Form DFC-11
(7-52)
Bureau of Reclamation

Memorandum

Denver, Colorado
October 28, 1957

Chief, Canals Branch

ACTING

Chief, Division of Engineering Laboratories

Evaluation of friction factors from field test data--Eklutna Tunnel--Alaska

On June 24, 1957, you transmitted to the laboratories a memorandum with attached field test data for the April 23, 1957 friction loss tests of Eklutna Tunnel. According to your request, the data have been analyzed. The method and results are discussed in the following paragraphs.

Data from the test were used to evaluate the Darcy-Weisbach resistance coefficient f in the equation $h_f = \frac{fL}{D}\frac{V^2}{2g}$ where h_f represents the head loss between the gate shaft and the surge tank. The head loss was obtained directly from charts of A-35 stage recorders installed in the shaft and tank. A 1-inch deflection of the recorder pen represented 1 foot of water level change in the gate shaft and 5 feet in the surge tank. Columns 2 and 3 of Table 1 contain the chart indicated water surface elevations and Column 4, the differences or head losses.

Discharges necessary to compute the average velocity in the tunnel were obtained from the equation $Q = 111.13D_1^{0.525}$. This empirical equation came from a preliminary curve of the Gibson calibration of the flow meter taps of Turbine Unit 2. D_1 is the measured mercury differential of the taps in inches, Table 1, Column 5, used to compute the discharge in Column 6. D_1 is tabulated separately for Turbine Units 1 and 2, but Q is the total discharge through both units. The Gibson calibration of Unit 2 taps was applied to the differential readings of Unit 1 taps to obtain discharges through Unit 1.

A nominal diameter of 9.0 feet and an area of 63.617 square feet were assumed in lieu of tunnel measurements for computing the velocities of Column 7. This diameter and the distance from Stations 27+25 to 255+30, center lines of gate shaft and surge tank, determined the number of pipe diameters, or the $\frac{L}{D}$ ratio of the head loss equation.

Column 8 contains the measured water temperatures necessary for establishing the kinematic viscosity.

Schuster 10/30
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Computed resistance coefficients range from 0.01710 to 0.01372, Table 2, Column 4. The Reynold's Number ranges from 709,000 to 4,640,000, respectively, Column 6. These results have been plotted in Figure 1. The coefficients decrease consistent with the generally accepted trend of the Moody diagram based on the Prandtl-Von Karman experiments, the Colebrook and White function, and experiments on commercial pipes. The value of the resistance coefficient is higher than might be expected for this diameter pipe. Rugosity of the surface of a pipe with this resistance coefficient would correspond to unusually rough classification, (rough wood formwork, erosion of poor concrete, poor alinementsat joints or combinations of these, see Engineering Monograph No. 7). Although the interior surface of the concrete lined portion of the tunnel was not inspected before the test, it would be hard to imagine that it was deteriorated to the extent indicated by the coefficient. There is no proof that the resistance coefficients are incorrect but there are the quantities of head loss, discharge and diameter, that bear inspection.

To do this, write the resistance equation in terms of the pipe diameter and discharge $h_f = f \frac{L}{D} \frac{V^2}{2g}$

$$f = \frac{h_f D 2g}{L V^2}, \text{ since } V = \frac{Q}{A}$$

$$f = \frac{hf\ D\ 2g}{\frac{L Q^2}{\left(\frac{\pi D^2}{4}\right)^2}} = \frac{2g \pi^2}{16} \frac{hf\ D^5}{L Q^2}$$

$$f = K \frac{hf\ D^5}{L Q^2}$$

The resistance coefficient thus varies directly as the head loss, to the fifth power of the diameter, and inversely as the discharge squared.

Head loss was measured as the difference in water surface elevations between the gate shaft and surge tank above an opening in the tunnel that may not have reflected the true pressure. Either of the measurements may have increased the apparent hydraulic gradient and thus h_f. This does not seem to be a possible major cause of error because of the relatively low velocities. At maximum velocity, the velocity head if it were fully recovered in the gate shaft or surge tank would be 2.9 percent of the head loss. At minimum velocity, this would reduce to approximately 2.3 percent.

Some evidence of a water surface measurement error was noted on the recorder chart of the gate shaft. Calculations indicate that a water surface decrease of approximately 0.041 feet should have occurred in Run 2 where instead a slight increase was recorded. This amount would have decreased the value of f by approximately 4 percent in Run 2, 1 percent in Run 3 and in progressively less percentages with increasing head loss for later runs. If the reading for each run, instead of containing a constant error, contained one which progressively increased with velocity; the head loss indication would remain high. This would result in an indicated high resistance coefficient.

