Lightweight fill in dam remediation - a case study

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SYNOPSIS. The east dam at Millbuies Loch was reconstructed following observations of crest settlement. Investigations found the embankment was founded on a layer of peat. It was concluded that there was significant potential for further settlement of the peat foundation if additional soil were added to make up the freeboard. The embankment was reconstructed using a combination of existing fill and new expanded polystyrene lightweight block fill.

INTRODUCTION

Millbuies Loch is an amenity reservoir located about 6km south of Elgin, in Moray in the north-east of Scotland. It is understood that the reservoir was originally used for water supply, but is now redundant for that purpose. The loch now forms the centrepiece of Millbuies Country Park, an important recreational asset owned by The Moray Council. The park is popular with walkers and the loch is also used as a trout fishery operated by the Council.

The reservoir is situated in a narrow valley with steep forested slopes to north and south. On the north side the ground rises steeply about 15m to a ridge and then falls away. On the south side the ground rises steeply to an escarpment and then continues to rise steadily at an average gradient of about 1 in 10. A catchment area of about 1km^2 drains to the reservoir from the south.

The loch lies approximately east-west and is about 900m long but with an average width of only about 50m. The reservoir is retained by two small earth embankments at the east and west ends which drain to separate tributaries of the River Lossie. The location of the loch is shown on the plan in Figure 1.

The west embankment is about 5.5m high and 45m long. The east embankment is about 3 m high and 40 m long. Each dam has a narrow stone pitched overflow channel at its north abutment with the weir crests set at the same level. The date of construction is not known and no original

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record drawings are available. The smaller but deeper western part of the reservoir is joined to the eastern part by a narrow channel over a ridge at the original watershed. The depth of water here is less than 1m, so the reservoir divides in two if significant drawdown occurs.

