DEATHERAGE, J. D., BECKWITH, G. H. and HANSEN, L. A.
Sergent, Hauskins and Beckwith Consulting Geotechnical Engineers, USA

RESTORATION OF McMICKEN DAM
RESTAURATION DE McMICKEN DAM
WIEDERHERSTELLUNG DES McMICKEN-DAMMS

After being declared unsafe, and then breached, McMicken Dam was restored through the use of a geotextile-geomembrane cutoff and drainage system. Constructed in 1955, the 15 km-long flood control structure was breached in 1972, when extensive cracking was discovered. The use of a polypropylene-coated and uncoated woven geotextile lined rock-fill drain through the center of the existing structure proved the optimum economic solution. Design considerations required high-strength elastic geotextiles and geomembranes which could withstand future cracking, as well as intercept seepage through existing cracks during infrequent flood flow events. Tests were conducted in the laboratory to determine the ability of various materials to span a 25.4 mm simulated crack. McMicken Dam was restored to service after completion of construction in 1984. A total of 227,000 m^2 of polypropylene geomembrane and woven geotextile were used with a savings of over 1.5 million dollars from the next most economical alternative.

Nachdem Es nicht sicher und durchgebrochen erklaeren wurde, das McMicken Dam wuerde durch die Benutzung eiher Kanalisation die von geotextile geomembrane gemacht wurde, wiederhergestellt. Gebaut imjahr 1955, der 15.000 meter-lang Ueberschwemmungskontrolsystem wurde im jahr 1972 durchgebrochen erklaert, als viele Risse endeckt wurde. Die Benutzung eines von Polypropylene ueberstrichent und unueberstrichent Geotextile gefuettert Abfluss der durch das Zentrum der bestehenden Struktur eingebaut wurde, wurde die optimume oekonomische Loesung. Die Gestaltungsruecksichen brauchen sehr starke elastische Geotextile und Geomembrane die zukuenftige Risse wider stehen und die Sickern die von seltener Ueberschwemmungen durch existierende Risse abfangen koennte. Die Pruefungen wurde im Laboratorium fuehren gelitten um fest zu stellen die Fahigkeiten verschiedener Stoffen eines Riss von 2,5 CM um zu ueberspannen. Das McMicken Dam wurde nach die Fertigstellung von bauen im jahr 1984 zum dienst widerhergestellt.

INTRODUCTION

McMicken Dam was constructed to intercept and divert flood runoff from the Trilby Wash drainage area, northwest of Phoenix, Arizona. Trilby Wash had flooded the predominantly agricultural area downstream of the damsite on several occasions prior to the dam's construction in 1955. Design details of the dam are summarized in Table 1.

Table 1
McMicken Dam Design Details

Length	15 km
Maximum Height	10 m
Crest Width	3.7 m
Upstream Slope	2 1/2 to 1
Downstream Slope	2 to 1
Storage Below Spillway	22,200,000 m^3
Upstream Drainage Area	640,000,000 m^2
Peak Design Inflow	3,400 m^3/second

Inspections made by the Los Angeles District of the U.S. Army Corps of Engineers from 1964 to 1971 revealed surface irregularities described as surface erosion, small holes and tunnels (1). Trenching of the irregularities exposed transverse cracks within the embankment in excess of 4.5 m deep.

Additional investigations revealed that severe cracking was probably present throughout the northernmost two-thirds of the dam. Noting that a failure of the dam could cause loss of life and severe flood damage, the Corps of Engineers recommended breaching the dam. McMicken Dam was breached in July, 1972 by the owner and operator, the Maricopa County Flood Control District.

At the time the dam was breached, the cause of the cracking was believed to be either differential settlement of foundation soils or groundwater withdrawal induced subsidence, which can result in the formation of earth fissures.

INVESTIGATION

Detailed geotechnical studies revealed the cause of cracking was differential settlement of a surface layer of moisture sensitive foundation soils. The collapsing soil strata typically was 1 to 2.5 m thick and subject to an average settlement of 75 mm upon an increase in moisture content. Impoundment of runoff behind the dam had wetted zones of soil under the dam with resultant differential settlement, which induced transverse, tensional cracking in the dam.

