Reconstruction of Llangollen Canal

G. Haider

P. Lacey, *Ove Arup & Partners*

Has it been the policy of British Waterways to give consideration to bank stabilization since the 1960 failure, or was this started when such failures became very frequent?

52. The second question concerns the length between bridges 35 and 36, where all the trouble seems to have occurred. I am wondering if it was monitored consistently as, after the most recent failure, namely that of 1982, it must be considered a weak spot by an outsider.

53. The third question concerns the precast edges of the existing canal. I think they were precast set in puddle clay on some sort of foundation which I could not tell from the figures in the Paper. Is it possible that these could have been nudged over by amateur boaters and thus let water down through the sealing of the puddle clay or between the walls? Did they actually have cracks in these side walls?

54. Could the Author expand on the joint detail that was actually used. I presume that the price per metre of the concrete canal includes the joints, because they are fairly frequent and must have been quite a costly item in the finances? Could the Author also explain the pinhole test defined for the puddle clay.

55. With regard to the long drainage system, the Author explained that he took surface water, in pipes, down the hill, presumably to the river. At what sort of centres did he have these pipes running down the hill, as presumably they form water runs in their own right within the embankment?

56. Going back to first principles, was consideration given to altering the embankment slope or profile itself before the canal was rebuilt? Was releveling of the canal box itself considered as an option, or was it left exactly as it was?

57. Finally, could the Author give any information on navigation in the canal.

F. H. Hughes, *Cementation Piling & Foundations*

As the deposits in the valley side are of glacial origin, these must be variable; and no matter how many investigation boreholes were sunk, each would be different. However, it appears that the information obtained on the silt layers was sufficient for design.

59. My first question concerns a plan which, I believe, considered the use of permanent inclined and/or vertical filter drains to intercept perched water, and the conducting of this water to the lower sands and gravels in order to improve stability. Was any such relief drainage undertaken? Drilling with temporary lining casing in the variable deposits would be difficult with the need to hold the permanent filter in place as the lining casing was removed. However, such systems

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have been used, for example, to improve slope stability at Herne Bay where Sandwich drains were placed into the bore.

60. The Author mentioned the issues of water in the slope below the canal. Was his staff checking these for flow on a regular basis and was a further check made to ascertain if the water was clean or cloudy? A rapid rise of flow together with silt particles might indicate a piping failure.

61. Was rock fill used to repair the breach, and to ease the slope in order to provide increased future stability? Where there have been failures in motorway cuttings, benching followed by the placement of rock or large granular fill over a geotextile has been used as an infill repair. The geotextile would need to act as filter medium.

62. My final question concerns the use of puddle clay. This material would remain intact, provided that it was moist. However, the Author mentioned that on numerous occasions in the winter the canal was dewatered for maintenance. Was there any concern that, during a dry period, the puddle clay might shrink and so allow leakage later? Is there any evidence to show that such a canal left dewatered for some time is more prone to leakage?

63. It is probably not economic nowadays to undertake the traditional puddle work where 'heeling' by men skilled in working clay is used. Is this method used in repair by anyone? In 1969, we collaborated in raising the puddle of a reservoir which had settled some 1.5 m as a result of mining subsidence. A suspension of brick clay was added to a sand and gravel, and a small quantity of cement mixed to produce a gel (the cement content was about 4% of total solids). The clay was pre-mixed in a pug mill; the final slurry was made to be non-segregating. This slurry was despatched by means of a monorail tipper to the trench excavation and fed into the core trench. It is not suggested that such a procedure would have been applicable for the repair at the breach described.

M. Puller, *Butler-Puller Partnership*

Mr Haider's Paper mentions that Telford was responsible for the original canal design. Can Mr Haider say why this structure was sited at mid-height of this slope, or on this particular slope. Was it for hydraulic or land usage reasons, or was land short in Llangollen in 1830?

65. The Author has explained that the new structure as built was chosen, in spite of its being the most expensive option, because it was known to be thoroughly waterproof. However, it does appear to be a relatively stiff structure which is replacing a relatively flexible structure. In view of the fact that some movement might occur in the slope in the future, is the Author sure that the structure is going to stay waterproof?

66. My third question refers to design philosophy: Telford's original work has lasted 150 years, with some relatively small problems during the last 30 or 40 years. This is a relatively long design life. What is the Author's attitude towards the design life of the new structure in terms of years?

M. F. Kennard, *Rofe Kennard & Lapworth*

My questions relate to instrumentation and monitoring. One of the purposes often put forward for instrumentation is to give early warning of trouble, so that there is time to do something about it. This case is another one showing that there is usually insufficient time to take action unless the sort of problem that could arise had already been foreseen; and if the problem had been foreseen, the question

remains of whether or not something could have been done about it beforehand. Observations of the flows were apparently being taken at about fortnightly intervals during that period, and it would appear from the records that the catastrophic failure occurred about a fortnight after the flow had increased.

