Grouting of Badger Setts in a Flood Storage Reservoir Embankment

D. A. BRUGGEMANN, Atkins (formerly Jacobs Engineering UK Limited)

SYNOPSIS. A flood detention reservoir was created by adding a throttled outlet to the original brick lined culvert under an existing disused railway embankment. However, the embankment has been damaged by extensive burrowing of badgers, with elimination of preferential seepage paths a matter in the interest of safety under the Reservoirs Act 1975. The paper will describe the grouting works carried out in 2011 to fill the network of badger tunnels within the embankment, which required around 70T of grout and was carried out in a two stage process. It will include known precedents of similar schemes where grouting was used to infill animal burrows. The environmental aspects of badger relocation are covered elsewhere and will be limited to a short background section at the beginning of the paper.

INTRODUCTION

A flood detention reservoir was created between 1998 and 1999 by utilising an existing disused railway embankment and original brick lined culvert under the embankment, with this reservoir transferred to the Environment Agency when the watercourse was enmained. The embankment was part a branch line from Sandling to Hythe and Sandgate which was opened in the 1874 and taken out of service completely in 1951 (kentrail.org.uk). The embankment is up to 18m high with a crest width of 10m. A flood storage reservoir was formed by throttling the flood flows on the stream which flowed through a brick culvert under the embankment. It is estimated that, although in normal operation impounding up to a depth of 6.5m may occur, in extreme dam safety floods impounding up to 16m may occur. The embankment has been damaged by extensive burrowing of badgers (*meles meles*) on the upstream and downstream slopes.

There were a total of 27 sett entrances, 16 upstream and 11 downstream, covering about a 250m length of embankment. On each side of the embankment there was an area of concentrated entrances and then a few entrances remote from the main concentrations.

An Inspection under Section 10 of the Reservoirs Act 1975 carried out in June 2010 recommended measures in the interests of safety which included permanently excluding the badgers from the embankment and dealing with preferential seepage paths along the badger tunnels within the embankment. Several options were considered and filling the tunnel network with grout was selected as the appropriate solution.

The badger exclusion was carried out under licence from Natural England and under the direction of a specialist ecologist. The exclusion process included the creation of an artificial sett nearby and gating of the sett entrances. The location of the artificial sett was selected to be near a regular foraging route of the badgers. The badgers were successfully relocated to the artificial sett by the exclusion gates and food enticement to encourage them to explore the artificial sett. Permanent exclusion was effected by the installation of about 800m of badger-proof fence around perimeter of the embankment to exclude badgers from the area which would retain the reservoir.

This paper concentrates on the grouting up of the tunnels, but makes a brief mention of construction of an artificial sett which might be of interest others.

ARTIFICIAL SETT

The location of the artificial sett was chosen to make it easy for the badgers to find and thereby increase chances that the badgers would take up residence once they no longer had access to the established setts. The ecology specialist chose the location following observations of the behaviour of the badger colony. At this site, a convenient location was found on a gentle slope in a field a few hundred meters from the embankment. The construction was set into the slope by about 1m depth, covered with turf and upon completion was inconspicuous from a distance.

The artificial sett was constructed as a series of tunnels and chambers covering an area about 20m long x 15m wide to emulate a natural sett. The construction material comprised 400mm diameter polypipe to form tunnels and chestnut posts to construct a series of chambers (seven in this case). The polypipe was perforated and subsequently water proofed by wrapping in plastic sheeting to prevent condensation which tends to form in the crown of solid pipes. The chambers were also water proofed with plastic sheeting. The pipes and chambers were partly backfilled with earth and other organic materials for the badgers to dig out and thus simulate natural conditions. At the time of the relocation, very dry conditions prevailed and food trails to the artificial proved very useful in enticing the animals to the artificial sett so that when access to the natural setts was closed, the badgers quickly colonised the artificial sett. The cost of construction of the artificial sett was about £25,000.

PROGRAMME

Disturbance of active badger setts is only permitted from the beginning of July to the end of November. The artificial sett was completed at the beginning of January 2011 to allow plenty of time for to badgers to discover and familiarise themselves with the sett. An outline programme from the start of the exclusion of the badgers from the existing sett is shown below.