Concerns that the regional subsidence of up to 1 m, induced by groundwater withdrawal, had caused the extensive cracking in the northern portion of the dam were not substantiated by the investigation. One set of earth fissures was found at the southerly end of the dam approximately 200 m downstream, but there was no trace of subsidence related fissuring in the dam. Continued groundwater pumping and resultant ground subsidence may cause fissures to propagate under the dam in the future. Earth fissures studied typically had open cracks less than 20 mm in width.

REMEDIAL REPAIR ALTERNATIVES

Analysis was made of several alternative design features to intercept seepage through the cracked portions of the embankment during infrequent flood flows. Inherent in the repair criteria was the necessity to defensively design against future development of subsidence-related fissures extending through the dam. Alternatives investigated included upstream asphaltic concrete or gabion-mastic liners, downstream zoned rockfill filters, and a central horizontal drain.

Common to all alternatives was a cutoff through the erodible moisture sensitive surface soils to relatively strongly cemented soils below a depth of 2.5 m. This feature incorporates a defensive design against development of a path for internal erosion at the base of the dam, forcing flows in cracks through the more cemented soils, which are relatively high in resistance to erosion. As the flood flows are of short duration, the cutoff provides a high degree of protection against piping through the erodible foundation soils.

The alternative selected included a central horizontal drain with perpendicular finger drain outlets, and a downstream toe cutoff through the erodible surface soils. This design yielded the highest level of protection against internal erosion through existing and anticipated future cracks in the dam.

CENTRAL DRAIN DESIGN

Design details of the central drain are presented in Figure 1. The granular drain was excavated through the center of the existing dam. The drain material is a coarse gravel and is separated from the embankment soils on the downstream side with a geomembrane, and on the upstream side with a geotextile.

The upstream geotextile intercepts erosion through cracks and is intended to promote plugging of cracks. The high degree of internal drainage provided will transmit flow from the geotextile. The downstream geomembrane is intended to prevent flow into cracks downstream from the center drain. Outlet finger drains spaced laterally at 60 to 300 m are intended to transmit seepage from the center drain safely out the downstream toe of the dam.

The geotextile-geomembrane drain system is very flexible and is expected to withstand the differential settlements and tensile strains which could potentially occur. A laboratory test program was developed to simulate a subsidence earth fissure opening through the dam to verify that the geotextile and geomembrane could bridge the opening without failing.

DOWNSTREAM TOE CUTOFF

A single sheet of pervious geotextile material was installed in a narrow trench at the downstream toe of the dam. The width of the sheet was the same as the trench depth. The downstream toe cutoff was originally conceived as a blind drain to intercept flow through a fissure, which might propagate through potentially erodible soils under the dam embankment. Any flow thus intercepted would flow longitudinally into the drain and eventually percolate into the soil. With this concept, the drain would have been similar in construction to the center drain trench. However, it was determined that the permeability of the geotextile would be quickly diminished by 2 to 4 orders of magnitude when exposed to a flow of water carrying soil fines. Therefore, it was decided that a single sheet of geotextile would form an effective barrier to crack propagation without the added cost of constructing this barrier as a dual function barrier and drain.

TESTING

The use of a geotextile and geomembrane system to line both the center drain and downstream cutoff required determination of elastic properties which are not described by the standard suite of strength tests conducted on geotextiles and geomembranes. In order to evaluate a material's ability to strain across a crack in the dam, a special laboratory test was devised. In the test, the geotextile-geomembrane-soil interaction could be observed during simulated crack formation. The results of the special testing, as well as conventional strength and elastic property testing, allowed the selection of several suitable geotextiles and geomembranes.

