Durability of a 13-Year Old Test Embankment Reinforced with Polyester Woven Fabric

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ABSTRACT: In the summer of 1980, a geotextile-reinforced steep earth dam was built, using a polyester woven fabric. The purpose was to investigate construction techniques and greening and protection systems. The dam, with an overall length of 50 m, was built with 2:1 and 4:1 slopes, using partly sand and clay as fill.
The investigations planned for the project concerned the functioning of the surface covering designed to protect the fabric from over-exposure to UV-radiation, and the endurence properties of the reinforcing fabric.
The dam was removed 13 years after its construction, and the following soil properties were investigated: compaction, angle of friction, bearing capacity, particle distribution, moisture content and pH.
After recovery of the fabric, residual strength and modulus of fabric and yarns, as well as polymer degradation of the yarns, were measured. This paper presents the results and conclusions.

1 INTRODUCTION

In 1980, Akzo Industrial Systems decided to look into the possibilities of building steep earth slopes with reinforcing fabric woven from high modulus polyester yarns. At the time, the development group was housed on Akzo's " Kleefse Waard " (Arnhem) site and was so lucky to have a test location available on-site for about 13 years.

The first aim in constructing these steep earth slopes in 1-metre-high layers was to determine the construction possibilities offered by the then available 200 kN/m polyester reinforcing mat.
The second aim was to create a reinforced earth structure to test ways of providing aesthetic protection against UV-radiation, and to afford a means of subsequent recovery of material for measurement of its endurance properties.

The experimental dam was accordingly built in the summer of 1980; the recovery of the materials used took place in the summer of 1993.

