

The Queen Mother Reservoir, Datchet ~some aspects of its design and construction

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IN NOVEMBER 1969 men and plant of W. & C. French (Construction) Ltd. arrived on the vacated farm land site to commence the moving of 14 million m³ of earth to create the 37 700 MI capacity Datchet Reservoir for the Metropolitan Water Board.

On July 9, 1976, some 6½ years later, Her Majesty Queen Elizabeth, the Queen Mother, inaugurated the reservoir, then almost filled, and named it the Queen Mother Reservoir. Thus for Thames Water who succeeded the Metropolitan Water Board was added a new direct supply water resource for London at just the right time to cope with the present drought situation.

Also added was an important new water space for recreation, which will include sailing and trout fishing. At one point the embankment has been widened to provide a "beach" sloping at 1 in 8 from which sailing boats can be launched, and space for the clubhouse built at the top of the embankment overlooking the water. For the first time with a reservoir of this type, provision for recreation has been incorporated into the embankment design.

Site investigation

The reservoir lies to the west of London Airport not far from Windsor Castle, the whole of the site being underlain by London Clay. At this point the London Clay is thinning rapidly towards the Windsor upthrust and the strata encountered were:

- top soil — 300-600mm thick
- overburden — a variable alluvial sandy clay up to 2m thick
- sand and gravel — 1.5-7.5m thick (ballast)
- London Clay — 18-36m thick

During the initial site investigation by borehole and auger drilling from which the soil parameters and quantities were determined, a thin plane of weakness in the London Clay was revealed. A distinctive silvery grey in colour, the plane was 10-38mm thick and lay at a constant interval of about 11m above the base of the London Clay—an influential depth over substantial lengths of the embankment. In a subsequent investigation, the plane was further sampled and its location verified by sinking a number of trial pits around the proposed embankment line. Both vertical and inclined 102mm samples were obtained.

It has been suggested that this feature had resulted from flexure of the clay. In appearance and strength it was quite dif-

ferent from a "shear" plane discovered at less predictable horizons in the London Clay approximately 2km away from the Datchet site during the construction of Wraysbury Reservoir in 1971.

General design considerations

A continuous earth fill embankment 5.35km in circumference was formed to build a bunded reservoir for storing the maximum volume of water that could be contained at reasonable cost on the site. This was taken as being achieved when all materials above the London Clay available on site within the embankment which were suitable for bank building were utilised. An embankment height up to 19.8m above the original ground level resulted. A lower cost per unit of water stored could have been achieved with a lower embankment but more intensive use of the land was felt to justify the higher cost.

To economise in the use of gravel and so increase the volume of water stored, layers of compacted London Clay were incorporated into the upper levels of the

outer shoulder of the embankment where mass rather more than strength is a virtue. More extensive use of London Clay as a general bank building material was found to be uneconomic.

To carry water into and away from the reservoir, extensive use was made of tunnels driven in London Clay at depths below the original ground level over the reservoir site of between 24m and 31m. The tunnels were shield driven and lined with MWB's patented Wedge Block lining, and were built under separate contracts prior to construction of the reservoir. The Wedge Block has successfully carried the increased overburden pressure under the embankment and the decreased overburden under the floor which resulted from the reservoir construction. The tunnels terminate in shafts directly under the inlet and outlet structures.

Embankment design

The embankment comprises a central vertical core wall of compacted London Clay taken down and keyed into the

TABLE I. EFFECTIVE STRENGTH PARAMETERS OF LONDON CLAY

		Normal clay		Plane of weakness	
		C' lb/in ²	φ'	C' lb/in ²	φ'
Wraysbury	Peak	2.0	20°	1.7	18°
	Residual	0	16°	0	16°
Datchet	Peak	1.0	18.8°	1.5	12°
	Residual	0	16°	0	10.6°



Fig. 1. A 600mm inlet jet in action during the reservoir's first filling in January 1975