In a specially designed pullout test, a 13.0 mm thick plate steel box used to contain a geotextile or geomembrane sample placed between compacted clay and subangular 10 mm diameter gravel. These soils simulated the center drain in McMicken Dam, modelling the interface between the drain rock and the existing clay dam with the geotextile or geomembrane separation. The test

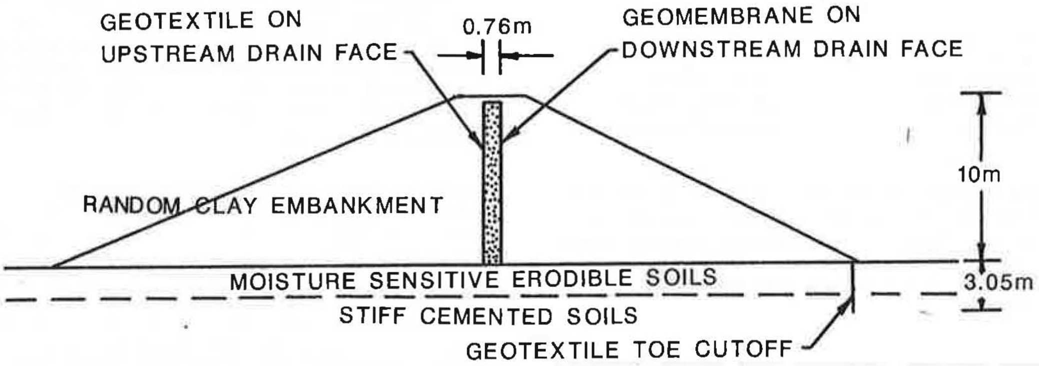

Figure 1: McMicken Dam Restoration Design Details.

box was 610 mm by 610 mm in plan view and 230 mm in height. This height allowed for 100 mm of both compacted clay and gravel separated by a 305 mm by 455 mm section of geotextile or geomembrane. A 610 mm by 610 mm rubber air bladder was placed over the gravel, which could be pressurized to provide a variable pressure load of gravel against geotextile or geomembrane. The test box had a 13 mm slot cut in one side, 100 mm from the bottom and 460 mm long, as shown in Figures 2 and 3. The geotextile or geomembrane protruded 50 mm from the slot and was connected to a 40 mm by 460 mm grip along its 305-mm wide exposed side. Testing consisted of the following sequence:

A. Selection and cutting a representative geotextile or geomembrane sample 305 mm by 455 mm. Samples were cut with 455 mm dimension taken from machine or warp of roll direction, as opposed to width of roll direction. This assured testing of anisotropic geotextiles and geomembranes in their principal axis, corresponding to the development of a crack in the dam across the center drain.

B. The geotextile or geomembrane was placed in the test box and buried under 100 mm of gravel, then pressure loaded to either 34.5 kPa or 69.0 kPa to simulate at-rest earth pressure against the fabric at the mid-depth trench location of 5.0 m or the deepest depth of 10.0 m.

C. The geotextile or geomembrane was loaded with a hand-operated tensioning device, with load measured by a direct reading load cell. Load could be measured to 7.1 kN in 5 N increments. As the geotextile or geomembrane was loaded, the strain was measured with a dial gauge located in the middle of the grip. Loads in excess of 7.1 kN were not measured.

D. Each test was continued until the geotextile or geomembrane either failed or strained 25.4 mm.

RESULTS OF TESTING

Results of pullout testing are presented in Table 2. The results of the pullout testing graphically determine which of the geotextiles will successfully bridge across a hypothetical 25.4 mm wide crack extending through the drain. The testing procedures modelled half of the crack, so a geotextile or geomembrane which elongated 25.4 mm in the test would successfully bridge a 50.8 mm crack in the dam. The 25.4 mm acceptance criteria yielded a factor of safety of 2 relative to failure, allowing for some loss of strength or elasticity with time.

The results of the pullout testing are shown in Figures 4 through 7. It was observed during testing that the portion of the geotextile sheet which elongated would become smeared with the clay underlying it. This smearing allowed the effective length of geotextile which strained to be approximated. Photos of the soil smear on the geotextiles after testing are shown in Figures 8 and 9. The approximate length of smear is listed with the pullout test results in Table 2.