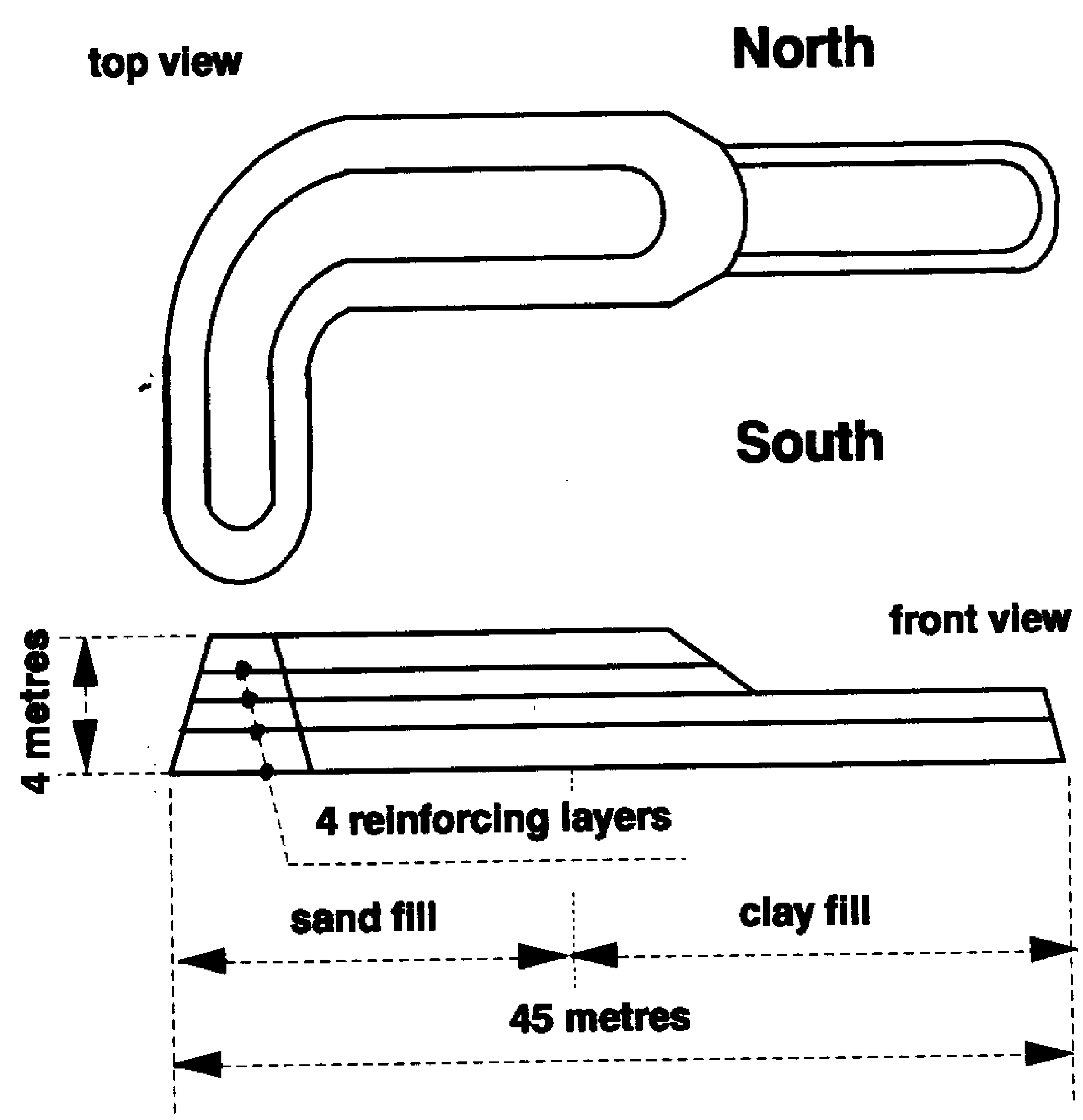

Fig.1 Design and shape of the dam

2 DESCRIPTION OF THE EXPERIMENTAL DAM AND THE MATERIALS USED IN ITS CONSTRUCTION

Figure 1 shows the design of the dam. The 90° bend in the dam was made to test the feasibility of providing an emergency path through such a dam in the event of its use along a highway without adversely affecting the dam's function as a noise-abatement barrier. The base width of the dam section with 2:1 slopes was 5 m; in the section with 4:1 slopes it was 3 m.

Both sand and clay were used as fill, but in separate sections, to test slope stability and moisture balance, essential in keeping the protective layer green, for either material. For reinforcement, a high-modulus STABILENKA® 200/45 fabric with polyester in the warp and polyamide in the weft was used, with a breaking strength of 200 kN/m in warp direction and 45 kN/m in the weft direction, being the fabric with the lowest breaking strength level available in those times.

The dam was constructed in 1-metre-high layers, as shown in Figure 2.

Fig.2 View of dam under construction

For greening, and for protection of the reinforcement against UV-radiation, the following systems were tried out:

- The horizontal part of the top layer was covered with Enkamat® 7020 en 7220.
- In two sections of the dam, these erosion control mats were also installed so as to follow the contours of the entire fabric envelope.
- All of the surface of the dam was hydroseeded, using seed of specially selected grasses and herbs, chopped straw and bitumen emulsion.
- Ivy was planted on the south side at the foot of part of the sand-filled and clay-filled sections.

3 CONDITION OF THE WALL AFTER 13 YEARS

The stability of the dam was perfect over its entire life. There was no evidence of movements or deformations of any significance. The hydroseeded sections of the dam looked quite green one year after seeding, as shown in Figure 3.

But after 13 years, only reasonably green spots remained on the north side and a few green spots on the south side of the dam.
The flat Enkamat section was fully green even after 13 years. On the sloping portions of the fabric envelope the erosion control mat was a failure, however, in that the mat lost contact with the fabric, causing the vegetation to die from lack of moisture.
On the south side of the wall only the bitumen cover remained to protect the fabric against UV - radiation. The sections where ivy (Hedera) had been planted showed a fine continuous plant cover after 13 years.

