Geosynthetics at New Esna Earth Dam

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ABSTRACT: The design of a recent earth dam across the Nile was changed from hydraulic sandfill to a conventional sand-and-gravel embankment. In the new design all filters were obtained with geotextiles of different grade. A large part of the geotextiles have been placed underwater. The papers provides the methodology followed during design and describes how construction was carried out.

1 THE PROJECT

The construction of the New Esna Barrage and Power Plant on the Nile, was decided in replacement of the original Esna Barrage, built in 1908 and in need of repairs to cure scouring and age damages. The new barrage is located about 1 km downstream from the old one and consists of four parts: a navigation lock on the left bank, a low head powerhouse equipped with 6 units of 15.4 MW capacity, a 6 bays spillway controlled by 12 x 16 m radial gates, with an overall discharge capacity of 2600 m3/s and an embankment dam 22 m high.

Lock, powerhouse and spillway, i.e. the concrete portion of the barrage, were built, behind a semicircular cofferdam closing off nearly half of the original river width. Once all concrete structures completed, the removal of the cofferdam and extensive dredging of the Nile bed were carried out, to create appropriate head and tail channels.

The original design called for the closure of the Nile and its diversion through the spillway by means of a coarse, granular, stream cutting dike later becoming the d/s toe of an hydraulic fill made of medium-fine sand dredged from the Nile bed. Part of such fill had to be placed underwater, part above it. In order to compact the hydraulic fill placed underwater, extensive vibroflotation, reaching 20 m into the underlying natural riverbed sand, was specified. The top portion of the embankment dam was designed as a compacted sandfill.

A modified design of the embankment dam was proposed by the authors with the aim of obtaining higher quality and a shorter construction time. The new design was based on the substitution of the hydraulic fill with a well graded, processed, alluvial material coming from a nearby wadi and on the extensive use of geotextiles as filters and erosion preventors. Vibroflotation was thus eliminated. Fig. 1 shows the typical cross section of Esna embankment according to the modified design. As it can be seen, geotextiles were used at 4 specific positions:

-1 between the fine, alluvial sand of the Nile and the uniform cobbles of the stream cutting dike, forming the free-draining toe of the dam.

-2 between the well graded sand-and-gravel dumped in water to create the body of the embankment, and the toe cobbles.

-3 under the rounded rip-rap protection specified on the u/s slope.

-4 under the granular slope protection specified on the d/s side of the dam. Fig. 2 compares some characteristics of the original hydraulic fill with those of the sand-and-gravel fill.

2 THE DESIGN PROCESS

The geotextiles of Esna embankment were designed with a comprehensive and systematic approach according to recent literature (Luettich et Al., 1992) and the author's practice. Fig. 3 presents the grading bands of the significative materials.

The toe zone is characterised by a large percentage of voids. The riverbed is mostly composed of fine, uniform sand, containing some silt in form of isolated, rounded balls. By far the largest part of the embankment is made of a well-graded sand-and-gravel. Part of this material is simply dumped in water. Selected cobbles, in the 50 -

