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A SCOURING ROCK TRAP IN LEMONTHYME POWER TUNNEL

by

P.T.A. Griffiths, B.E., B.Sc., M.I.E. Aust.*

and

T.M. Brett, B.C.E. M.I.E. Aust.

S U M M A R Y

A rock trap is described which has been successfully used in trapping debris which is carried along an unlined pressure tunnel. Material caught in the trap can be removed through a scouring pipe without interrupting the tunnel flow. Model and prototype information have been used to formulate a set of design rules for use in future designs of such scouring rock traps.

Civil Design Division,

Hydro-Electric Commission,

Hobart, Tasmania, Australia.

* (since deceased)

Description of Lemonthyme Power Development

Parangana dam diverts the headwaters of the Mersey River through a four mile (6.4 km) long unlined 18 ft. (5.5 m) wide, inverted U, pressure tunnel, past the rock trap, thence through a 4500 ft. (1370 m) long penstock to Lemonthyme power station which discharges to the Forth River. The combined flow then passes through Cethana, Devils Gate and Paloona ponds and power stations.

Turbine rated discharge is 1497 cusecs (42.4 cumecs) at 457 ft. (139.3 m) head to produce 54 MW. Tunnel flow is permitted to be increased by simultaneous operation of the rock trap scouring to a maximum of 1600 cusecs (45 cumecs).

Lemonthyme tunnel was driven through quartzite and schists containing extensive graphitic joints and was holed through on 3rd August, 1967. The power station went into service on 21st April, 1969. The scouring rock trap has operated satisfactorily to remove all trapped material passing into the hopper.

Description of the Scouring Rock Trap

The rock trap is situated at the downstream end of the tunnel, and was developed as a self-cleansing unit to protect the penstock and turbine from erosion. Material deposited in the rock trap is discharged through a 31-3/8" (797 mm) dia. scour pipe into a by-pass dissipator, on opening first a 24" (610 mm) butterfly valve and then a 24" (610 mm) reversed radial gate on the pipe outlet. An upstream splitter shield protects the butterfly valve from being struck by rock particles.

Stone particles moving along the tunnel invert are trapped between transverse baffles (Fig. 1) which are 3" (76 mm) wide by 12" (305 mm) deep. The original spacing was 9" (229 mm) apart, and there were 29 baffles and 30 spaces. Subsequent hydraulic model studies showed that the trapping and retaining of material would be improved by putting cover plates over the two upstream baffles and the three downstream baffles. The third upstream baffle was removed together with the fifth, seventh, ninth, eleventh, thirteenth, fifteenth, seventeenth, nineteenth and twenty-first. The fourth baffle was raised 6" (152 mm). Eddies are sustained between the baffles, and carry material down into a hopper with a large hole through which material passes to a lower chamber where it lies at its angle of repose.

100 ft. (30 m) of the tunnel upstream of the rock trap was lined with gunite to prevent material in this area falling from the roof and by-passing the trap.

The hopper was in the shape of an inverted pyramid with sides sloping 40° to the vertical and ends 50° to the vertical.

Fig. 2 gives details for future designs of the scour box at the bottom of the pyramidal hopper. Stone particles fall through the connecting slot and come to rest at the angle of repose. There is a baffle in the scour box, at the upstream end of the slot, which prevents material rilling upstream. When sufficient material is in the lower chamber, it seals the hole in the base of the hopper. Additional material fills the hopper without disturbing the material in the chamber. The dimensions are such that water, from an upstream duct can pass on both sides of the material and into a pipe downstream of it.

In the scheme a 500 cusec (14.2 cumec) by-pass was provided to enable flow to be diverted from the downstream end of the tunnel via Lemonthyme Creek to the Forth River downstream power stations while Lemonthyme penstock or power station is closed for maintenance. The 48" (1219 mm) by-pass pipe ends in a concrete energy dissipating structure. This structure is also used to receive the outflow from the scouring rock trap and is fitted with stoplogs across the outlet so that debris can be trapped, and the quantities measured. The outlet pipe extends 700 ft. (213 m) from the scour box and is buried below the invert of the tunnel. It was planned to be not less than 30" (762 m) dia. so that man access would be possible to clear a blockage if one occurred.