WEEK ENDING	30/07/2011	06/08/2011	13/08/2011	20/08/2011	27/08/2011	03/09/2011	10/09/2011	17/09/2011	24/09/2011	01/10/2011	08/10/2011	15/10/2011
Exclusion Period	■	■	■	■								
NE Authorisation to close existing sett				■								
Mobilisation for Grouting					■	■						
Grouting from Sett Entrances							■	■	■			
Lance Grouting										■	■	■

Figure 1. Outline Programme

GROUTING WORKS

Ground Conditions

Ground investigation showed that the embankment fill is generally fine, sometimes medium, silty sand believed to have been derived from a cutting in the Greensand some distance up the line. The material was probably end-tipped across the valley as the railway line progressed. Standard Penetration Tests (SPTs) indicated that the material was generally loose to medium dense. This material was likely to highly susceptible to internal erosion by piping and hence the Inspecting Engineer's concerns about preferential seepage paths through the embankment.

Estimating the volume of voids

An estimate of the volume of voids within the embankment was required to estimate the volume of grout required to fill tunnels and chambers. Consideration was given to using Ground-Penetrating Radar (GPR) to detect the extent of tunnels and chambers (Nicol et al (2003)). However, it was judged that for the site under consideration, the depth of the setts below the crest and extensive tree root systems within the embankment would reduce the reliability of GPR. An alternative approach was therefore adopted to estimate the volume of grout required.

An estimate of the likely volume of voids formed by badger tunnels and chambers was made on the basis of the number of entrances and estimated length of tunnels. Roper (1992) noted that tunnels are generally 250mm to 350mm wide and 170mm to 250mm high and Rimmington (2004) suggested that tunnels generally extend 20m from an entrance. On this basis and 27 entrances, a preliminary volume of 16m^3 was estimated.

The extent of badger setts can be extensive as noted by Roper who showed plans of excavated setts and the tortuous nature of some of the well established setts. He presented a volume estimate of 25m³ for a sett with 38 entrances and 360m length of tunnels. McKillop (1993) mentioned a set with 94 tunnels with a total length of 310m and a volume of 15m³. Although the preliminary estimate was of the same order as these estimates, it was recognized that tortuous nature of tunnels could result in a substantially greater volume of grout being required. On this basis the contract for the work included a significant risk allowance on the volume grout.

Estimates of the volume of grout likely to be used will be influenced by tunnel collapses and the material in which the tunnels have been formed. Tunnel collapses will reduce the grout take and are difficult to quantify. In sandy materials, the grout could penetrate the inter-particle voids and thereby increase the volume of grout consumed.

<u>Grouting Procedures</u>
A two phase procedure was adopted to fill the voids. The first phase comprised filling the setts from the entrances under gravity followed by a second phase of lance grouting from crest. The gravity grouting commenced at the lowest setts and moved up to the higher setts. Sand bags were placed around the set entrance for to contain the grout when the tunnel was filled and contain grout to level above the crown of the entrance. The grout mixer was located on the crest and the grout introduced via a 50mm diameter pipe pushed in from the entrance as far as it would go. Efforts were made to incorporate a second pipe to act as a vent, but this was not always successful as it was difficult to support it in the crown of the pipe. The grouting procedure is shown schematically below.