Seven geotextiles were determined acceptable by pullout testing. These fabrics included Propex 1325, Polyfilter X, Fibertex Ten-1, Mirafi 140N, Mirafi 500X, Typar 3601 and Transguard 2000.

Figure 2: Pullout Test Box with Geomembrane Prior to Testing.

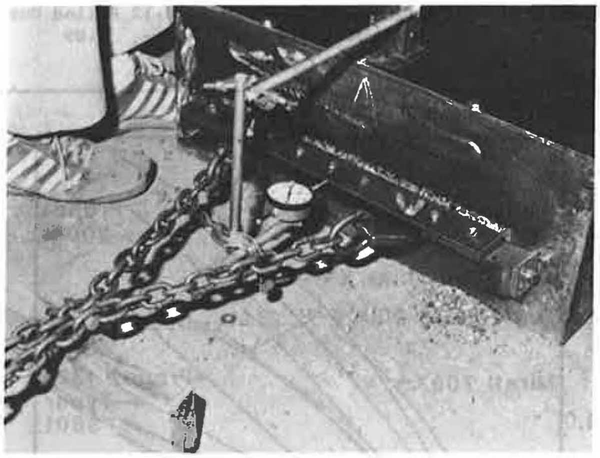

Figure 3: Pullout Test Box with Geomembrane in Grip During Test.

Of four geomembranes tested at 34.5 kPa surface loading, three successfully elongated 25.4 mm. These included Mirafi MCF600, Mirafi MCF500 and Typar T063. Subsequent testing at 69.0 kPa showed acceptable elongation in three of four geomembranes tested. Mirafi MCF500, Typar T063 and two new geomembranes, AMOCO C7305 and AMOCO P6838, were tested. The AMOCO P6838 continuously yielded from 20.5 mm to 30.5 mm prior to break, and was not acceptable. Therefore, three coated geotextiles were judged acceptable for use in the center drain, including Mirafi MCF-500, Typar T063 and AMOCO C7305.

TABLE 2
RESULTS OF PULLOUT TESTING

Manufacturer	Geotextile or Geomembrane* Type	Pullout Load at 34.5 kPa With 25.4 mm Elongation (kN)	Soil Smear (mm)	Pullout Load at 69.0 kPa With 25.4 mm Elongation (kN)	Soil Smear (mm)
Amoco	Propex 4545	2.11	89.0		
	Propex 1325	5.34	127.0	>7.12	127.0
	Propex 2002	5.34	165.0	6.68 Break @ .21 mm	178.0
	C7305*			>7.12	178.0
	P6838*			3.8 Failed @ 30 mm	76.0
Carthage Mills	Polyfilter X	5.34	Entire Sheet	6.68	Entire Sheet
	Polyfilter GB	4.45	203.0		
Crown Zellerbach	Fibertex 200	1.56	64.0		
	Fibertex Ten-1	4.01	178.0	7.12	140.0
	Fibertex Ten-3	6.68	165.0		
Dominion Textile	Mirafi 140N	2.89	89.0	3.34	114.0
	Mirafi 500X	6.23	178.0	>7.12	165.0
	Mirafi 600X			>7.12	178.0
	Mirafi 700X	5.12 Pulled Out	Entire Sheet		
	Mirafi MCF500*	6.23	279.0	7.12	254.0
	Mirafi MCF600*	6.68	Entire Sheet		
Dupont	Typar 3341	2.23 Break @ 19 mm	89.0		
	Typar 3401	2.45	114.0	2.0 Break @ 23 mm	89.0
	Typar 3601	4.45	127.0	6.68	140.0
	Typar T063*	2.89	127.0	2.89	165.0
Griffolyn	Transguard 2000	5.12 Pulled Out	Entire Sheet	>7.12	203.0
	Transguard 4000*	0.89	76.0		

*Indicates geomembrane.

