Cut and Try Method.

For comparison with results obtained by formula

Head-- 0-200 Feet

Dia. inches	Thickness Calc.	Actual	Cost of pipe	Vel.	Friction loss	Value of Energy lost	Cost of pipe + Vlue of energy lost
110	.375	.4375	$ 9560	4.55	.18	$ 4030	$ 13580
113	.409	.4375	9820	4.32	.159	3540	13360
114	.412	.4375	9900	4.23	.155	3430	12330
116	.419	.500	11500	4.09	.143	3190	14690
115	.416	.500	11400	4.17	.148	3300	14700

Head---200-400 Feet

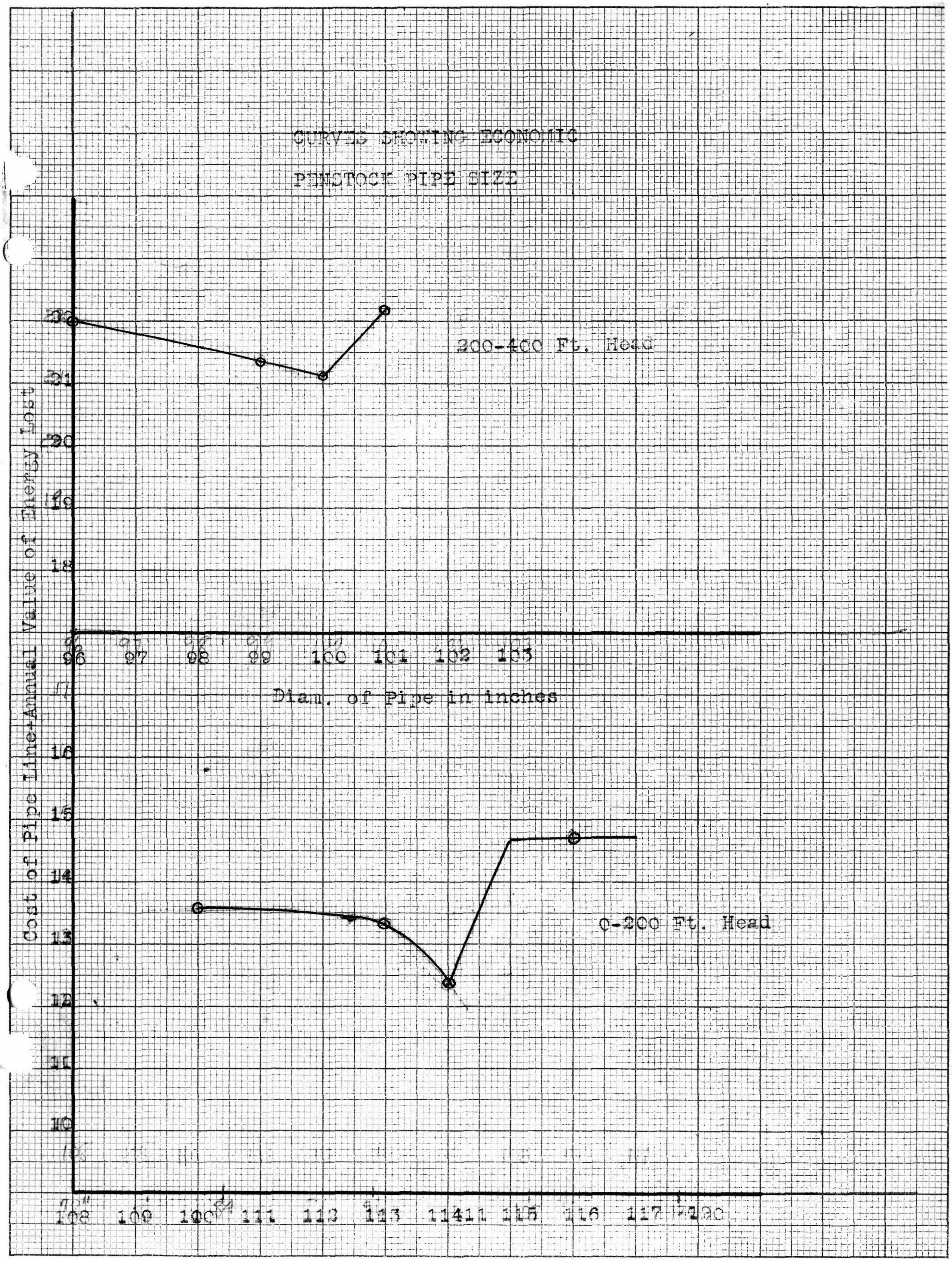
99	.717	.75	$14750	5.62	.296	$ 6600	$ 21350
101	.731	.813	16250	5.39	.271	6040	22290
96	.694	.75	14300	5.97	.345	7700	22000
100	.724	.75	14800	5.51	.284	6330	21130

The above data has been plotted in curve form and the minimum points compared with that obtained by formula.

Economic Diameters Compared

Section	By Formula	By "Cut and Try" Curve
0-200	113"	114"
200-400	102"	100"

Note: The 200 foot sections were arbitrarily chosen as representing an average for the conditions of the problem. In a more complete study the 800 foot head should be varining lengths of section and a comparison made.


CURVES SHOWING ECONOMIC
PENSTOCK PIPE SIZE
200-400 Ft. Head
0-200 Ft. Head
Cost of Pipe Line+Annual Value of Energy Lost
Diam. of Pipe in inches
22
21
20
19
18
16
15
14
13
12
11
10
96
97
98
99
100
101
102
103
108
109
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