Gorge 2nd Tunnel

# Appendix J: G2T Friction Technical Memorandum

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**PROJECT MEMORANDUM**

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| **From:** | Jeremy Johnson |
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| **Subject:** | Gorge 2nd Tunnel: Friction Coefficient Evaluation |

## 1 Introduction

This memorandum presents results of our evaluation of friction coefficient for design of the Gorge 2nd Tunnel (G2T). The friction coefficient is a key parameter in calculating the frictional head loss for the design of hydropower tunnels. Frictional head loss is determined using the theoretical Darcy–Weisbach friction factor, or the empirical manning coefficient of friction (Manning number). The objective of this evaluation is to determine the friction factors that will be used in the hydraulic model for tunnel optimization studies. The evaluation includes a review of existing information on surface roughness and friction losses in rock tunnels from past projects.

## 2 Project Summary

The G2T project, located on the western slopes of the north Cascade Mountains near State Highway 20 in Washington State, involves the construction of a second water tunnel to convey water from Gorge Dam to the existing Gorge Powerhouse. This tunnel, which will parallel the existing water tunnel, is anticipated to have a finished diameter of between 16 and 20 ft and a length of approximately 11,000 ft. The tunnel will be excavated with a tunnel boring machine (TBM). There will be two connections to the existing tunnel, one upstream just below the Gorge Dam Intake, and one downstream above the existing powerhouse. It is expected that these connections will be excavated with drill and blast methods and lined with cast-in-place concrete.

## 3 Geology

The bedrock along the G2T alignment consists of gneiss, a foliated (mineralogically banded), granite-like metamorphosed igneous rock. This bedrock, commonly referred to as Skagit Gneiss, is predominantly medium- to coarse-grained (crystals 1 to 20 mm in length) with mineralogy that includes plagioclase feldspar, quartz, biotite, and hornblende. It is predominantly fresh and unweathered, except in fault/shear zones, and is generally widely jointed, with joint spacing ranging from 3 to 10 ft. Based on preliminary observations, the gneiss has been determined to be weakly to moderately

foliated, with foliation commonly (but not exclusively) sub horizontal. Jointing is also commonly sub horizontal and follows the foliation.

# 4 Tunnel Friction

## 4.1 *Tunnel Surface Roughness*

The first step in developing a friction coefficient for an unlined rock tunnel is to determine the appropriate surface roughness value for the tunnel walls (ε). This is typically done by measuring roughness from either a plaster cast of the tunnel wall or from a roughness profile generated from a laser scanner.

In order to estimate tunnel surface roughness for G2T, empirical tunnel surface roughness data from the Grizzly Powerhouse Project tunnel was reviewed (Stutsman, 1995). This project is located in the Sierra Nevada mountains of California and was excavated in granite rock with a TBM. The gneiss that will be encountered in the G2T is anticipated to fracture in a similar fashion to the granitic rock of the Grizzly Project, so the surface roughness will be similar. For the Grizzly Project, tunnel surface roughness casts were made for both the lined (shotcrete) and unlined portions of the tunnel. Average surface roughness values for the tunnel are as follows.

- Unlined Tunnel Portions:
    - Minimum: 1/16 in.
    - Maximum: 3/32 in.

- Shotcrete-Lined Tunnel Portions: 1/4 in.

For concrete linings, the United States Bureau of Reclamation design guidelines for tunnels (USBR Technical Service Center, 1994) include the following recommended roughness values for rough and smooth concrete:

- Rough (Old and Eroded) Concrete: 0.002 ft (approx. 1/32 in.)

- Smooth (New) Concrete: 0.0003 ft (<1/64 in.)

## *4.2 Darcy–Weisbach Friction Factor*

Following determination of surface roughness, the Darcy–Weisbach friction factor (f) can be determined. This is a value that takes tunnel surface roughness, diameter, and flow velocity (Reynolds number) into account.