The table below rates the performance of the greening systems investigated:

Greening System	Appearance after: 1 year	Appearance after: 13 years
1. Hydroseeding only	++	--
2. Enkamat on top layer plus hydroseeding	+++	+++
3. Enkamat fitted against slope plus hydroseeding	---	---
4. Hydroseeding and ivy plants (Hedera)	++	+++

Fig.3 Hydroseeded section after one year

4 PROPERTIES OF SOIL IN THE DAM

The following properties of the soil in the various layers were determined, some in situ and some in the laboratory.
The results are given in the table below:

Soil property	Sand	Clay
Specific weight, dry (tons per cubic metre):		
Bottom layer	1.86	1.61
Second layer	1.83	1.59
Third layer	1.72	1.48
Top layer	1.65	1.35
Angle of friction soil/soil (°)	48	63
Angle of friction fabric/soil (°)	45	42
Angle of friction pull-out test (°)	40	n.a.
Dimensions of particles (mm)	0.045 - 8.0	up to 0.06
pH value	5.1 - 6.5	5.8 - 7.7
Moisture content (%)	4	4 - 25
Cohesion (kN per square metre)	2	7 - 27
Bearing capacity subsoil (kN per square metre)	980	

The bearing capacity of the sand, as determined by the Barentsen cone penetration test on the material immediately below the reinforcing layers showed that each layer could easily sustain the load imposed on it by the others.
The bearing capacity of the sandy sub soil on which the dam was erected was 980 kN/m²; well in excess of the required capacity of 700 kN/m² established by calculation.

With regard to the clay, the following facts should be noted:

= The bearing capacity of the reinforced clay layers was too high to be amenable to measurement by the Barentsen cone penetration test.

= Moisture content measurements detected considerable variation through the layers as shown in Figure 4.

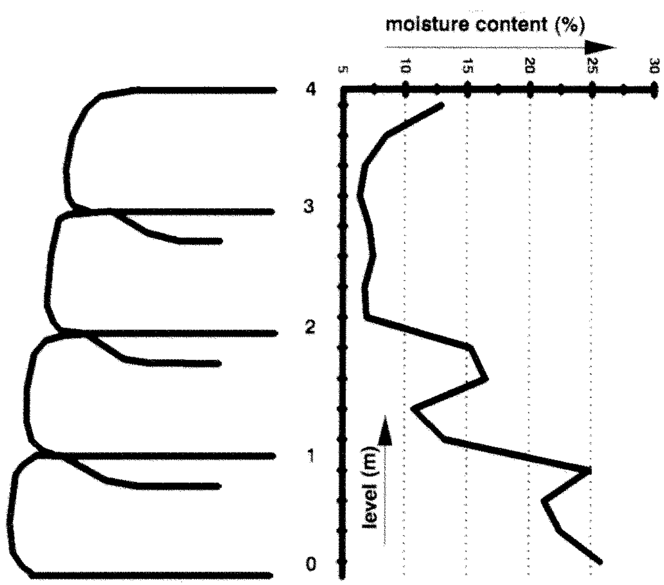

Fig.4 Moisture content through the clay layers

= Cohesion values vary with moisture content from 7 kN/m^2 to 27 kN/m^2.

Laboratory measurements showed that the angle of friction and the cohesion of the clay decrease rapidly when moisture content exceeds 25 % .

5 RECOVERY OF THE REINFORCING FABRIC AND SUBSEQUENT TESTS

5.1 Recovery

In preparation recovery of the fabric, the vegetation had to be removed. It was found that the roots generally did not penetrate the envelope; instead, they followed the fabric as shown in Figure 5.

