PAP-595

SAYR TUNNEL SURFACE ROUGHNESS INVESTIGATION

CENTRAL UTAH PROJECT, UTAH

BY

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PAP-595

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D-3750

D-3751
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595

MAY 03 1991

Memorandum

To: Chief, Water Conveyance Branch, D-3120

From: Chief, Hydraulics Branch, D-3750

Subject: Sayr Tunnel Surface Roughness Investigation, Bonneville Unit, Central Utah Project, Utah (Information Record Dated May 2, 1991) (Construction Contract, Tunnel System)

The Hydraulics Branch has completed the evaluation of the surface roughness of Sayr Tunnel as requested by D-3120. It is our understanding that during the construction of Sayr Tunnel, the lower half of the concrete conduit was observed to have many bug holes. These were repaired by screeding mortar over the bottom half of the pipe surface. The screeding procedure left a nearly uniform but rougher surface on the bottom half of the tunnel than on the top half.

To estimate friction factors for the tunnel, we requested field personnel make several surface roughness impressions of the tunnel wall. These negative roughness impressions were recast in hard material in the laboratory to obtain positive surface roughness samples.

Direct surface roughness measurements were made of each of the samples. These data were used to determine a statistical average rugosity (K) of the screeded surface. We were then asked to estimate friction factors for the tunnel. This required a method be determined to account for the very different roughness characteristics of top and bottom surfaces.

Following is a summary of the steps taken to develop screeded surface rugosity and the theoretical basis for our estimate of tunnel friction factors.

Laboratory Measurements of Screeded Surface Roughness

Construction personnel used dental alginate to obtain the tunnel surface impressions. This material worked reasonably well to mold the fine scale roughness, but due to its flexibility after curing, larger scale surface deviations could not be accurately reproduced in the laboratory samples.

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Plaster casts were made from the negative impressions to provide a hard positive replication of the pipe surface. The surface texture was digitized along 4-inch-long straight line traverses using a calibrated linear voltage differential transducer. Some of the impressions were not used because of problems with determining a datum due to their flexible nature. For each traverse the mean peak to trough difference (X) was determined along with its corresponding standard deviation, table 1.

Table 1. - Surface roughnesses measured from tunnel samples.

Sample No.	Traverse No.	Mean peak to trough difference X (inch)	Standard deviation σ (inch)
2	1	0.015	0.008
3	1 2	0.012 0.022	0.006 0.029
4	1	0.017	0.019
5	1	0.014	0.015
6	1	0.012	0.009
	Mean	0.015	0.0143

Standard deviation was computed as:

$$\sigma = \frac{\sqrt{\Sigma\ (\overline{X} - X)^2}}{n - 1} \qquad (1)$$

and

$$\overline{X} = \frac{\Sigma X}{n} \qquad (2)$$

where n is the number of X values.

From studies of bed material in natural channels, it has been found that rugosity (K) can be estimated as 2 times the 90 percent particle size. For a statistically normal distribution, the 90 percent size (K) can be expressed in terms of the mean and standard deviation as:

$$K = 2\ (\overline{X} + 1.283\sigma) \tag{3}$$

Using the average mean and average standard deviation (columns 3 and 4, respectively) in equation 3 gives an average screeded surface rugosity of 0.00555 ft.

Determining a Total Tunnel Roughness Value

Investigators conducting laboratory sediment and friction flume studies often separate sidewall effects to determine the friction factor of the material on the bottom of the flumes. To do this it is generally assumed that each partial perimeter of distinctly different hydraulic roughness influences a part of the total flow area. Hydraulic equations applied to partial areas and perimeters must produce the same head loss, friction slope, and velocity as would be measured for the combined total system.

Equations formulated on these assumptions will be given and discussed briefly. The subscripts r,s, and c denote association with the rougher part of the perimeter, the smoother part and the total combined perimeter of the conduit, respectively. Obviously the sum of the partial perimeters (P) add up to the total combined perimeter of the conduit as given by:

$$P_c = P_r + P_s \tag{4}$$

The above assumptions implicitly assume that the imaginary perimeter lines are normal to the isovels. Also as stated previously, it is assumed that the distinctly different roughnesses on top and bottom of the tunnel perimeter affects separate flow areas (A) which add up to the total combined flow area. Thus:

$$A_c = A_r + A_s \tag{5}$$

Analogous to parallel pipe flow the friction slope (S) of the flows associated with each partial perimeter must produce the same friction loss, thus:

$$S_c = S_r = S_s \tag{6}$$

The partial flows have a common velocity (V), thus:

$$V_c = V_r = V_s \tag{7}$$

The Darcy-Weisbach equation expresses the relationship between the variables in the above equations as:

$$S = \frac{fV^2}{8Rg} \tag{8}$$

where (R) is the hydraulic radius which is equivalent to (A/P) or (D\4) and (f) is a nondimensional friction factor.

If the flow is fully turbulent, then the Darcy-Weisbach friction factor (f) can be calculated by:

$$\frac{1}{\sqrt{f}} = 2\log\frac{4R}{k} + 1.14 \tag{9}$$

Reynolds number N_R must be sufficiently large to comply with the criteria expressed as:

$$N_R = \frac{4VR}{\nu} > \frac{200}{\sqrt{f}} \left(\frac{4R}{K}\right) \tag{10}$$

where ν is kinematic viscosity.