The operating head on the scouring system varies from 87 ft. (26 m) to 136 ft. (41 m) so that clear water velocities of 25 ft/sec (7.6 m/sec) to 34 ft/sec (10.4 m/sec) are possible.

To empty the trap, the butterfly valve is opened wide, then the reverse radial gate is opened. Water passes on both sides of the material in the scour box and carries it downstream where it is trapped in the by-pass dissipator structure from where it can be readily removed. Material eroded from the scour box is automatically replaced by gravity from the hopper until finally both are emptied, except for a small quantity which remains in the lee of the baffle. The trap, of about 105 cubic yards ($80 m^3$) capacity can be emptied in 8 minutes. Power production is not interrupted.

Trapped material sizes range from 1 mm to 80 mm with much finer material passing to the penstock where it does no damage.

Blockage with Sticks

One of the major concerns was to avoid blockage of the trap by sticks of either bush timber or sawn timber. Hydro-Electric Commission intakes are normally equipped with trashracks to minimize the passage of sticks, but at Tungatinah intake on one of the older power tunnels, a 6 ft. (2 m) long stick of 1½" (40 mm) dia. has passed through a 2" (51 mm) clear rack spacing. The rack spacing at Lemonthyme tunnel intake is 2½" (63 mm) clear and the trap is proportioned to pass 12 ft. (3.7 m) long timbers without blockage. Nevertheless, it was decided as a safety measure to suspend a 6" x 6" (152 mm x 152 mm) mesh 9" (229 mm) below the baffles along the tunnel invert. Unfortunately considerable blockage was caused by a build-up of material on the 6" x 6" (152 mm x 152 mm) mesh which filled up to the top of the 12" x 3" (805 mm x 76 mm) concrete baffles. Bush timber was found on the mesh with milled timber and smaller pieces of rock with up to 5" (127 mm) material on the top. With the blockage covering a good deal of the baffle area some material passed over the trap, but this caused no noticeable damage to the turbine or penstock. Following this discovery the baffle spacing was doubled as already described, with some end spaces covered to reduce currents in the hopper tending to lift rock particles up and out.

Hydraulic Model Tests

Several models were used to assist in the design of the rock trap. Some modelled complete traps, others were of parts of the trap.

The linear scales of the models ranged from 1:30 to a full size unit, which was later installed as an operating unit in Todds Corner flume which is part of the Great Lake Power Development.

The materials used in the tests ranged from uniform gravels to actual scaled down material from the Lemonthyme Tunnel. A mixture of gravel and steel nails was used in one study to assess the effects of sticks which might find their way into the trap.

For the studies of trapping efficiency of the baffles, crushed anthracite was used.

Basically the tests centred around several aspects of the operation of the trap:

(1) The trap must be capable of being completely emptied without blockages or hold-ups of the material, even under such severe and unusual conditions as feeding nails into the model;

(2) The trap should still operate even when nearly empty and water could pass down from the hopper into the scour box;

(3) The rate of movement of material must be such that troublesome concentrations of solids cannot occur in the discharge pipe;

(4) The arrangement of the baffles over the trap should be such that a maximum amount of material is caught and retained.

A considerable amount of testing was done to determine the rate of movement of material out of the scour box, for different dimensions of the box, and different waterway configurations. From this information it was possible to formulate an empirical equation to cover the rate of movement of material. The use of several different size models allowed the formula to be checked for universal application.

The model studies did indicate that there were certain patterns of behaviour of the trap system which should be carefully avoided. Thus it was possible to set up a cyclic pattern in which the scour discharge pipe would run alternatively in a deposit and non-deposit regime. The system hunted. This is the main reason why a factor of safety of three as regards solids concentration was introduced into the design rules.

Tests were also done to ensure that should the flow be turned off during the process of emptying the trap then there would be no blockage when operation commenced again.

Choice of Rock Trap

The Haas tunnel (Ref. 1) was used as a guide to the amount of material which could be deposited in a rock trap. This tunnel which was unlined was driven through granite which broke into pieces of cubical shape. The amount deposited in the Haas rock trap was equivalent to 0.9 in. (23 mm) from the whole of the invert. Conventional rock traps of such capacity that they need never be cleaned were considered. Because Lemonthyme tunnel passes through well foliated, highly contorted quartz mica shist, it was expected that flaky particle shapes could increase the amount deposited in the trap to the equivalent of 1.5 in. (38 mm) depth eroded from the invert making a total quantity of 1500 cu.yd.