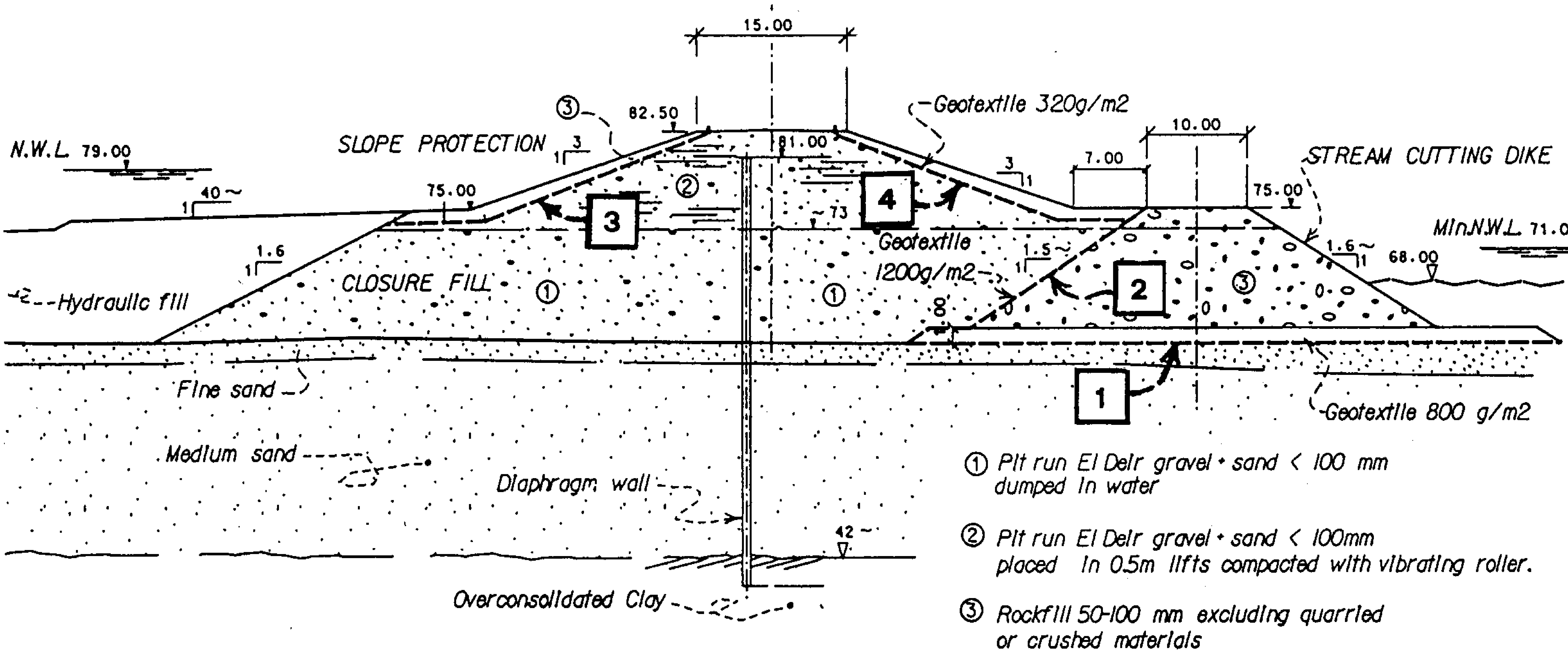

Fig. 1 New Esna Barrage. Cross section of the embankment portion also used for stream diversion. The lower part of this dam was built underwater, in a fast running stream. The 4 positions where geotextile filters have been used are shown with dashed lines. Their primary function was retention.