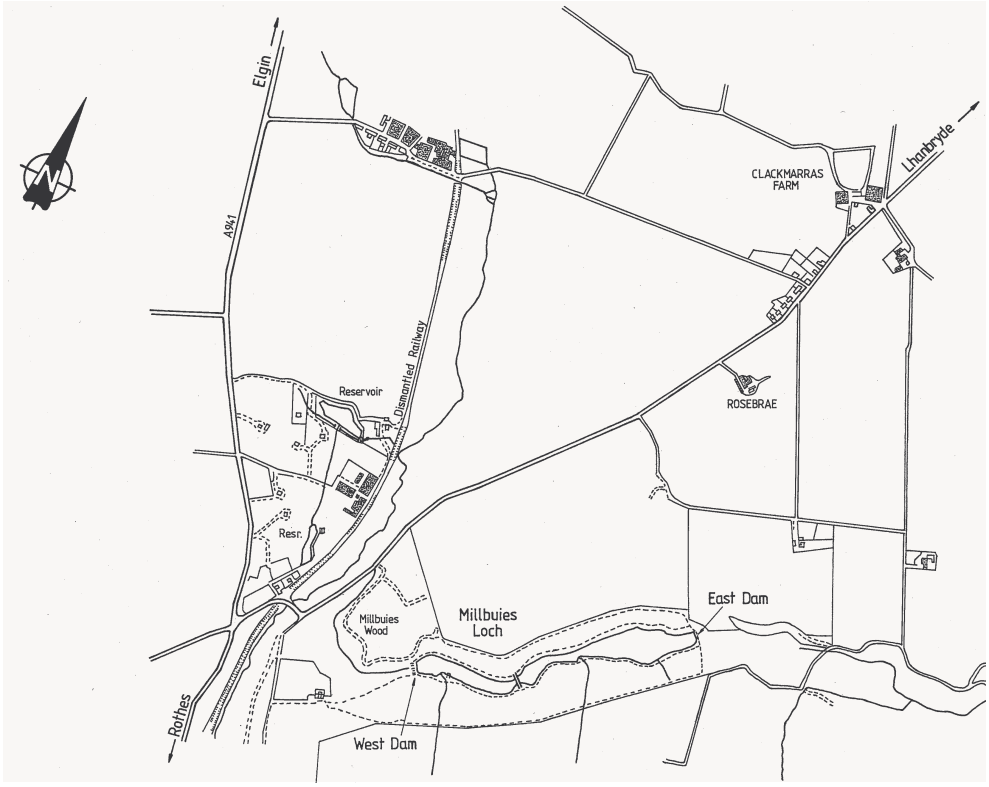

Fig. 1. Location plan

The control valve on the bottom outlet of the west dam is operated by a spindle located in the downstream slope of the embankment. This may suggest that the west dam originally retained a smaller reservoir and was raised at a later date, at the same time as the east dam was constructed.

There is poor vehicular access to the embankments at Millbuies Loch. An unsurfaced forest track runs close to the north abutment of the west dam, but at a level further up the slope well above the dam crest. At the east dam, a long length of unsurfaced forest track with steep gradients runs to the top of the escarpment above the south abutment of the dam. At this point the ground level is about 20m higher than the dam crest. Access is only possible for tracked vehicles via a cleared path through the trees directly down the slope to the dam. Access for wheeled vehicles is very difficult.

Previous remedial works

There is no record of the Loch having been inspected under the Reservoirs (Safety Provisions) Act 1930. The first inspection under the Reservoirs Act 1975 occurred in 1986 The overflow capacity and freeboard were found to be deficient. In addition, both embankments were showing signs of seepage at their respective downstream toes.

Remedial works were carried out in 1989-1990. The crests of both embankments were made up by a modest amount to improve the freeboard and 300mm high rubble masonry wave walls and stone pitching on the upstream faces installed. The two overflow channels were widened and gradients improved and new overflow weir sills installed. The existing mortared stone pitched channel linings were retained. A rockfill toe was installed at the west dam and a berm and toe drainage was installed at the east dam. A new outlet pipe was installed at the east dam to allow the reservoir to be drawn down to the level where its two parts separate.

FLOOD DAMAGE AND INVESTIGATIONS

Flooding on the Moray Firth coast often occurs during summer and autumn rainfall events and in northerly airflows associated with frontal systems. There is a long history of flooding from similar events.

On 30 June and 1 July 1997 persistent rain was driven onto the Moray coastal plain and hills by a strong north-easterly wind. Rainfall of up to 150mm was experienced over a two-day period in the band of countryside from Inverness to Banff. This severe rainfall event caused widespread flooding. Local to Millbuies, significant flooding of property was experienced in the Fogwatt and Longmorn areas, downstream of the west dam, and in the Lhanbryde area, downstream of the east dam. In the wider Moray area serious flooding of property was experienced at Elgin and Forres.

During the flood event the outlet valves were opened to reduce the water levels in the reservoir. The water level was estimated to be 450mm above the overflow crest level near the time of the peak of the event.

At the Supervising Engineer's visit to Millbuies Loch following the flood event damage that had occurred to the east overflow during the flooding was discovered. A large scour hole had formed at the bottom of the overflow channel, with undercutting of the slope of the hillside above. Cracking was evident in the south side slope of the overflow channel in the vicinity of the access bridge, suggesting settlement of the dam. There was also minor cracking of the mortar of the rubble masonry wave wall. No damage was found to the west dam. A periodical inspection was carried out the

following day and a topographic survey shortly thereafter.

The survey of the flood damage revealed that significant settlement had occurred at the east embankment. The minimum crest level established in 1990 had reduced by about 300mm, effectively eliminating the additional freeboard that had been created by the earlier remedial works.

No survey of the crest levels had been undertaken between 1990 and 1997, so it is not known how much of the settlement occurred between these dates. However, the evidence of damage seen in late August 1997 suggested that at least some of the settlement was recent. It is not thought that the duration of the flood event was sufficient for the weight of the flood surcharge to have a significant effect, so the mechanism of further settlement is not fully understood. However, the elapse of time before the damage was discovered and the survey carried out may be significant. It is speculated that the additional weight from saturation of the embankment may have resulted in further settlement over that period.