(1147 m^3) to be trapped. Had the actual thickness become of real significance, an attempt might have been made to assess this more closely by subjecting actual spoil from the tunnel to the invert shear stress anticipated. A conventional trap would have required about 3500 cu. yd. (2676 m^3) additional excavation over normal tunnel excavation and was thought to be more expensive than the scouring rock trap.

Actual results show a rate of trapping of material of about 6 cu.ft. (0.17 m^3) per machine running hour, falling to 1 cu.ft. (0.028 m^3) per hour. The present yield is unknown, because for some time, in order to divert the maximum flow to the Forth River, the tunnel discharge has been held at 1600 cusecs (45 cumecs) with the by-pass operating continuously and with the scour valve used for fine discharge control. Trapped material is washed through the dissipator box and away. However, it is estimated that 1000 to 1500 cu.yd. (765 to 1147 m^3) have been passed through the scouring trap and the present rate of trapping is about 1 cu.ft. (45 cumecs) per hour of machine operation.

The material trapped was (a) quartz, (b) shist, (c) concrete or concrete aggregates (mostly from guniting), (d) quartz (from veins in the tunnel).

Unlined Invert

After completion of the tunnelling, the locomotive rails and sleepers were removed and the spoil was removed from the invert down to the rock points using a bulldozer which finally backbladed the remaining spoil smooth.

The filling rate of the tunnel was restricted to a maximum of 65 cusecs (1.8 cumecs) by water by-passing the emergency intake gate through a 2 ft. 6 in. (762 mm) dia. butterfly valve restricted by a fixed orifice plate in the downstream section of the by-pass pipe. The tunnel filling time varies from 33 to 40 hours depending on Parangana pond level. The tunnel filling rate was kept small to minimize the disturbance to the smooth invert, particularly that due to the increased shear at the steep fronted advancing wave front moving over a dry bed, which gives about twice the shear produced by normal flow depth corresponding to the filling discharge.

During operation of the tunnel, fine material was removed from the surface of invert leaving coarser material which protected the fine material below. The higher the planned tunnel velocity, the coarser the surface which will be left on the invert, and the higher will be Manning's n. It appears the invert will finally be armoured with stones about 3 in. (76 mm) size in the quartzite reach and 4 to 5 in. (100 to 130 mm) size in the schist reaches.

Tasmanian tunnels and conduits generally grow an internal coating of manganese bacterial slime which greatly increases head losses of smooth conduits. This same coating has grown over much of the tunnel invert sides which indicates stability has been reached there. Invert material generally moves near the middle half of the invert.

One interesting observation of the slime deposit on the 20 ft. (6 m) concrete apron upstream of the rock trap showed that material moved to the trap along a 5 ft. (1.5 m) wide path parallel to the tunnel axis, so that the right hand side of the rock trap only was being used. This was overcome by placing a 6" x 6" (152 mm x 152 mm) angle iron as a deflector on the concrete apron. Great care should always be exercised to avoid eddies in the flow approaching a trap, adequate enlargement transitions should be used to avoid separation at the boundaries.

Design Rules

The following design rules are presented for use in designing a scouring rock trap for no deposit flow regime.

NOTATION

d is maximum stone size that will move in the tunnel.

D is depth of scour box.

L is length of straight wall section of scour box.

W is width of scour box.

T is width of opening between hopper and scour box.

S is length of opening between hopper and scour box at its shortest point.

A is the scour box waterway area when there is material in the trap.

Q is discharge through the system.

M rate of movement of material from scour box.

U is mean tunnel velocity in ft. per sec.

V is scour box waterway velocity.

v is scour pipe velocity.

min. is subscript minimum.

Max. is subscript maximum.

Procedure

(1) From a knowledge of the project, calculate the maximum velocity in the tunnel or channel.

(2) From the appropriate curve in Fig. 3 showing the relationship between the stone size moved and the water velocity, pick a stone size 'd' corresponding to the maximum velocity. These curves were derived from work reported by Condolios and Chapus for closed conduits and U.S. Corps of Engineers Data Sheets 712-1, 712-1/1 for open conduits.