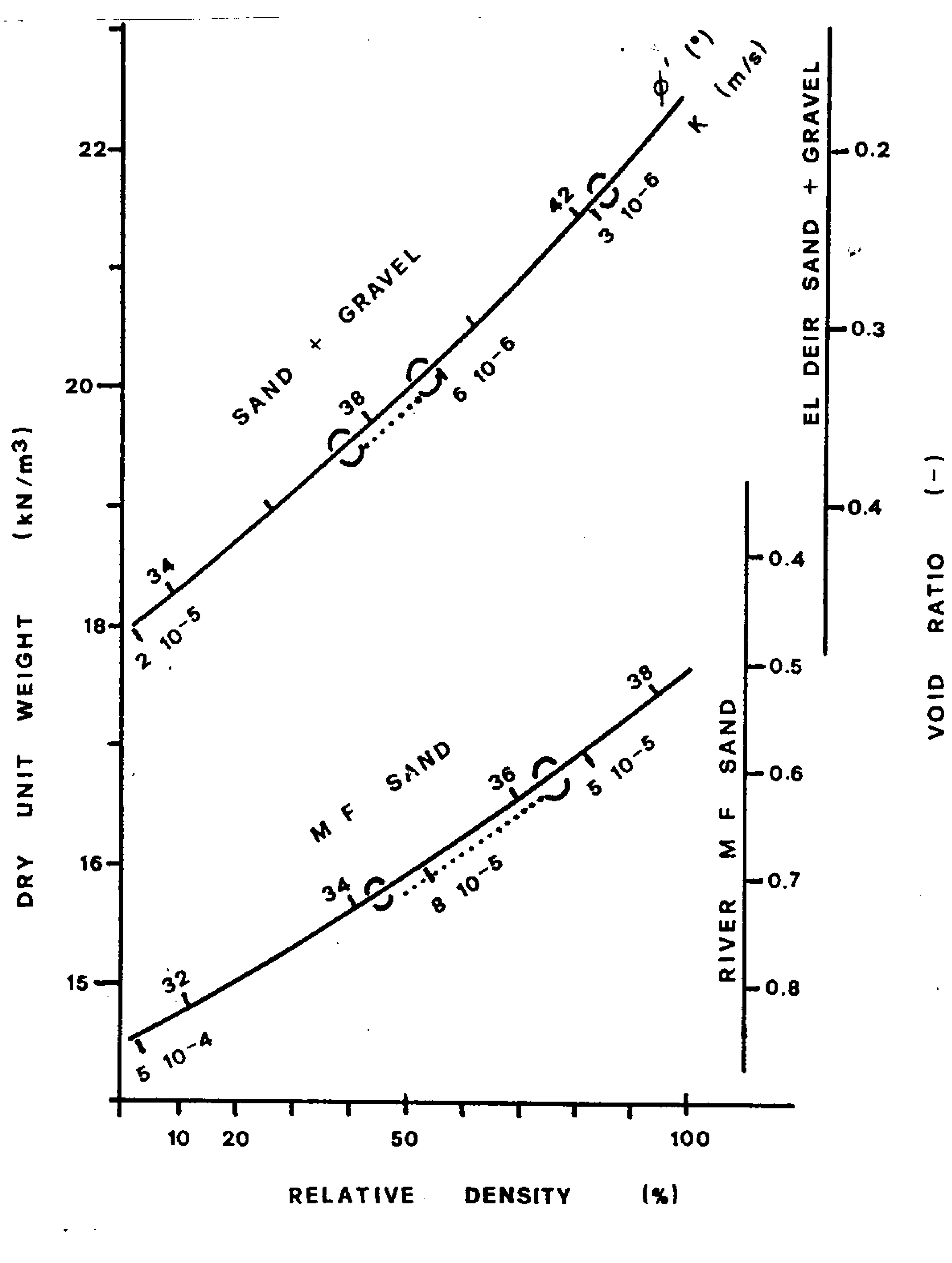

Fig. 2 New Esna Barrage. Main geotechnical characteristics of the embankment material finally used for construction. The lower curve provides the corresponding characteristics for the hydraulic filled sand considered in the original design.

100 mm size range, protect the u/s and the d/s slope of the crown portion of the dam.

Hence, the primary function of geotextiles will be retention, i. e. preventing the riverbed sand and the fines of the embankment from migrating into the toe and further. Permeability will be a secondary function and anti clogging characteristics will be third priority.

Static and hydrodynamic stresses, at the boundaries where geotextile filters are installed, were defined from deformational and seepage analyses, both based on finite element models. A conservative seepage analysis, assuming zero efficiency for the diaphragm wall, was used for this purpose. Normal effective stresses and maximum hydraulic gradients i_s considered for design were respectively: 140 kPa and 0.4 at position 1 (riverbed/toe interface) and 270 kPa and 0.2 at position 2 (embankment/toe interface). Contact stress at positions 3 and 4 was assumed to be 20 kPa.

The retention adequacy has been determined according to the criteria proposed by Giroud (Giroud, 1982). The main numerical values are summarised in Table 1.

The resulting maximum Apparent Opening Size O95, for each position, were determined as:

- O95 < 1.5 c'u d50 at positions 1 and 2
- O95 < d50 at positions 3 and 4

and the following maximum values were obtained: O95 < 0.5 mm for the geotextile filtering the riverbed sand, O95 < 34 mm for the geotextile filtering the embankment sand-and-gravel against the toe cobbles, O95 < 20 mm for the geotextile under the rip-rap.

Minimum values were obtained for the geotextile required permeability $k_g > i_s \times k_s$ as follows:

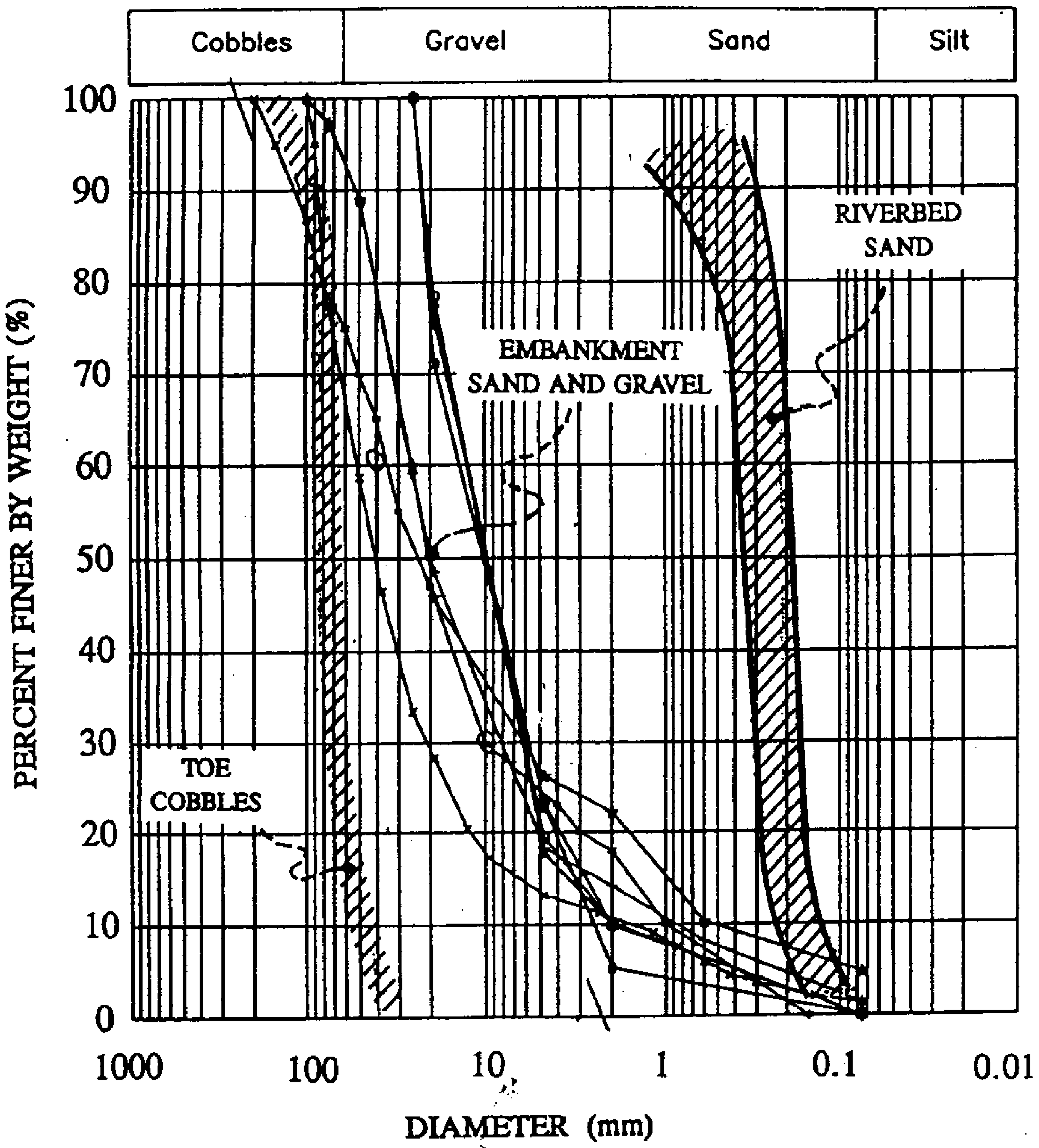

Fig. 3 New Esna Barrage. Grading curves and bands of materials used in the construction of the embankment dam.

$k_g > 3\ 10^{-5}$ m/s for the geotextile filtering the river sand, $k_g > 2\ 10^{-6}$ m/s for the geotextile filtering the embankment sand-and-gravel against the toe cobbles.

The selected geotextiles were:

- UCO NW800 a nominal 800 g/m2, non woven, staple fibre, needle punched, single ply, polypropylene fibre with actual O95 = .16 mm, thickness of 7.05 mm and unit weight of 941 g/m2.
- UCO NW1200 a nominal 1200 g/m2 non woven, staple fibre, needle punched, 2 ply, polypropylene fibre with actual O95 < 0.06 mm, thickness of 13 mm and unit weight of 1368 g/m2.
- VALBOND a nominal 320 g/m2 non woven, continuous filament, needle punched, polyester fibre with O95 = 0.05 mm, permeability 5 10^-2 m/s.