If N_R is not greater than the criterion given by equation 10, the friction factor can be calculated iteratively using the Colebrook-White equation:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{K}{12R} + \frac{2.5}{N_R\sqrt{f}}\right) \tag{11}$$

The Darcy-Weisbach equation 8, for combined and partial flow components can be regrouped and written as:

$$\frac{V_c^2}{S_c} = \frac{8gA_c}{f_cP_c} = \frac{8gA_r}{f_rP_r} = \frac{8gA_s}{f_sP_s} \tag{12}$$

A relationship defining the combined friction factor (f_c) can also be derived using principles of shear stress (τ). Tractive shear forces on the partial perimeters per unit flow travel length are additive, thus:

$$\tau_cP_c = \tau_rP_r + \tau_rP_r \tag{13}$$

By free body analysis it can be shown that:

$$\tau = \gamma RS \tag{14}$$

where (γ) is the specific weight of water.

Substituting the slope in equation 14 into equation 8 gives:

$$\tau = \frac{\rho f V^2}{8} \tag{15}$$

where (ρ) is the density of the water.

Substituting equation 15 into the tractive shear force equation 13 gives the combined friction factor in terms of the perimeter and friction values:

$$f_cP_c = f_rP_r + f_sP_s \tag{16}$$

By applying iterative techniques, friction factor (f_c) and effective rugosity (K_c) due to different perimeter roughnesses can be determined from equations 9 or 11, 12, and 16.

For Sayer Tunnel, combined rugosities (K_c) were computed for two discharges using two assumed rugosity values for the smoother perimeter and derived rough wall rugosity values. The procedure given, Q, A_c, K_r and K_s is:

* Using the last two terms of equation 12 and equation 9 or 11, determine by iteration the areas (A) that make $A_r/(f_rP_r)$ equal to $A_s/(f_sP_s)$.

* Multiply $A_r/(f_r P_r)$ by 8g to get V_c^2/S_c.

* Solve for f_c.

* Use friction equation 9 or 11 as applicable to solve for K_c.

* Check f_c using equation 16.

This procedure results in a flow area split (A_r/A_s), of 55/45 percent for K_s=0.002 and 62/38 percent if K_s=0.0003. The results for Sayr Tunnel are summarized in table 2 (enclosed).

The results in table 2 show that the (f) values do not vary for the range of discharges chosen. However, the (f) values will vary if Reynolds numbers fall into the transition range of the Darcy-Weisbach friction function. Computations would then require the Colebrook-White equation (11) be used.

The tunnel friction factors presented in the table are based on several assumptions and a small number of wall roughness samples. We thus recommend these values be field measured after the tunnel is put into service. This can be done by installing two pressure taps separated by a long straight reach of Sayr Tunnel. To do this requires a thorough survey of the elevations, stationing, and geometry at the pressure taps. During operation measurements of both discharge and pressure are required.

Brent W. Mefford

Enclosure

cc: D-3120 Narvaiz
D-3750
D-3751 Dodge
D-3751 Mefford
D-3751 PAP file
D-3752
(w/encl to each)

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Table 2. - Estimated tunnel rugosity and friction factors.

Discharge (Q) ft^3/s	Slope (S)	Velocity (V) ft/s	Perimeter* (Part)	Area (A) ft^2	Friction factor (f)	Hydraulic radius (R) ft	Rugosity ψ (K) ft
800	.00578	14.10	Smooth	25.53	0.0145	1.916	.00200
			Rough	31.21	0.0173	2.338	.00555
			Combined	56.74	0.0159	2.125	.00342
600	.00325	10.57	Smooth	25.53	0.0145	1.916	.00200
			Rough	31.21	0.0175	2.338	.00555
			Combined	56.74	0.0160	2.125	.00342
800	.00494	14.10	Smooth	35.18	0.0104	1.615	.00030
			Rough	21.56	0.0169	2.635	.00555
			Combined	56.74	0.0136	2.125	.00167
600	.00278	10.57	Smooth	35.18	0.0104	1.615	.00030
			Rough	21.56	0.0169	2.635	.00555
			Combined	56.74	0.0136	2.125	.00167

* Diameter conduit (d_c) = 8.5 ft
Perimeter (P_c) = 26.70 ft
Half perimeter = (P_r) = (P_s) = 13.35 ft
Area of conduit ($A_c = \pi d^2/4 = 56.745\ ft^2$

ψ Rugosity (K_r) determined by physical measurements as per table ~~2~~. 1.

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Research and Laboratory Services Division
INFORMATION RECORD

ROUTING	INITIAL	DATE
D-3750		
D-3700		
D-3751		

Date 5/2/91

Time 10 am

Phone call

Oral discussion X

Other

Feature/Project/Region: Sayer tunnel wall friction

Participants: Brent Mefford (D-3751) and John Narvais (D-3120)

Discussion: Mefford meet with Narvais to discuss results of D-3751's estimates of the tunnel friction based on the wall roughness samples taken in the field and future plans for installing pressure taps near each end of Sayer Tunnel. We chose two locations along the tunnel to install pressure taps. As a rule of thumb, pressure taps used for measuring average pressure head at a station should have at least 10 pipe diameters of uniform pipe upstream and 1 pipe diameter downstream. This is often difficult to comply with and measurements must be taken at the best available sites. To isolate the energy loss due to wall friction, a long section of pipe with as few minor losses (bends, changes in size or type of lining, junctions, ect.) as possible is best. Wall friction loss can then be determined by measuring discharge and the pressure drop between measuring stations. At Sayer tunnel the best sites for pressure taps to be installed are near station 75+50 and station 378+31. Properly installed pressure taps at these locations would provide excellent data for determining Darcy-Weisbach friction factors. Mefford will prepare drawings of the pressure tap installation at each site for Narvais. This information in conjunction with our previous measurements of wall roughness will benefit the operation of Sayer tunnel and our ability to predict friction losses for large conduits in the future.

Action: Prepare drawings of the pressure tap installations discussed.

Signature Brent W Mefford

Copy to:
D-3120 Narvais, D-3750, D-3751, D-3752