(3) Make scour box depth 'D' equal to 6 x d, (Fig. 2) except that 'D' shall not be less than 6 in. (152 mm).

(4) Make L = 5.6 D

(5) Make W = 5.3 D

(6) Make T = 2 D

(7) Make 5 = 4 D

(8) Take V min. = U max. as a 1st approximation.

(9) Then $A = 1.65\ D^2$ assuming spoil rills to the outside edge of the scour box.

(10) And $Q = 1.65\ D^2V$ as a 1st approximation.

(11) Choose a scour pipe diameter. As a first guess it can be made equal to the scour box depth D. For this pipe size calculate the maximum and minimum velocities in the pipe and scour box waterways. The headloss between the tunnel and a point just downstream of the scour box may be taken as:

$$H_L = 1.75\ \frac{v^2}{2g}$$

(12) Calculate the rate of movement of material out of the scour box for minimum and maximum velocities, and for a velocity equal to approximately the mean of the maximum and minimum, using the equation:

$$M = 5.6 \times 10^{-4}\ D\ V^{3.6}$$

(13) From (11) to (12) calculate the concentrations of material in water for the maximum, minimum and intermediate velocities.

(14) Check, that each concentration in (13) is lower by a factor of about three compared with that taken from the curve Fig. 4 which was adapted from work by Condolios and Chapus Ref. 2.

(15) If necessary repeat steps (11) to (14) until the concentration is clear of the deposit flow regime by a factor of safety of three.

(16) Round off the pipe size if need be to the nearest size available commercially and recheck concentrations.

(17) Check that the maximum velocity through the scour pipe is not less than 9 ft. per sec. For this calculation the hopper is assumed to be virtually empty, and the headloss between the tunnel and a point just downstream of the scour box is assumed to be $H_L = 1.5\ \frac{v^2}{2g}$. For total head add friction downstream and velocity head at exit.

(18) Complete other details of design as shown in Fig. 2.

Conclusion

It is believed that use of the design rules presented here will enable users to design scouring rock traps which will not block. We have used a scouring rock trap in our Tods Corner open channel virtually designed as a large model. We also have another trap in Wilmot tunnel with the trap of dimensions half those used at Lemonthyme.

References

1. "Unlined inverts and sand traps, HAAS Hydro Electric Power Project" by J.B. Cooke, Trans A.S.C.E. Paper No. 3008 p. 989 (1959).

2. Condolios and Chapus - "Chemical Engineering" - 24th June, 8th July, 22nd July, 1963.

Acknowledgements

We wish to express our appreciation to the Hydro-Electric Commission and to the Commissioner, Sir Allan Knight, C.M.G., M.E., B.Sc., B. Com., F.I.E. (Aust.) for the opportunity to present this paper, and to thank all those who have helped in the team effort of developing the scouring rock trap, particularly Hydraulics Laboratory Engineer, W.F. Navin who developed our latest design procedure.

Addendum by T.M. Brett

The work described in this paper was carried out under the direction of the late Mr. P.T.A. Griffiths, who died suddenly as our report neared completion, and who was a source of inspiration to all who were associated with him.

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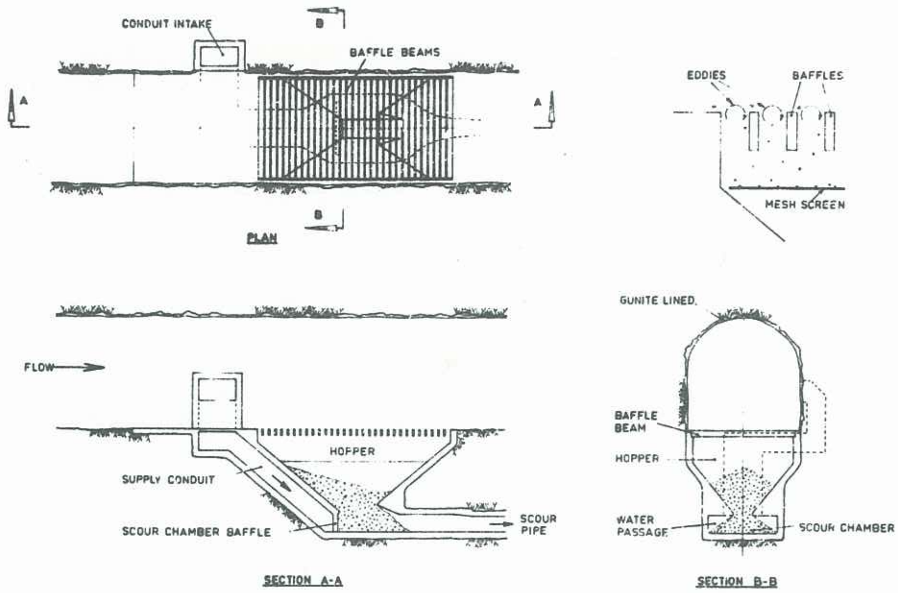