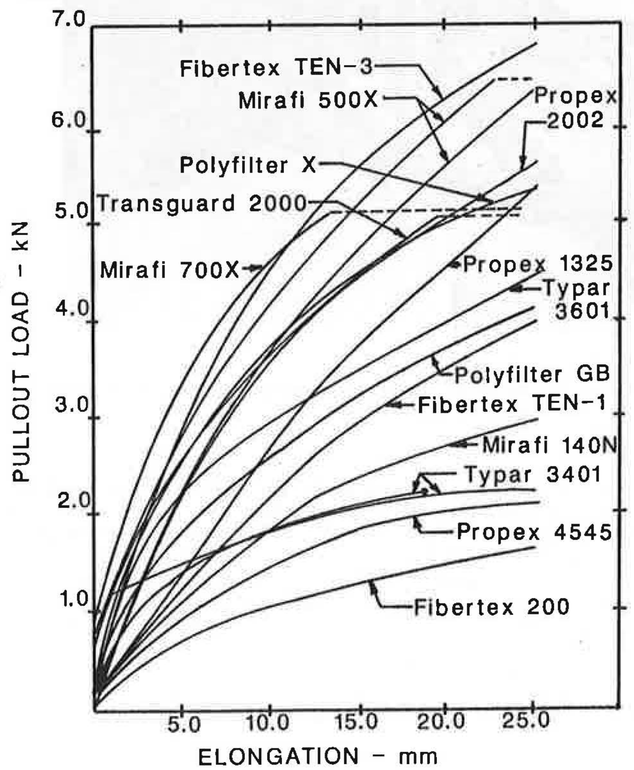

Figure 4: Pullout Test Results for Geotextiles with 34.5 kPa Surface Loading.

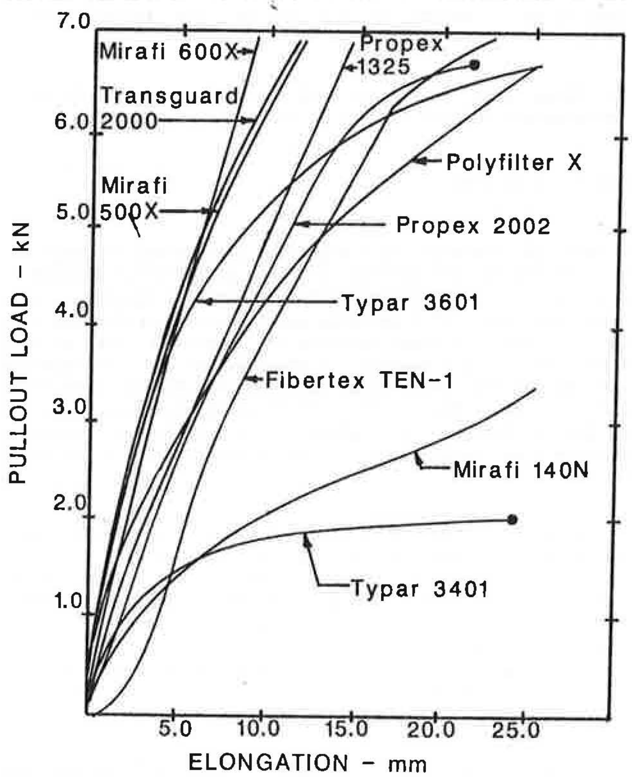

Figure 5: Pullout Test Results for Geotextiles with 69.0 kPa Surface Loading.