68. Perhaps the Author could say something about the philosophy of the instrumentation: what he was hoping that it would show? An inclinometer was installed yet I do not think that the observations from that inclinometer were discussed. I tend to the belief that it told him nothing, but it would be interesting to know why he put it down and what his views are on inclinometers.

69. On the question of instrumentation generally, now that the old structure has been replaced with a non-erodible permanent structure, are any observations in fact made along that length of canal?

W. L. Wakeling, Consulting Engineer

Could the Author say how he decided on the priorities for reconstruction, as Fig. 13 shows that it is obviously not a sequential programme.

71. There is now a concrete channel from one end to the other. Did the Author ever consider a means of improving the quality of the thickness of the puddle clay lining by using pulverized fuel ash—for example, to fill the cracks? As the failure is probably due to damage to the lining by boats, and a number of failures occurred in one particular area, was this a difficult section of the canal where boats were frequently running aground and having to be pushed off, thus damaging the linings?

72. How frequently would the channel be dewatered for normal inspection and maintenance?

M. H. Goldsworthy, Senior Resident Engineer, Bekok Dam, Malaysia

With a previous employer, I was involved in the detailed investigations discussed in the Author's Paper, and in the initial formulation of the remedial works programme. This work was greatly facilitated by the existence of British Waterways performance records for earlier periods. With old structures within the ground, it is frequently only by the comparison of earlier and current observations that it is possible to detect the insidious effects of erosion and decay. This point is made in an article in *New Civil Engineer*⁶ which was based, in part, on the Llangollen Canal experiences. This point is not made lightly. Consider the issue of *Proceedings* in which this Paper is published—the average age of the works discussed in the papers is 151 years.

74. An interesting question in investigations of failures of old structures is 'Why now?'. For the Llangollen Canal, the answer seems to have been a combination of the type of lining, the current resulting from its water supply function, and of changes in the number and the propulsion system of the boats. In the Paper, it is noted that the canal was lined with puddle clay; but there was not much evidence of this when investigations were made of the canal bed. Also, there was sometimes a pronounced groove in the bed corresponding to the propeller track. Evidence from bridge sites was that there was significant longitudinal transport of gravel sized material, and it seems likely that much, if not all, of the puddle clay would have gone the same way. Increasing outflow from the canal is noted in the Paper as being an observed precursor to at least one of the failures.

75. Reports of other deficiencies were considered during the studies. One of these, not mentioned in detail in the Paper, was the occurrence in some areas of

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Fig. 18. Joint details for slab and walls: (a) contraction joint (at 7.5 m c/c), (b) expansion joint (at 30 m c/c)

local depressions in the canal bed. The favoured hypothesis was that these were a result of seepage from the canal, this flow causing internal erosion in the underlying materials. The complex suite of glacial materials meant that this could not be discounted in any case, but the field investigations provided additional support. One of the extruded samples of clayey till had a pipe of washed gravel running right through it.

76. It is noted in the Paper that gravel filters have been placed over the springs issuing from the slopes below the canal. This could be hazardous if a combination of filtration with continued erosion internally were to lead to a marked reduction of permeability near to the slope face. Has any deterioration in piezometric levels been observed which might be attributed to this treatment?

Mr Haider

With the 1960 failure in the background, and the existence of water issues from embankments, British Waterways had been following a policy of surveillance and visual inspection of the canal from Chirk to Llangollen. No detailed investigations were carried out to justify works necessary to safeguard against further failures. In any case, stabilization of banks sufficient to prevent the kind of failures which have occurred would not be the right solution. Considering the height and steepness of slopes, prevention of leakage from the canal would be the only viable solution. The length between bridges 35 and 36 has particularly steep slopes, and it became the centre of attention after the 1982 failure.

78. Mr Lacey observed the possibility that puddle clay under the concrete walls of a composite cross-section could have allowed the wall to be nudged over

by amateur boaters. This would be possible only if the puddle clay below the wall had softened which, by definition, means failure must already have started.

79. Joint details and the pinhole test apparatus are shown in Figs 18 and 19 respectively. Costs of construction given in the Paper include those for the joints. The pinhole test as developed by J. L. Sherard is a very practical test to identify dispersive soils. The flow of water through the specimen under a constant head causes erosion of soils of dispersive nature with high sodium content; only erosion resistant clays with a preponderance of calcium and magnesium make good puddle clays for canal lining.

80. Mr Lacey asked if consideration had been given to altering embankment slopes. Where possible, further land was purchased and finished gradients of new embankments were made easier. However, this was not possible at all the sites. Drainage pipes down the embankment did not go all the way to the river. An erosion resistant apron some 20 m down the embankment was made to allow the drainage pipe to discharge. Any alteration in the canal levels was neither needed nor possible: the weir at Horseshoe Falls is at a fixed level. Minimum draught requirements and minimum discharge as a feeder are factors determining the existing levels.