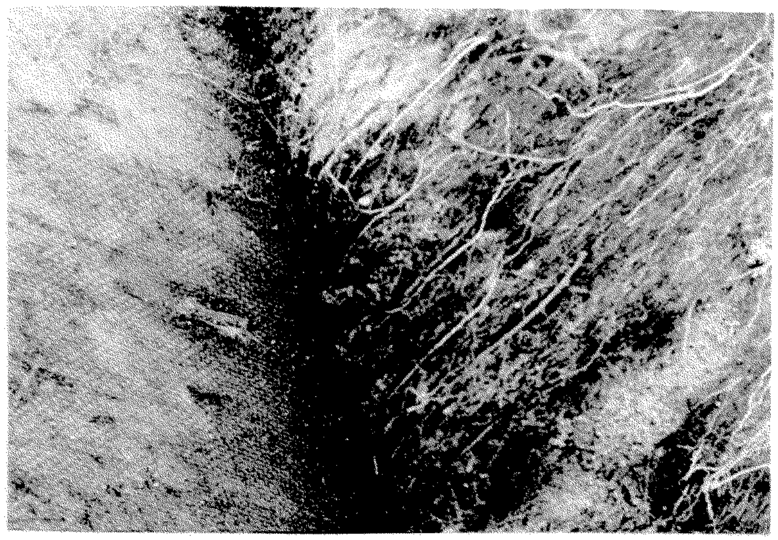

Fig. 5 Root pattern along the fabric surface

The inference is that sufficient water was available for the roots at the fabric surface.

Three samples of the seam closing the envelope at the top were taken for tensile testing before the envelope was opened. These and all other fabric samples were carefully removed and stored for conditioning prior to testing.

In the construction of the dam, rebar steel pins had been used to temporarily fix fabric overlaps untill such time as the earth layers would be self-supporting. In the sand-filled sections of the dam, these pins exhibited extreme corrosion precisely where they pearced the fabric. Figure 6 shows a pin removed from a sand-filled section in which it pierced the fabric in two spots.

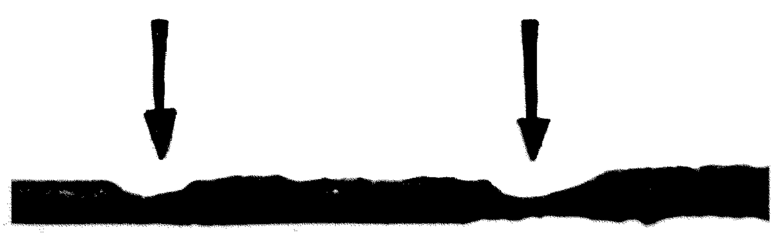

Fig. 6 Corroded steel pin. Note extreme corrosion where the pin passed through fabric

The heavily rusted pins, the root pattern of the vegetation and the moisture distribution in clay as shown in Figure 1 all point to the fabric's serving as a sort of wick which conducts the flow of water, also into the inner part of the dam.

Some spots on the south side of the dam covered with bitumen only lost their protective layer in the first two or three years. Samples from these spots were taken to establish the effects of exposure to UV-radiation.

5.2 Mechanical properties of reinforcing fabric

The most interesting parts of the fabrics were sampled; the load - elongation behaviour was measured in accordance with DIN 53857 on 50-mm wide fabric strips.
The results are presented in the table below.

In the inner part of the dam the fabric lost only 3 - 6 % breaking strength and modulus was only slight affected. The strength loss must be attributed to mechanical damage during construction (Troost et al., 1990).

The fabric on the outside of the dam covered by the hydroseeding layer only but no vegetation shows the load - elongation curves presented in Figure 7.

The samples taken from the ivy-grown sections show 12 % strength loss and no los in modulus (FASE 6). Most of this strength loss is probably due to mechanical damage caused by scraping and scuffing when the wooden forms used in