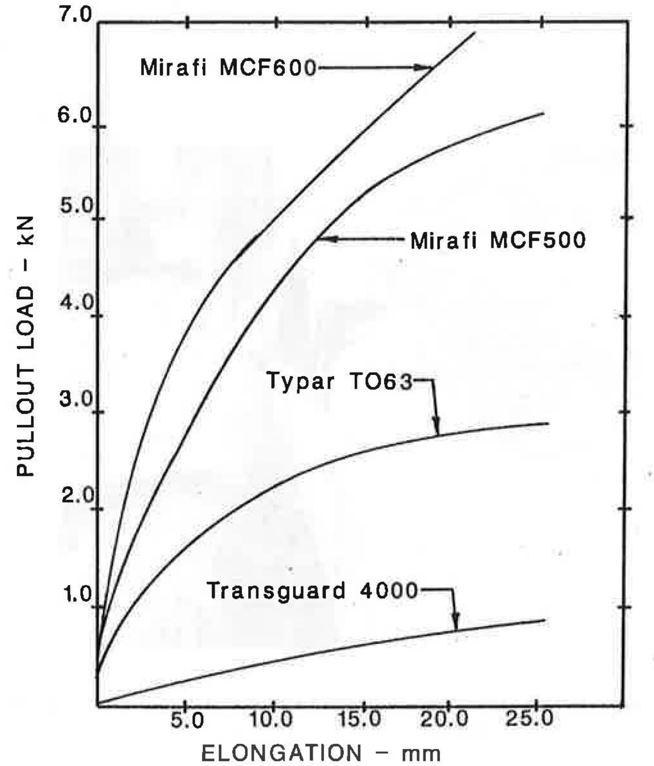

Figure 6: Pullout Test Results for Geomembranes with 34.5 kPa Surface Loading.

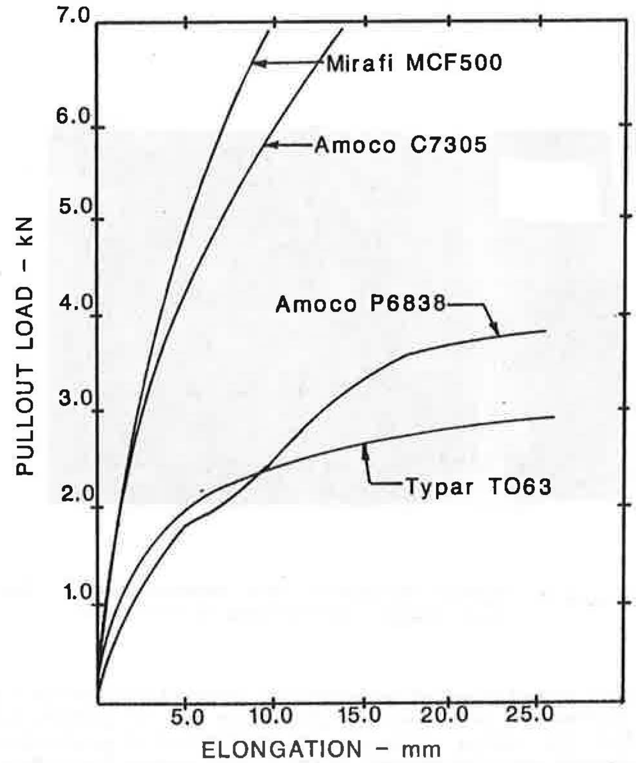

Figure 7: Pullout Test Results for Geomembranes with 69.0 kPa Surface Loading.