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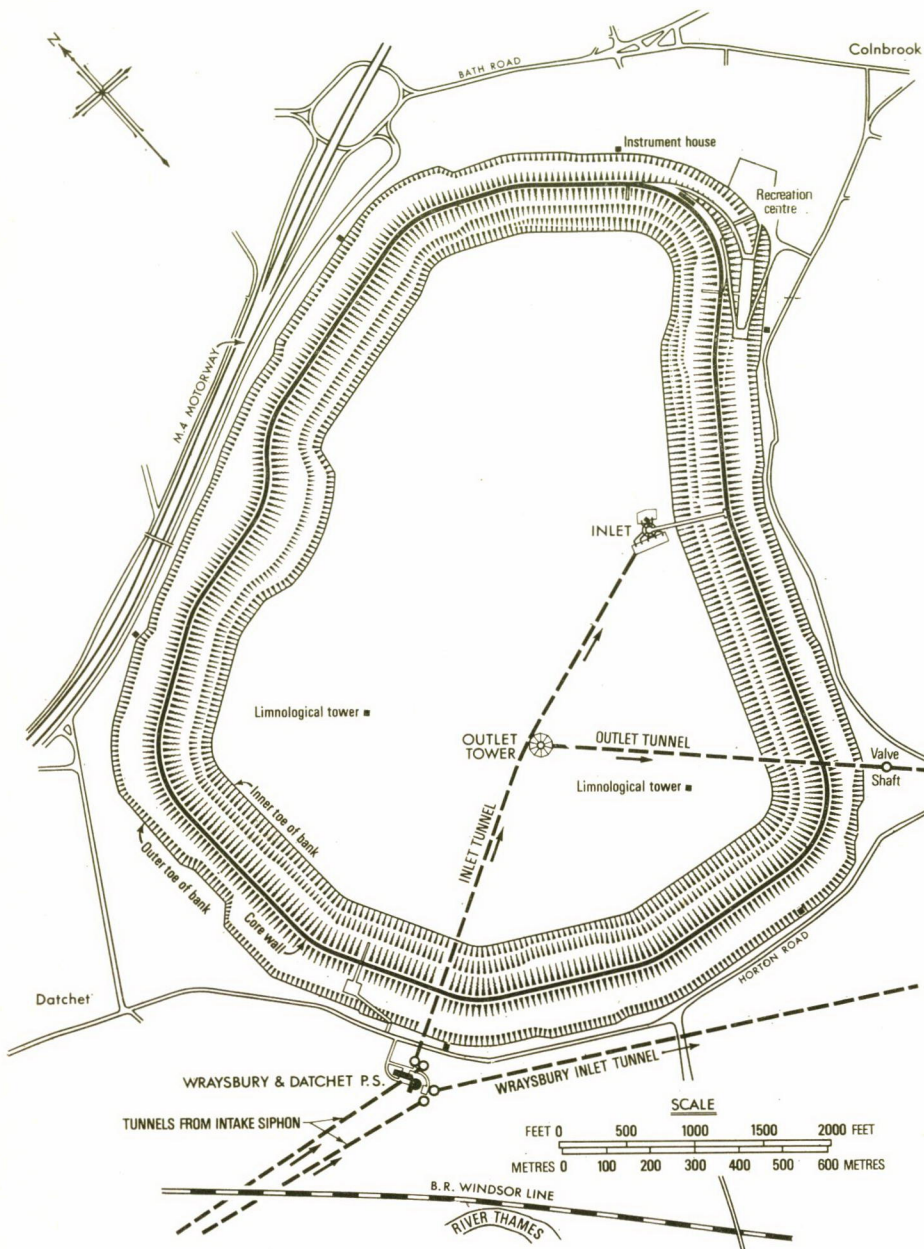