Ground investigation

In May 1998 a ground investigation contractor was appointed to carry out trial pits and boreholes to examine the causes of the observed settlement. Five cable percussion boreholes and four trial pits were taken in the east dam and one cable percussion borehole was taken for comparison in the west dam.

It was found that the east dam is founded on a layer of peat. The boreholes in the centre section of the east dam showed over 5m of sandy gravelly clay dam fill material overlying l.5m of soft fibrous peat. Below the peat there are glacial tills. In the wetland area downstream of the dam about 3-4m depth of peat was found.

It appears that the east dam was constructed by spreading dam fill material on top of an area similar to the wetland downstream of the dam. The peat foundation would have been compressed as the fill material was placed until an approximate equilibrium was reached when the weight of the fill material matched the bearing capacity of the peat layer. Settlement is likely to have continued over the life of the embankment. By 1989 the freeboard was inadequate and it was restored by making up the dam crest with fill material. Crest levels may have been made up on previous occasions although no record of this is available. The existence of the peat layer in the foundation was not known in 1989. Although a ground investigation was carried out, it was limited to relatively shallow trial pits because of the difficulty of access for drilling rigs and consequent cost.

The foundation conditions at the east dam are in contrast to the west dam, where below the dam fill material thin deposits of peaty topsoil associated with original ground level were found overlying glacial sands, silts, and gravels.

REMEDIAL WORKS OPTIONS

The first option considered was to reduce the overflow level to restore the required freeboard. However, this option would have reduced the viability of the fishery and required reconstruction of a boathouse, so the Undertaker did not wish to pursue it. It was decide to examine methods of restoring the freeboard at the Loch at a reasonable cost by raising the crest.

A number of alternative methods were considered for restoration of the freeboard. It was considered that adding more infill to raise the crest would result in further settlement and be self-defeating in the long term. Thought was also given as to whether it was practicable to surcharge the crest with additional material until the peat layer was compressed such that no further settlement would occur. It was not considered that this point could be defined with precision and the access difficulties made import of any significant quantity of material problematic. Excavation and complete reconstruction of the embankment was also ruled out on the basis of cost.

Geotechnical solutions involving some form of piling or ground improvement to increase the bearing capacity of the foundation were also considered. However, all the available methods required plant that could not easily reach the embankment or had significant establishment costs that could not be justified by the limited extent of work. The most likely candidate appeared to be jet grouting but the practice had previous experience of unsuccessful jet grouting trials in peat dam foundations and the cost was considered too high relative to the risk.

An alternative philosophy was considered involving reducing the loading on the peat foundation by removing some of the dam fill material and raising the dam using a lightweight material. In this way the dam could be raised without increasing the load on the foundation. Lightweight fill has been used starting in the 1970s in Scandinavia in road embankments on compressible foundations and is now considered an established technology. This option was chosen as representing the best value for money.

The lightweight fill material chosen was the Fillmaster, an expanded polystyrene (EPS) block system with a density of about 20kg/m^3. It is available in various grades to suit different loading conditions. EPS is an inert and durable material, the main hazards to it being fire prior to being buried and solvents such as petrol and diesel. In road embankments it is

normally protected from solvents by wrapping it in a low density polyethylene membrane. The manufacturer did not consider this necessary for Millbuies, so a geotextile separator was substituted.

It was decided to retain the existing upstream face of the embankment below top water level and to reconstruct the crest without a wave wall. This required crest levels to be raised by up to about 500mm and levels on the downstream slope to be increased by over 1m in places.

The main design considerations were ensuring no significant surcharge of the underlying peat, the stability of the EPS fill and maintaining the watertightness of the dam.