The selected geotextiles possessed an AOS about 10 times smaller than the computed maxima and coefficients of permeability at least 10 times greater than the computed minima. A porosity $n > 30$ % in both geotextiles, ensured the anticlogging adequacy.

Survivability of the geotextiles to placement was of paramount importance. As a matter of facts the geotextile in position 1 had to be placed in running water and ballasted with 1 metre of stones dropped from a clamshell releasing its load above the water surface. The geotextile in position 2 had to survive the bruise of an advancing embankment front. Both the geotextiles in

Table 1. New Esna Barrage. Main numerical values used to determine retention adequacy according to criteria proposed by Giroud (Giroud, 1982).

Position	d10 (mm)	d30 (mm)	d50 (mm)	d60 (mm)	Cc -	C'u -	Dr (%)
1 riverbed sand	.15	.22	.30	.30	1.1	1.15	45
2 embankment	1.	10.	20.	40.	2.5	11.18	55
3, 4 compacted sand-and-gravel	1.	10.	20.	40.	2.5	11.18	85

positions 3 and 4 had to survive the impact of a machine placed rip-rap. Table 2 summarises the characteristics specified for survivability together with the actual values obtained from quality control tests carried out for the acceptance of the geotextiles.

Of particular importance was the strain at failure for geotextile in position 2. A substantial elongation of the geotextile under the pressure of the embankment material, would allow it to drape much of the surface of the cobbles, thus reducing unsupported lengths.

Table 2 New Esna Barrage. Characteristics specified for survivability of the geotextiles and actual values obtained from quality control tests.

Position		Grab Str. (kN/m) (1)	Elongation (%)	Puncture Str. (N) (2)
1 riverbed/toe	SP	8.9	15	360
	QC	38.1	76	5192
2 embankment/toe	SP	8.9	15	360
	QC	80.1	63	13607
3 & 4 emb./rip-rap	SP	4.0	15	180
	FA	30.1	50	-

(1) according to ASTM D 4632, (2) according to ASTM D 4833, SP = specified minimum, QC = quality control test, FA = manufacturer's data

3 THE PLACEMENT OF GEOTEXTILES AND THE CONSTRUCTION OF THE EMBANKMENT

The modified design based on the use of a single fill material and on geotextiles in substitution of multiple filters, allowed a high quality end-product.

Completing the placement of the 800 g/m2 geotextile over the bottom of the river was possibly the most demanding operation. Six roll widths of geotextile were placed side by side and machine sewn. The resulting 23.5 m wide strip, was rolled over a 500 mm diameter steel pipe. The strip length reached, where the final gap of the stream cutting dike had been foreseen, up to 95 m in length. 2 pontoons and cranes, lifting the roll by 2 slings, were towed in place and moored against steel piles driven in the riverbed. The roll was lowered to the riverbed at the u/s end of the area to be covered, pegged with rebar nails and then slowly unrolled toward downstream by ropes passing through pulleys fixed to the second pontoon, as Fig. 4 shows.

Adjacent rolls were overlapped about 1 m corresponding to 4 % of the band width, a remarkably small overlap that narrower bands would have increased substantially. As the band was unrolled in position, it was ballasted with about 1 m of cobbles dumped in heaps. A 2 m wide selvage was left on one side to allow the planned overlap.

Placing the geotextile in position 1 was made particularly difficult by stream velocities in the order of 2 m/s and by depositing over the geotextile. Compressed air blown by nozzles held by frogmen proved an efficient method to ensure a clean geotextile - geotextile contact. Each overlap was inspected and TV recorded.

The placement of the 1200 g/m2 geotextile in position 2 was done from the crest of the toe dike. Individual rolls, pre-cut to the appropriate length and rolled around a 200 mm steel pipe, were lowered along the dike slope, some 20 m behind the tipping end. The underwater fill was placed by end tipping assisted by a D6 dozer. The dozer operator was instructed to tip smaller volumes of fill whenever working within the 15 m adjacent to the geotextile and never to approach within 1 m of distance.

The geotextile under the u/s and d/s rip-rap was placed once the crown filled to grade. Individual rolls were pre-cut and unrolled from the edge of the crest.