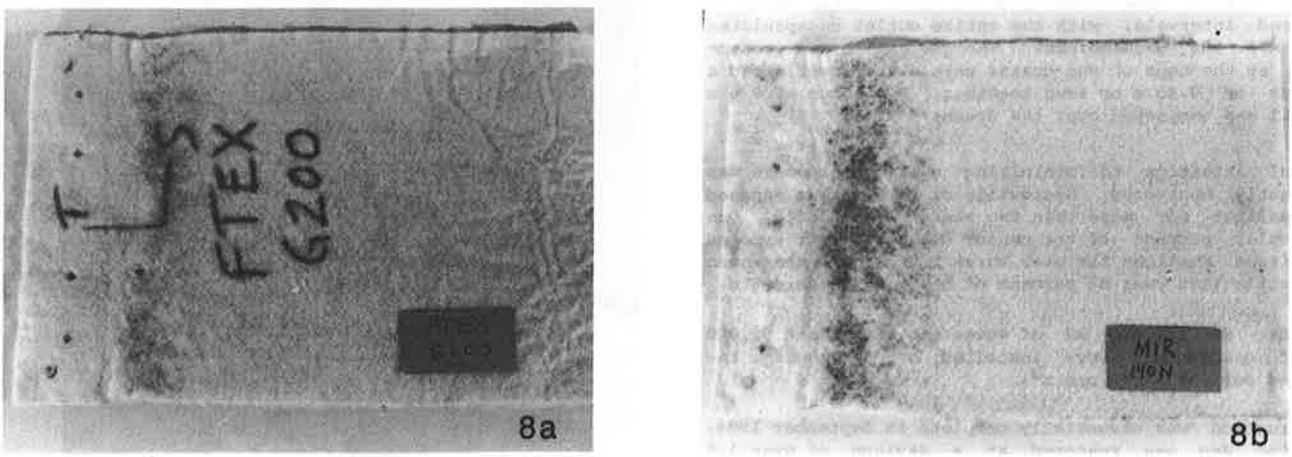

Figure 8: Tested Geotextiles - Note Soil Smear.

CONSTRUCTION

Remedial construction began in October 1983, with the contractor selecting Mirafi 500X woven polypropylene geotextile for the upstream wall of the center drain and the downstream cutoff. The relatively impervious polypropylene-coated woven polypropylene geomembrane Mirafi MCF 500 was selected for the downstream wall of the center drain and for downstream outlets.

Installation of the downstream geotextile cutoff was accomplished as the first phase of the work. The geotextile rolls were attached to a large spool connected to a backhoe, and the material was unrolled inside the trench as the excavation progressed. Figure 10 shows this portion of the construction.

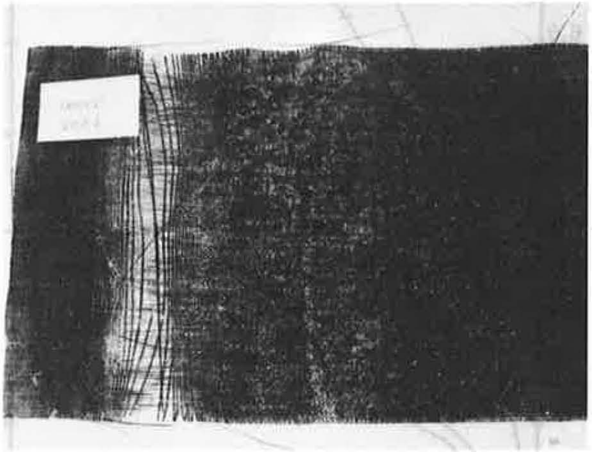

Figure 9: Tested Geotextile and Geomembranes - Note Soil Smear and Failures of Geotextile

The second phase of construction involved prefabricating 30.5-metre long panels of geotextile sewn to geomembrane for the center drain. The prefabricated panels were dropped into the maximum 10-metre deep center drain excavation immediately following the trencher. Coarse gravel was promptly placed into the geotextile-geomembrane-lined excavation by conveyer or truck. Figure 11 shows this portion of the construction.

Outlet drains were connected to the center drain at required intervals, with the entire outlet encapsulated with MCF 500 geomembrane. The geotextile and geomembrane at the tops of the drains were either overlapped a minimum of 0.45 m or sewn together. A minimum of 0.6 m of soil was compacted over the drains.

Careful attention to minimizing sunlight exposure was constantly monitored. Geotextile or geomembrane exposed to sunlight for more than two weeks was replaced. One particular section of the center drain was left exposed to direct sunlight for over three months, and the woven geotextile lost over 80 percent of its tensile strength.

A total of 135,000 m2 of woven geotextile and 92,000 m^2 of geomembrane were installed at an average installed cost of \$1.50 per m^2.

Construction was essentially complete in September 1984, and the dam was restored at a savings of over 1.5 million dollars from the next most economical alternative considered.

ACKNOWLEDGMENTS

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Figure 10: Installation of Downstream Geotextile Cutoff.

Figure 11: Installation of Center Drain. Geotextile is on Left Side of Trench, Geomembrane on Right Side of Trench.

References

(1) U.S. Army Engineer District, Los Angeles, Corps of Engineers, "Trilby Wash Detention Basin, Lower Agua Fria River, Maricopa County, Arizona," January, 1973.