Standard profiles of the block fill were derived for different dam cross-sections. These provided sufficient lightweight fill to eliminate additional loading in each part of the crest and downstream slope. EPS blocks are water resistant, but water from the reservoir could escape through the joints between the blocks so it was decided that a new low permeability element was required in the dam cross-section upstream of the blocks. The chosen design was a self-setting bentonite/cement slurry wall in a trench excavated in the existing dam crest following demolition of the existing wave wall.

To prevent uplift pressures on the base of the EPS blocks, they were constructed on a drainage layer. A filter drain and sand layer was placed before the blocks were installed. The blocks were then carefully backfilling using excavated fill material.

The downstream face of the dam was protected with an erosion control mat to prevent erosion if any occasional over-topping should occur. A perforated pipe drainage system was included to drain the filter drain under the EPS blocks.

CONSTRUCTION

Following tendering Balfour Beatty Construction Limited was appointed to construct the works in 2000.

During the early stages of construction the contractor approached the designers with a view to consideration of alternatives to the cement-bentonite slurry trench. The contractor was concerned over the financial risk associated with delays to its specialist sub-contractor in the event of adverse weather or access difficulties. A review was carried out with the contractor of the design concept and possible alternatives. Following consideration of various possibilities the contractor proposed the use of lightweight steel sheet piling installed using a small piling hammer mounted

on a midi-excavator. It was considered this alternative offered advantages over the original design so the contract was amended accordingly. Mabey M11 interlocking lightweight steel sheet piling was used. The final design cross-section was as shown on Figure 2.

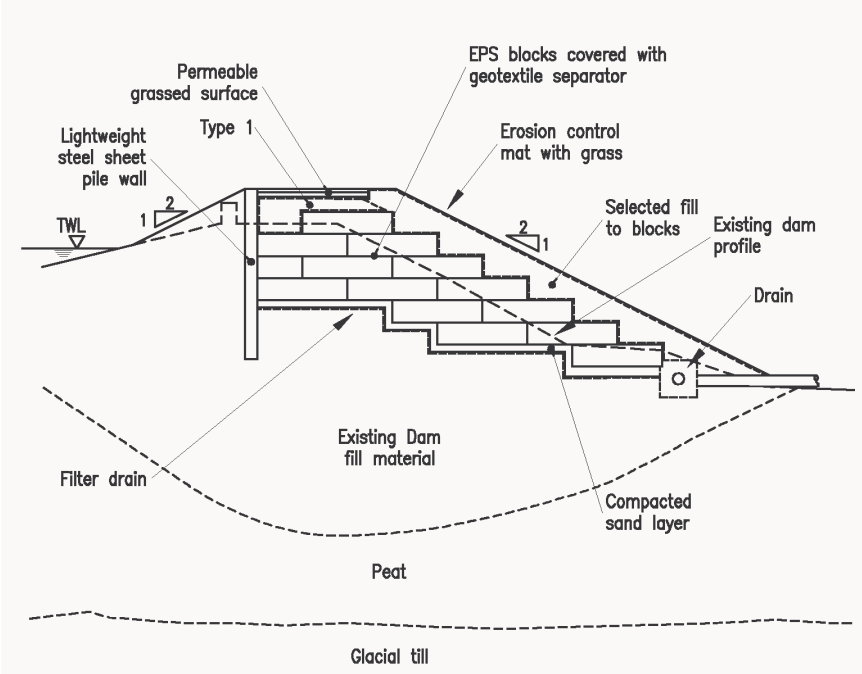

Fig. 2. Typical cross-section

Construction of the remedial works at Millbuies Loch was completed in early 2001. The reservoir was certified following a periodical inspection under the Reservoirs Act in the same year. The dam has now performed satisfactorily for 5 years since completion of the work.

CONCLUSION

Millbuies Loch east dam presented particular problems in finding a suitable method of raising the embankment crest to restore freeboard. Lightweight fill was found to be a cost-effective method in a situation where access for more conventional solutions was difficult.

REFERENCES

VR Fillmaster - Technical Information and Design Details, Vencel Resil Limited, Kent.