A small error in the diameter of the tunnel would be reflected as a larger error in the resistance coefficient. Tolerance for concrete lining in Eklutna Tunnel was specified as a 1/2 of 1 percent variation from inside dimensions. Thus for example, if the diameter was an average of 8.95 feet (1/2 of 1 percent) instead of 9.0 feet, the resistance coefficient based on 9 feet would be reduced by the ratio $\frac{(8.95)^5}{(9.00)^5}$ or by approximately 2.75 percent. If the diameter was 1 percent less than 9.0 feet, the computed resistance coefficients would be reduced by approximately 5 percent. Since no field measurements were made at the time of the test, this is conjecture and the tunnel diameter may have been greater than the specified 9.0 feet or actually an average diameter of 9 feet as assumed.

The discharge curve for Unit 2 titled "Preliminary Calibration of Flow Index Piezometers," has an excellent grouping of data especially in the upper range of discharge. The extrapolation by a straight line to the low range of discharge is valid providing the change in deflection is caused by the change in discharge and not a flow curvature at the taps. The one point obtained near the minimum discharge of these tests seems an assurance of the extrapolation. According to information from the Hydraulic Machinery Branch, this preliminary curve is expected to be in agreement within less than 1 percent of the final curve.

A slight nonidentity of the turbine units might be reasoned from the data as evidenced by Table 2 and Figure 1. Data for Runs 2, 3, and 4 were obtained with only Unit 2 operating. When Unit 1 was added to increase the discharge, the computed resistance coefficient for Runs 5 and 6 seems slightly higher than might be expected from the trend of the first 3 coefficients. This increase is slight and well within the degree of test error although it occurs at a change in test conditions.

A review of test conditions and possible errors has failed to show a major reason why the resistance coefficient of Eklutna Tunnel cannot be accepted within 5 to 8 percent of a true value. This review indicates that determination of the condition of the tunnel surface and the average diameter of the tunnel is necessary to properly explain the apparent deviation. (Since the probability of obtaining actual measurements in the tunnel in the near future is very remote, a search of the inspection records should be made for assistance in resolving these questions.) Any major revision of the calibration curve of the flow index taps in the final report should be recognized and the resistance coefficients adjusted accordingly.

Returned with this memorandum are the field test data that you transmitted.

Enclosure

Table 1

1	2	3	4	5	6	7	8
Run No.	*Elev of WS at gate chamber	*Elev of WS at surge tank	Total head loss h_f - (ft of water)	Flowmeter taps D_1 - (in. Hg)	Flow rate**: Q - (cfs)	Velocity V - (ft/sec)	Temp of water (°C)
1	838.69	838.69	0.00	1. - 0 2. - 0	0.00	0.00	6
2	838.70	837.63	1.07	1. - 0 2. - 0.5375	80.22	1.261	6
3	838.47	834.36	4.11	1. - 0 2. - 2.156	166.34	2.615	6
4	838.38	829.99	8.39	1. - 0 2. - 4.194	235.89	3.708	6
5	838.23	822.93	15.30	1. - 4.182 2. - 0.516	314.04	4.936	5-1/2
6	837.70	814.14	23.56	1. - 3.902 2. - 2.076	390.46	6.138	6
7	837.39	806.18	31.21	1. - 3.860 2. - 4.140	460.15	7.233	6
8	837.01	800.32	36.69	1. - 3.916 2. - 6.506	524.60	8.246	6

*Obtained from original A-35 water stage recorder charts.
**Flow rate was computed by the equation:

$$Q = 111.13\, D_1^{0.525}$$

Correction for acceleration of gravity (g):

Latitude 60° N (Sea level) 32.215 ft/sec^2

Eklutna Tunnel Elevation Q = 1000 ft - 0.003 ft/sec^2

(g) = 32.212 ft/sec^2

Table 2

1 Run No.	2 Velocity head $\frac{V^2}{2g}$ (ft of H_2O)	3 h_f/V^2	4 Friction factor $f = \frac{h_f}{V^2}\frac{2gD}{L}$	5 Kinematic viscosity ν - $(\frac{ft^2}{sec})$	6 Reynold's No. $R = \frac{VD}{\nu}$	7 Manning "n"
1	0.00	0.00	0.00		0.00	0.00
2	0.0247	0.6729	0.01710	1.6×10^{-5}	7.09×10^5	0.0139
3	0.1061	0.6012	0.01528	1.6×10^{-5}	1.47×10^6	0.0131
4	0.2134	0.6102	0.01551	1.6×10^{-5}	2.09×10^6	0.0132
5	0.3781	0.6279	0.01596	1.62×10^{-5}	2.74×10^6	0.0134
6	0.5848	0.6254	0.01590	1.6×10^{-5}	3.45×10^6	0.0134
7	0.8121	0.5965	0.01517	1.6×10^{-5}	4.06×10^6	0.0131
8	1.0554	0.5396	0.01372	1.6×10^{-5}	4.64×10^6	0.0124