Fig. 2. Plan of the reservoir; Top Water Level = 35.1m OD

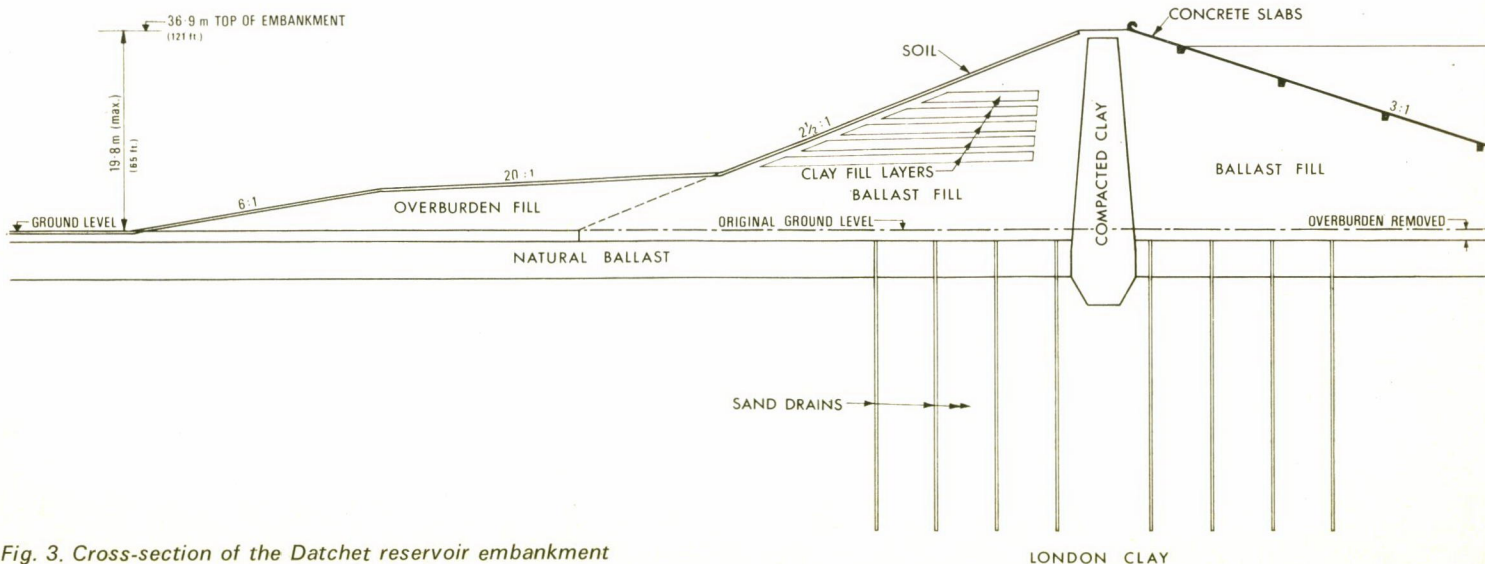


Fig. 3. Cross-section of the Datchet reservoir embankment

underlying London Clay stratum, and supported on either side by inner zones of ballast with outer zones or berms of overburden material. Under the inner zones, the overburden material being a relatively weak and compressible material was first stripped off.

The line of the embankment followed closely the boundary of the site and the heights and widths of the outer berms were varied so as to maintain overall stability sensibly constant at all cross-sections. Both circular and non-circular modes of failure were considered, using among others the method of Morgenstern and Price¹.

In addition to the height of the embankment, two significant factors were the depth below the ground level to the surface of the London Clay and the presence or otherwise at an influential depth of the weak plane. An exceptionally wide embankment resulted on the north-west side of the reservoir where the plane coincided with a peak in the London Clay.

For considerations of stability, the core wall was made as narrow as was consistent with mechanical compaction and having a slight taper in width towards the top. This taper was provided to assist in maintaining compressive stresses in the core during settlement of the embankment due to consolidation of the underlying London Clay. Being vertical and in a central position in an approximately symmetrical embankment, shear distortions in the core were minimised.

The natural moisture content of the London Clay as dug for the core was close to the plastic limit and about 3% of water was added to facilitate its compaction into a completely remoulded and homogeneous mass.

From measurements of pore pressure dissipation in the underlying London Clay at two similar reservoirs—Queen Elizabeth II (1960) and Wraysbury (1971)—more rapid rates of consolidation strengthening were anticipated (and taken into account in the design) than were predicted from conventional laboratory oedometer tests. In addition sand drains were installed in the regions of highest excess pore pressure to accelerate consolidation.

The predicted rates of consolidation were confirmed by the measurement of pore pressure dissipation during construction:

Firstly, under four sections of the outer

berm which, at the initial commencement of the construction contract, were raised as "trial" embankments, later to be incorporated into the finished profile. In two of the four sections, sand drains were also installed.

Secondly, under the main embankment as it was raised. Six cross-sections here were instrumented, four of them being at the same chainages as the trial berms, and two of them elsewhere.

The trial berms were of course somewhat less than full height trials and they increased effective stresses in the underlying London Clay to a correspondingly less extent than the main embankment. It was therefore necessary to extrapolate the results to allow for the decrease in the rate of consolidation which occurs with increasing effective stress. Records of behaviour at Queen Elizabeth II and more particularly at Wraybury where measurements were more extensive were utilised in this respect.

Construction of the embankment

The topsoil was first excavated and then the overburden over the area of the core and inner zones, to reveal the underlying ballast. This ballast was used to make haul roads above original ground level, so that materials could be moved effectively in wet weather. Carefully routed haul roads were built to and from the clay borrow pits and from the ballast and overburden strip areas.

An average 6m deep cut-off trench was dug along the centre line of the embankment and then a key was formed into the London Clay, 3m deep. To dig ballast from the cut-off trench use was made of 38-RB and 3W walking dragline excavators. Later, Caterpillar 631B's were employed to excavate this ballast. The clay core trench was dug using D8's and Cat. 463 boxes, while batters of the key were formed by a 14E grader with an angled blade. The water level near the cut-off trench was controlled by localised pumping for about two months ahead of the excavation. Four 100mm dia. and four 150mm dia. Sykes Univac pumps were used for this purpose.