FIGURE 1 SCOURING ROCK TRAP LEMONTHYME TUNNEL

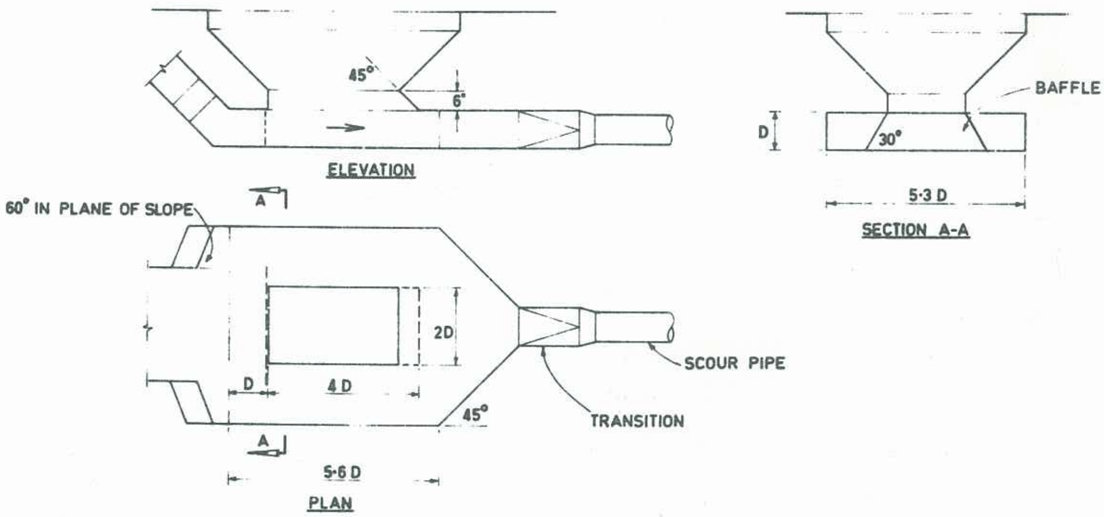

FIGURE 2 ROCK TRAP DESIGN DATA GENERAL LAYOUT OF SCOUR BOXES

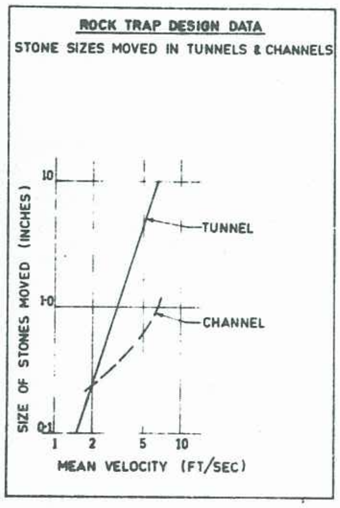

FIGURE 3

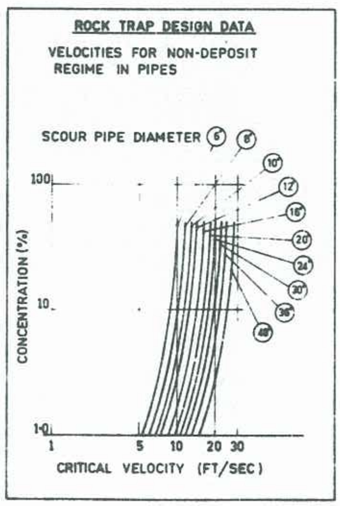

FIGURE 4