- Relative Roughness = $\varepsilon/d$

  where:
  $\varepsilon$ = tunnel surface roughness [in.]

d = tunnel finished diameter [in.]

- Reynolds number (Re) = VD/v

  where:
  D = tunnel diameter [ft]
  V = water velocity within the tunnel [ft/sec]
  V = 1.67 x $10^{-5}$ $ft^2$/sec @ 40°F (Average Value)

These two values are plotted on a Moody diagram, or the values are entered into the Colebrook-White equation, to determine the Darcy–Weisbach friction factor.

### *4.3 Manning Coefficient of Friction*

The Manning coefficient of friction, n, is often used to calculate head loss instead of the Darcy–Weisbach friction factor. Most design guidelines and case studies report the Manning number when addressing friction factors. The following equation is commonly used to relate the Darcy–Weisbach friction factor to the Manning number:

- Manning number, $n = ((f \times D^{1/3}) / 185)^{1/2}$

  where:
  D = tunnel finished diameter [ft]
  f = Darcy–Weisbach friction factor

## 5 Case Studies

Existing data from unlined, TBM-bored tunnels were reviewed to help determine the friction factor for use in the G2T hydraulic model. The projects included several in South Africa (Pennington, 1998) and two projects in the Sierra Nevada mountains of California. Table 1 presents calculated and measured friction values that were determined on these projects. The South African data separate the tunnel lining conditions, while the data from the Grizzly (Stutsman, 1995) and Kerkhoff 2 (Stutsman, 1987) tunnel projects are for the entire length of the tunnels, the majority of which were unlined granite.

Additional sources of friction loss information were also reviewed. Table 2 summarizes recommended friction values from the Army Corp of Engineers (USACE, 1997) and the Electric Power Research Institute (Brekke, 1987). The recommended friction values are generally consistent with the data reported in Table 1.

**Table 1: Manning Number Values for TBM Bored Tunnels in Granite**

| Location | Manning number |
|---|---|
| ***South Africa*** | |
| Unlined Granite | 0.0157 ±0.0008 |
| Cast-In-Place Concrete | 0.0119 ±0.0009 |
| Shotcrete | 0.0161 ±0.0011 |
| ***Grizzly Powerhouse Project (California)*** | |
| Calculated | 0.0160 |
| Measured | 0.0142 |
| ***Kerckhoff 2 (California)*** | |
| Calculated | 0.0150 |
| Measured | 0.0154 |

**Table 2: Typical Friction Values for Various Tunnels Linings**

| Source | Manning number |
|---|---|
| ***USACE*** | |
| TBM, Unlined | 0.018 |
| Cast-In-Place Concrete | 0.013 |
| Drill-And Blast, Unlined | 0.038 |
| ***Electric Power Research Institute*** | |
| Drill And Blast, Unlined | 0.027–0.041 |
| TBM, Unlined | 0.010–0.02 |
| Shotcrete | 0.020–0.025 |
| Cast-In-Place Concrete | 0.013 |
| Steel | 0.013 |

## 6 G2T Friction Calculations

Darcy–Weisbach friction factors were calculated for G2T using unlined tunnel surface roughness values ranging from 1/16 to 3/32 in. and excavated diameters ranging from 16 to 20 ft. Preliminary calculations assume a maximum flow rate for the Gorge Powerhouse of 7,700 $ft^3$/sec. The calculated Manning number ranges from 0.0143 to 0.0152. The results are summarized in Figure 1.