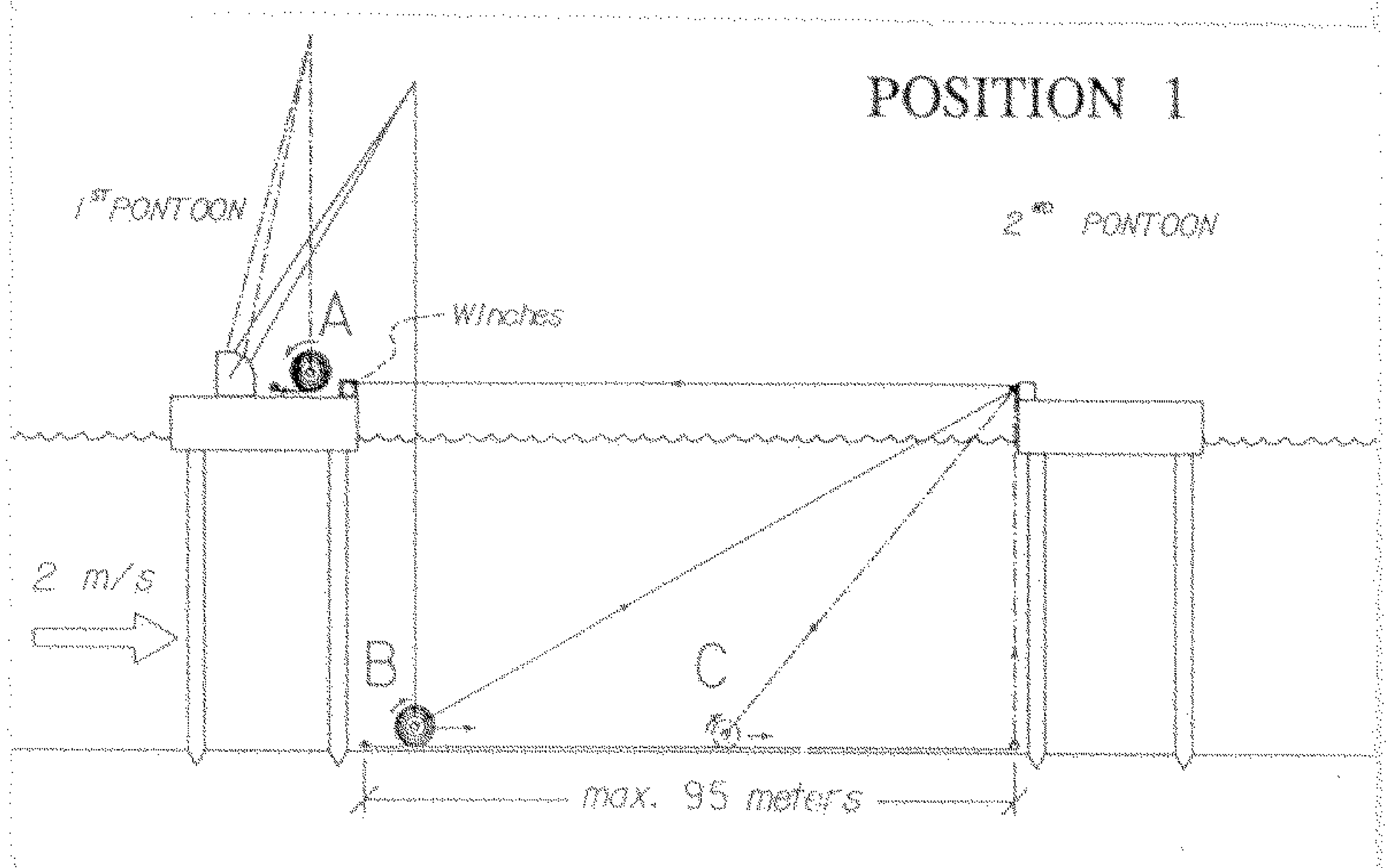

Fig. 4 New Esna Barrage. Underwater placement of the geotextile filter in position 1. A = pre-assembly, B = setting the roll in position by crane, C = controlled unrolling.