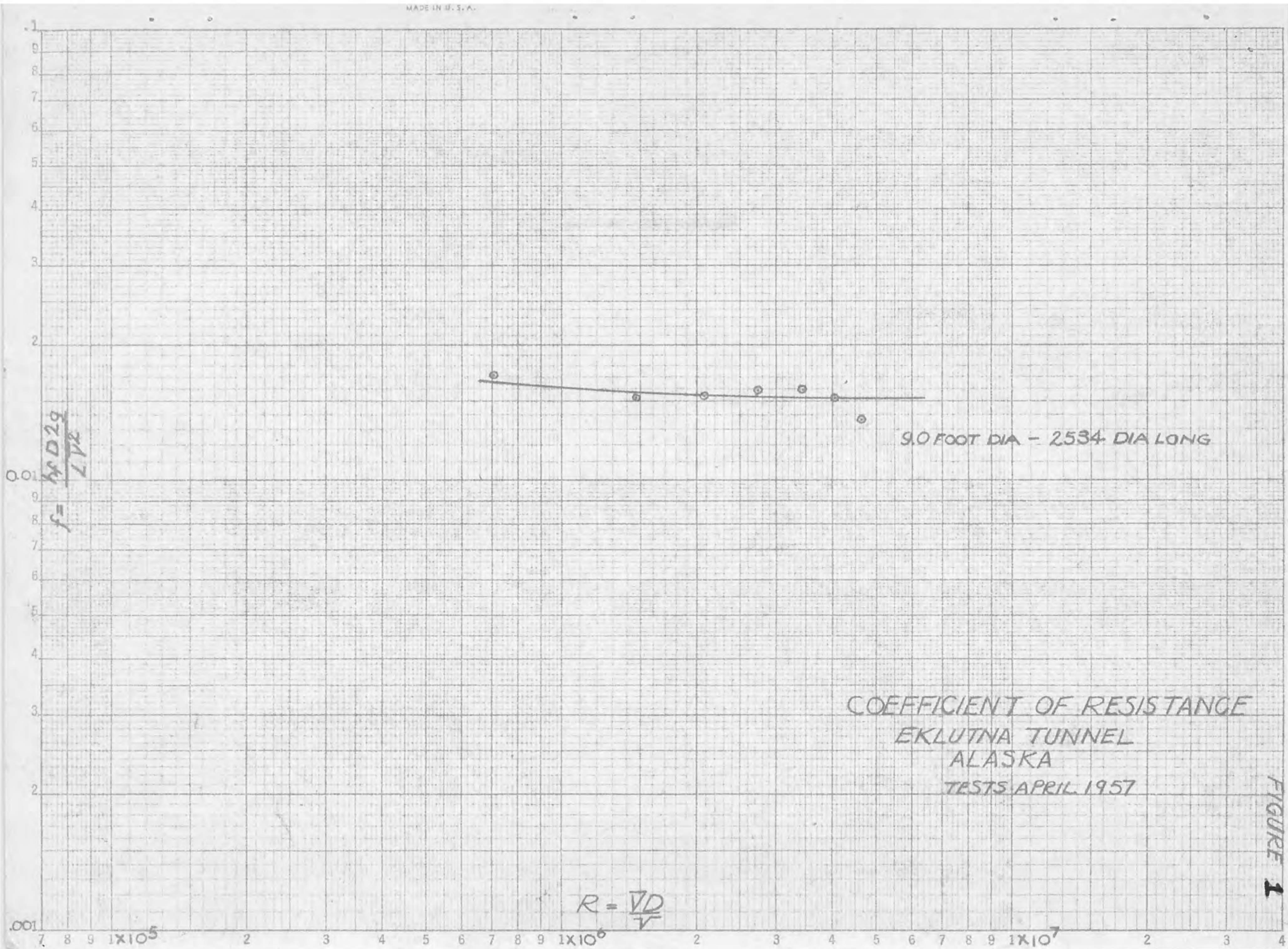
MADE IN U. S. A.
$f = \frac{h_f D 2g}{L V^2}$
9.0 FOOT DIA - 2534 DIA LONG
COEFFICIENT OF RESISTANCE
EKLUTNA TUNNEL
ALASKA
TESTS APRIL 1957
$R = \frac{VD}{\nu}$
.1
0.01
.001
1X10^5
1X10^6
1X10^7

FIGURE 1