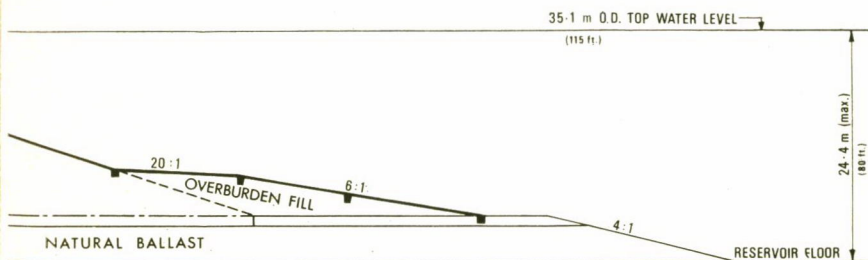
Clay was dug from two borrow pits in the centre of the reservoir by an O & K bucket wheel excavator, this machine excavating the clay in small-size lumps suitable for rolling. Water was added to the clay in the borrow pits and each layer of clay in the core was rolled with



Fig. 4. O & K bucket wheel excavator digging London Clay and loading into a Cat 631B



Fig. 5. Compacting the clay in the cut-off trench, showing the 20 ton Albaret roller towed by a D6 and the 14E grader with angled blade forming the battered side of the trench



not less than six passes of a 20 ton Albaret roller towed by a D6. This D6 was also used to level the clay prior to rolling.

The requirement was for compacted clay having not more than 3% air voids and an unconfined compressive strength of 24lb/in² at the specified moisture content, and this was consistently obtained. The strength test which could be carried out quickly on the spot was very valuable as a daily control, the results of the air voids test not being available until the next day. Likewise, the impression made by the rubber-tyred Albaret provided, with experience, a suitable indication of moisture content that was confirmed the next day by the results of soils tests.

The excavated clay was initially hauled from the borrow pits to the core by AEC dump trucks. Later, this duty was undertaken by the 631B's which proved more

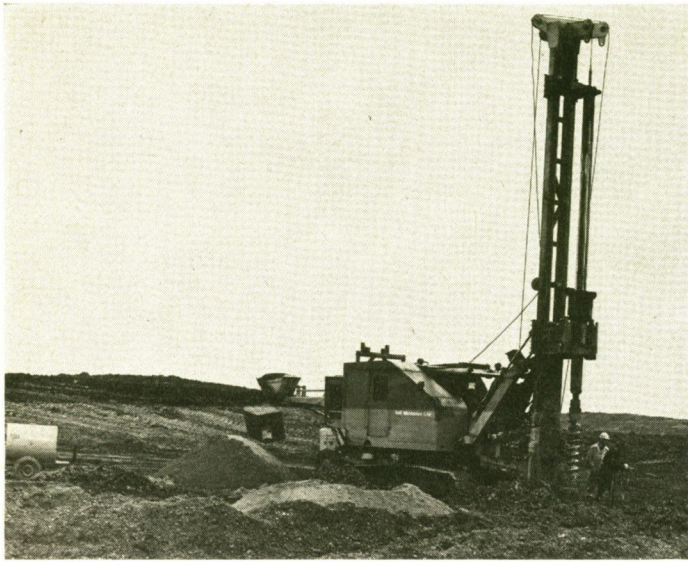


Fig. 6. CM 400 rotary auger boring a sand drain



Fig. 7. Caterpillar 631B placing ballast in the embankment

efficient. The clay core was raised to the original overburden strip level and the cut-off trench on either side simultaneously filled with ballast.

At this stage, Soil Mechanics Ltd. installed 6 000 sand drains in four rows on each side of the clay core round the line of the embankment, using track-mounted CM 400 rotary auger machines. These rigs bored 305mm diameter holes up to 20m deep into the clay without casings; the holes were then filled with sand.

Above the strip level the core wall and inner and outer zones of the embankment were raised simultaneously at each cross-section again using Cat. 631B's for both the overburden and the "as-raised" ballast materials. The required compaction and density of these materials was obtained from the passage of the earthmoving plant without the aid of special compacting machinery.

The fleet of machines used throughout the main earthmoving programme comprised ten 631B's, four D8's, two D9's, one 14E grader, one 824 and one 834.