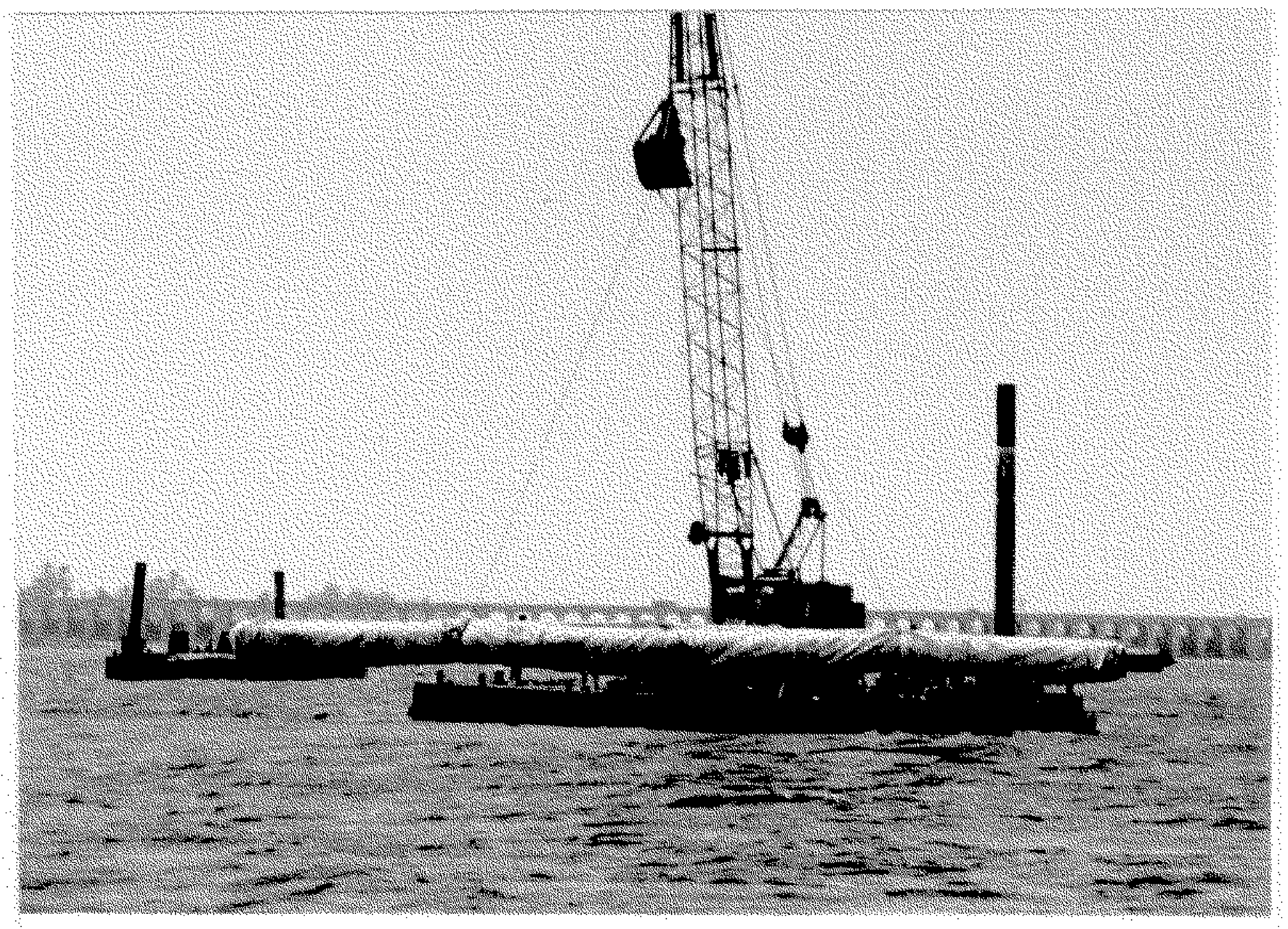

Fig. 5 New Esna Barrage. A preassembled geotextile roll ready for placement over the bottom of the Nile in running water.

The stone protection was machine placed and hand labour was used for finishing.

Construction of the embankment dam at Esna required the placement of 30 000 m2 of 800 g/m2 geotextile on the Nile bottom with a waste of about 20 %, of about 10 000 m2 of 1200 g/m2 geotextile with a waste of about 20 % and of 60 000 m2 of geotextile on the slopes with a waste of about 15 %. Placement of all geotextiles, of 93 000 m3 of ballast and stream cutting cobbles, of 260 000 m3 of underwater fill and of about 115 000 m3 of compacted fill and rip-rap, was completed in less then 10 months.

4 ACKNOWLEDGMENTS

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