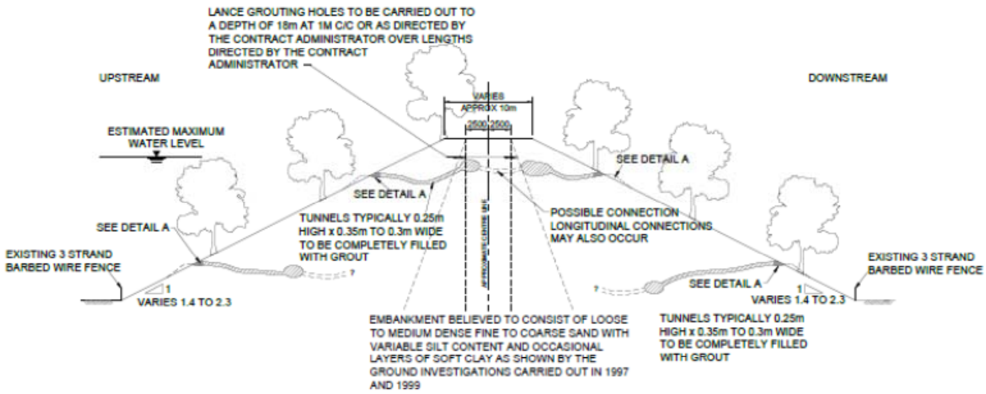

Figure 2. Schematic Showing Grouting of Setts

The lance grouting was carried out for 20m on either side of the outermost sett entrance and extended to 5m below the lowest invert in the group of entrances. A primary spacing of 2m was adopted with split spacing for secondary holes to provide a final hole pacing of 1m. The inclusion of secondary holes was based on the takes in the primary holes. The lance grouting was carried out from 102mm diameter casing rotary drilled to depth and withdrawn progressively while monitoring the grout level inside the casing in the ground. The applied pressure was the static head of grout which was about 0.16bar/m.

The plant used for the work comprised a Colcrete 410 high shear mixer for the grout and a Klemm KR802-2 top drive rotary drilling rig for the lance grouting. Drilling was carried out using air flush thereby eliminating the need to collect and control return flows which would have occurred with a fluid flushing medium.

Grout Mix

Owing to the likely tortuous nature of the tunnel network and the distance grout might have to travel from the outlet of the grout pipe to the end of a tunnel, a mobile grout was required. A high strength grout was not required and a minimum seven day strength of 135kPa was specified.

The grout material was a blended product comprising 1 part OPC : 4 parts PFA with 2.5% by weight of bentonite marketed as a thixotropic gel modified grout. The material was delivered to site in pre-mixed bags which avoided the need for weigh batching on site. However, the lead time for supply was a few days as the supplier batched to order so orders had to be placed in advance of grouting running out on site. A few stoppages were encountered due to lack of material, but overall this did not have an adverse effect on the programme.

Trial mixes with various water/solids ratios were carried out on site and a mix with a water/solids ratio of about 0.7 was selected for the works. Quality control during the works comprised Colcrete grout flow trough measurements and mud balance density tests each twice a day. The target flow distance was about 1300mm and a mud balance density of 1.58.

GROUTING RESULTS

Grout Consumption

The mass of grout powder consumed and the estimated volume of grout placed in the ground are summarized below.

Table 1. Summary of Grout Consumption Placed from the Sett Entrances

Location	Number of Entrances	Mass of Powder Consumed (t)	Volume of grout placed via the entrance (m^3)
Upstream	16	21.375	27.2
Downstream	11	20.850	23.2
Totals	27	42.225	50.4

The gravity grouting takes, based on the projected area treated above the toe of the embankment varied from about 20kg/m² in the areas of high concentration of sett entrances to 7kg/m² for an isolated entrance. The embankment on this project was up to 18m high and these takes per unit area would be higher for the same number of entrances in a lower embankment.

Table 2. Summary of Lance Grout Consumption

Sequence	No of Holes	Length of Holes (m)	Mass of Powder Consumed (t)	Volume of Grout[1] (m³)
Primary	141	1428	26.99	29.82
Secondary	71	820	7.3	8.13
Totals	212	2,248	34.3	37.95

[1] Volume includes the volume to fill the lance grout hole. The estimated volume of the lance grout holes was 18.2m³ which used about 16.45t of powder.

Table 3. Total Grout Consumption

No. of entrances	Total mass of powder (t)	Total volume of grout (m³)
27	76.525	88.35

During the lance grouting, voids were detected in a few places and high takes were experienced in these locations e.g. about 3.6m³ of grout in one place and 2.3m³ grout in another. Table 2 shows that on average the ratio of grout placed in the lance grout holes to the theoretical volume of the holes was about 2.1 and grout take was about 15.3kg powder per metre of hole. The take in the secondary holes was 8.9kg powder per metre of hole, a reduction from the primary holes.