Reservoir circulation

To prevent thermal stratification which would otherwise occur in a reservoir of 24m depth during the spring and summer months and cause water quality problems, the water is introduced into the Queen Mother Reservoir through one or more high velocity jets clustered around the foot of the inlet tower. The functions of the jets are to cause vertical mixing, to carry the mixture away from the mixing zone and so allow further mixing, and to involve the whole water mass in the circulation, whilst allowing as much sedimentation as possible, avoiding short-circuiting and allowing the maximum possible retention time.

The size and arrangement of the jets, and the positions of inlet and outlet, were determined from laboratory tests on a 1:800 model of the reservoir which was rotated on a turntable to simulate Coriolis effects. These tests were carried out at the MWB Soil Mechanics and Engineering Laboratory by Mr. P. Cooley, CEng, BSc, FICE, FIWES, an extension of the work carried out at Imperial College under the direction of Professor C. M. White².

The jets which are sized from 600mm

to 1 500mm dia. to give velocities of about 3m/sec at input rates up to 1 350Mld in 225Mld steps, are mounted just above the floor to leave an unswept sediment "sink" and are inclined at 22½° or 45° to the horizontal. Some of the jets are directed northeast generating a small anti-clockwise gyre in the northern end of the reservoir, and others are directed southwest to create a larger clockwise gyre in the southern end, at the centre of which is the outlet tower. When there is no inflow, three recirculating pumps hung on the inlet tower can be used. In the autumn and winter months when there is no risk of thermal stratification two low velocity 1m/sec jets, one directed north and the other directed vertically upwards (non-directional), may be used to introduce the water with little disturbance and allow greater sedimentation.

Acknowledgements

The design and supervision of construction of the works were under the direction of Mr. E. C. Reed, DFC, CEng, FICE FIWES, MBIM, Director of Opera-

tions, Thames Water Authority, and his predecessor as Chief Engineer to the former Metropolitan Water Board, Mr. E. S. Boniface, CEng, BSc, FICE, FIMechE, FIWES. The scheme was excuted by staff of the Metropolitan Water Division (Divisional Manager, Mr. Laurence O. Wild, CEng, FICE FIMechE, FIWES). The project engineer was Mr. H. R. H. Waters, CEng, FICE, who was also resident engineer for nearly the whole of the construction period until his retirement in 1974.

With the exception of the sand drains, the construction work was carried out by W. & C. French (Construction) Ltd. using their own labour and plant. The authors are grateful to Mr. Reed, and to the Directors of W. & C. French (Construction) Ltd, for permission to publish this article.

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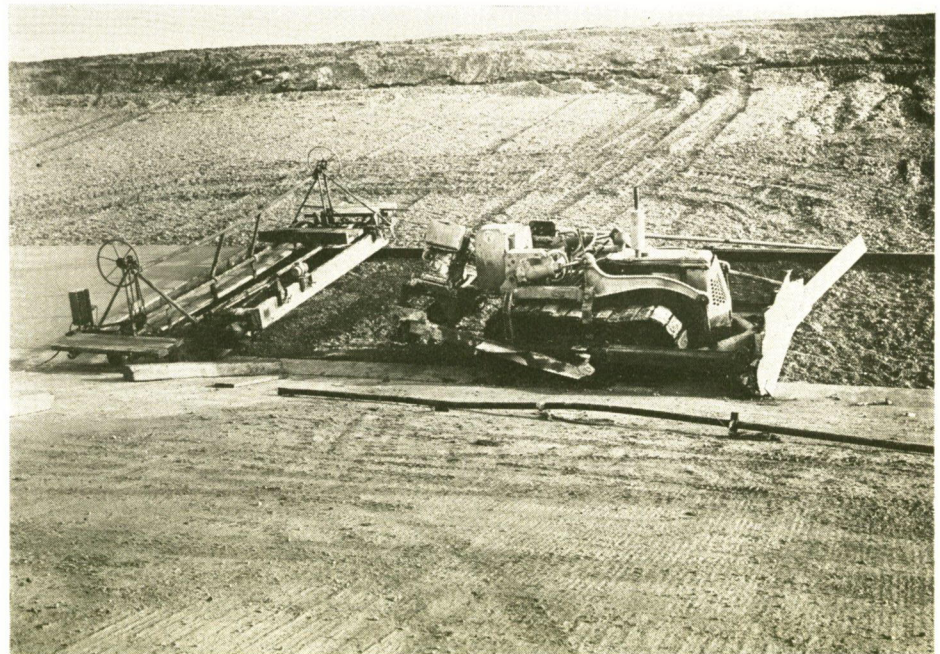


Fig. 8. Bank slabbing machine placing 100mm concrete slabbing on interior 1 in 6 and 1 in 20 slopes