81. Llangollen Canal is one of the most popular canals and at places it is very narrow. Navigation in such circumstances is not an easy task, especially for novice boaters. With two boats occupying most of the cross-section, the boaters invariably seek help from the use of poles, etc.

82. I share Mr Hughes's confidence in filter drains. However, none were used on this project, as the very detailed investigations carried out on the length between bridges 35 and 36 proved that the possibility of a perched groundwater level above the upper silt layer had to be ruled out. The stretch at Bontwood has a

Fig. 19. Pinhole test apparatus

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perched groundwater level, but use was made of the existing issues which either were trained to discharge in the drainage system or were protected against possible erosion at discharging positions.

83. Most of the significant issues of water below canal level were checked regularly for quantity by means of V-notches, and for any suspended particles. Fig. 9 in the Paper shows the observations of flow at V-notch 14A immediately before the 1985 breach.

84. Both the 1982 and 1985 breaches were repaired by means of imported crushed limestone. Carboniferous limestone was used for the upper 5 m depth of the fill. The failed part of the slopes was removed and benched into stable slopes. No geotextiles were used before the limestone was compacted into the benched hillside, as the entire supply of limestone was well-graded material.

85. Mr Hughes's concern on the puddle clay cracking when left to dry is correct. Every time the canal was dewatered, care was taken to use stop planks which would ensure a certain depth of water to keep the clay in moist condition.

86. *Mr Puller's* first question should really be addressed to Thomas Telford himself. I would suggest that the siting of the weir at Horseshoe Falls and the connecting point at Trevor were decisions which must have been made to fit the feeder channel with the mainline of the Llangollen Canal. The decision to stop the mainline near Trevor in the hope that it would continue eventually beyond Ruabon must also have some bearing on the siting of the feeder canal. For the purpose for which it was built, the feeder canal from Horseshoe Falls to Trevor had to be a contour canal.

87. The concrete channel has joints at every 7.5 m, with scope for accommodating expansion in the joints at every 30 m in length of the canal; this will provide the necessary flexibility. Provided that there is no leakage, consolidation of the sub-soil is in a satisfactory state.

88. There have been problems with the stability of the hillside since soon after completion of the canal in the Vale of Llangollen. It is hoped that by stopping leakage from the canal, these problems will cease to exist.

89. I agree with *Mr Kennard's* views that the installation of an inclinometer has not helped towards a better understanding of the problem. It was installed at the time when it was necessary to check everything. In the event, flows-through issues below canal level and readings of piezometers are the only data which have helped to provide a clear picture of the behaviour of the water-table and of the causes of failure. These data are still being collected to provide further confirmatory information.

90. The first major task immediately after reinstatement of the 1982 breach was to decide on the priorities for reconstruction, as raised by *Mr Wakeling*. A systematic examination of each slope, as well as of the behaviour of the groundwater table, was carried out for the entire length from Chirk to Llangollen. From this information, it was possible to conduct a risk analysis, giving each section an order of priority which was followed throughout the reconstruction programme.

91. The possibilities of repairing and indeed replacing areas of puddle clay were examined and, in fact, tried out in places. However, as I have explained in the Paper, the risks involved were too high, especially when allowance was made for unpredictable damage caused by the users of the canal.

92. A number of failures have occurred in one particular area between bridges 35 and 36, mainly because of the unique combination of very steep slopes, a steeply inclining configuration of layers of silt in the glacially derived formation and

leakages from the canal. It is not a length where boats would habitually run aground and cause physical damage to the lining as a matter of routine.

93. Dewatering of the canal does not follow any pre-fixed inspection cycles: most of the inspection is possible with the water in the canal. If necessary for repairing banks, bridges, culverts or any other structures, opportunity is taken thoroughly to inspect the lining in a dewatered state. Dewatering is carried out in a controlled manner and, in order to ensure the integrity of puddle clay, it is not allowed for long periods in the dry.

94. With regard to failures of old structures, the assumption underlying *Mr Goldsworthy's* question of 'Why now?' must be considered carefully. It must be remembered that only major failures tend to be retained in records. In the paper, I have described failures going back to 1945; I have no doubt that there must have been numerous failures, other than those in 1945, 1960, 1982 and 1985, which never made the headlines, as they were not as catastrophic. Since the publication of the Paper, a Mrs Edwards from Llangollen has written to me, explaining her vivid memory of a major failure in 1923, near Bridge 33.

95. I can well understand Mr Goldsworthy's concern over a possible blockage of filters placed at the discharging locations of water issues in the Bontwood length. A perched water-table exists in this area, and these issues have traditionally been fairly active. The flows are of good clean water which has formed its path over the years. A fairly large single-size material has been placed, primarily to discourage propagation of any erosion.

Reference

6. GOLDSWORTHY M. H. Buried treasure or wasting assets? *New Civil Engineer*. 15 January, 1987.