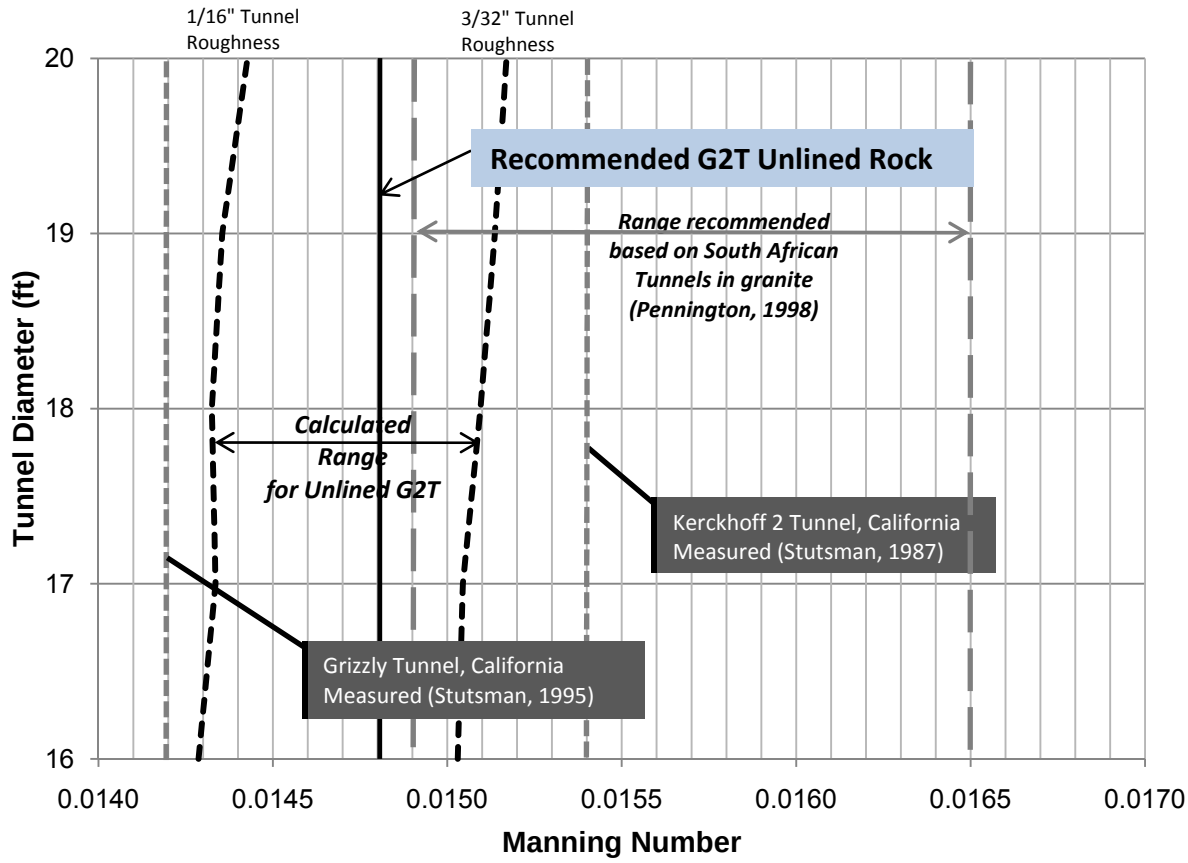


**Figure 1: Rock Friction Factors for TBM-bored Tunnel**

## 7 Discussions

There is general agreement among calculated, measured, and guideline values of friction. Recommended Manning numbers for the G2T hydraulic model are summarized in Table 3 for various tunnel linings.

As indicated in Figure 1, the recommended friction value for G2T for unlined rock is on the lower end of the range of the collected data from previous projects; however, this assumption is considered appropriate given modern tunneling techniques and the similarity between the rock at the Grizzly Peak project and G2T.

The Manning number for Cast-In-Place Concrete is derived from USBR design guidelines for tunnels.

For shotcrete linings, a Manning number has been recommended which is lower than the EPRI limits – this is based on the assumption that any shotcrete finish in G2T would be significantly better than achieved in the 1987 EPRI study.

**Table 3: Recommended Manning Number**

| Lining Condition | Manning number |
|---|---|
| Unlined Rock | 0.0148 |
| Cast-In-Place Concrete | 0.0100 |
| Shotcrete | 0.0175 |

## 8 References

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