The total area treated with lance grouting was 2,626m² and from the values in Table 2, the grout consumption was about 13.1kg/m² or 14.5litre/metre.

Table 1 and Table 2 show that the volume of grout placed in the ground, taking into account the volume required to backfill the lance grout holes was about 70m³ and considerably more than the preliminary estimate based on assumed tunnel lengths and diameters. The volume of grout placed in the voids represents 2.6m³/per entrance.

The Qualified Civil Engineer appointed to supervise the design and construction of the work reviewed the specification and drawings prior the start of the work. He visited site during the grouting work and was satisfied with the procedures adopted for the execution and control of the work.

Quality Control Test Results

A summary of control tests is given below.

Table 4. Summary of Grout Control Tests

	Water/solids ratio	Flow (cm)	Mud balance density
Maximum	0.87	140	1.62
Minimum	0.69	100	1.56
Average	0.72	127	1.57
Standard deviation	0.059	8.2	0.01

The average 7 day strength of 100mm x 100mm grout cubes was 1.9MPa.

The cost of the grouting was about £60,000.

PRECEDENT FOR GROUTING OF BADGER SETTS

Information that became available on grouting of badger setts concerned remedial works to a number of sections of railway embankment. The embankment was 5.5m to 8m high with slopes of 28^o to 35^o. Grouting was carried out by lance grouting on a 2m staggered grid into the face of the embankment. Lance grouting was carried out using machine mounted drill string and hand lancing. The face of treated sections of embankment was covered in mesh to prevent future burrowing activity. Soil nails were also installed on some sections of the embankment where instability had been detected.

Data for grouting up these badger setts was as follows:

Table 5. Railway Embankment Sett Information

No of Entrances	Length of embankment Treated (m)
10	60.1
1	23.5
1	23.7
7	44.0
6	34.5
9	68.8
3	25.3
3	50.6
Total 40	Total 330.5m

The volume of the tunnels was estimated to be about 230m^3 based on the estimated volumes of the spoil heaps (310m^3) taking into account bulking. This information suggests that there was about 5.75m^3 per entrance.

CONCLUSIONS

The project successfully relocated badgers and treated an abandoned railway embankment to make it suitable as a dam embankment for a flood detention reservoir. The need for planning of the works to allow time for licenses and the limited times of year when badgers can be relocated should be noted.

The project provided grout consumption information, which taken with data from another badger sett grouting project leads to the following conclusions:

- Estimating the volume of the badger sett complex is uncertain and a generous allowance should be included in the risk budget.
- The grouting results indicated takes between about 7kg/m² to 20kg/m² for the projected area of embankment.
- A two phase approach is recommended, of gravity grouting the setts. Followed by lance grouting either from the crest or into the face if accessible. Areas untreated during the filling from the sett entrances were picked up in the lance grouting phase.
- Where localised untreated zones were not detected, the lance grouting appeared to have some effect with a ratio of volume placed to estimated volume of the grout hole of about 2.

ACKNOWLEDGMENTS
The author acknowledges permission from the Environment Agency to publish this paper and BAM Ritchie for providing additional information on badger sett grouting.

REFERENCES

Nicol D, Lenham J W and Reynolds J M (2003) Application of ground-penetrating radar to investigate effects of badger setts on slope stability at St Asaph Bypass, North Wales, *Quarterly Journal or Engineering Geology and Hydrogeology*, No 36, pp 143 – 153.

Rimmington J N (2004) *Guidance manual for the care of archaeological earthworks under grassland management, Proactive Earthwork Management on Hadrian's Wall World Heritage Site Project*, A Heritage Laboratory Project funded by the European Union's Raphael Programme.

Roper T J (1992) Badger (*Meles meles*) setts – architecture, internal environment and function, *Mammal Review,* Volume 22, No. 1, pp 43 – 53.

McKillop G (1993) Burrowing Mammals and the Safety of Embankment Dams and Reservoirs: Potential Problems and Solutions, *Dams and Reservoirs*, October, pp 10 -12