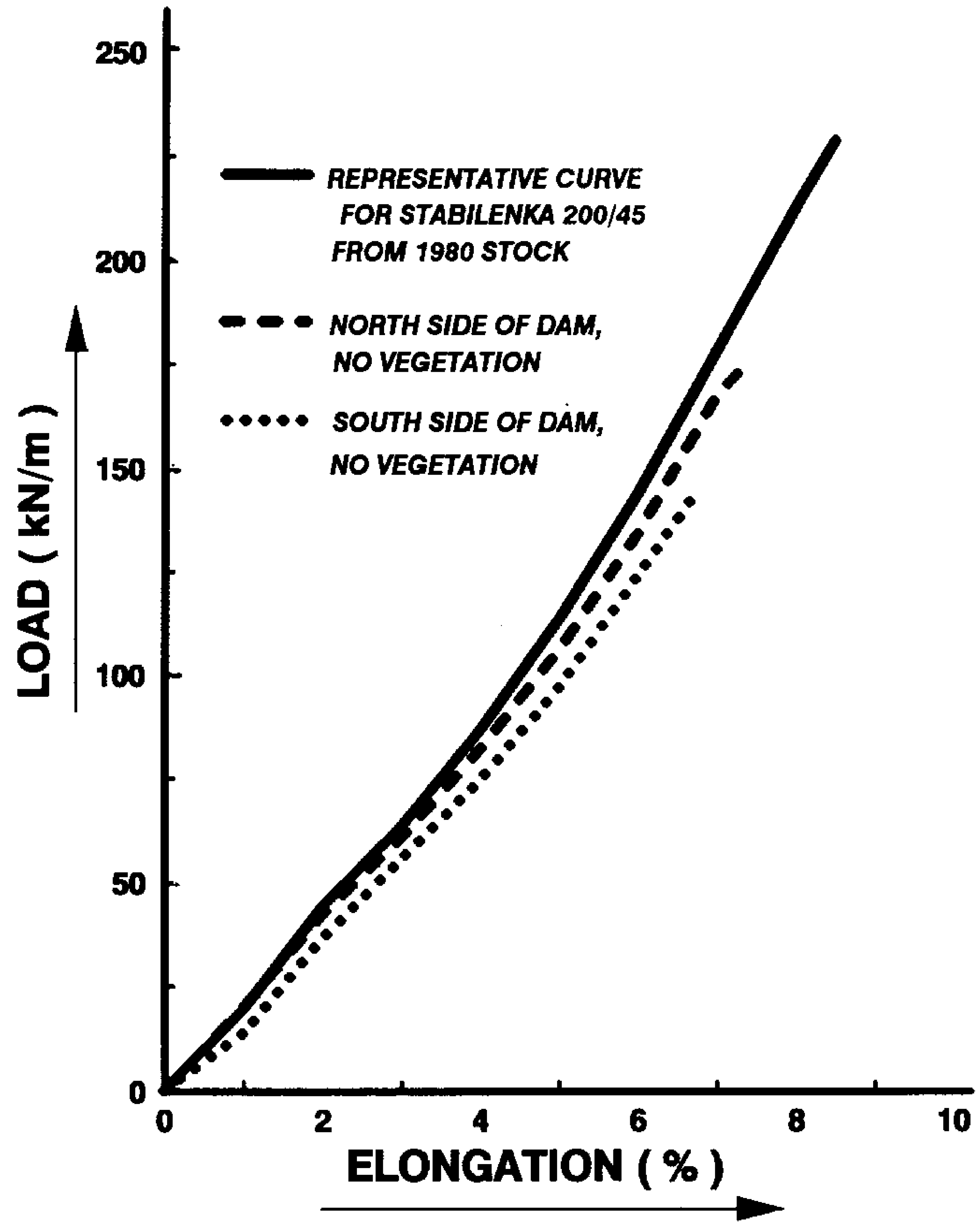

Fig. 7 Load - elongation curves of the reinforcing fabric taken from the outside of the dam without vegetation, compared with the original curve

MECHANICAL PROPERTIES OF FABRIC TAKEN FROM THE DAM

DESCRIPTION OF FABRIC	TENSILE STRENGTH kN/m	TENSILE STRENGTH SD	ELONGATION AT BREAK %	ELONGATION AT BREAK SD	FORCE AT 6 % ELONGATION kN/m	FORCE AT 6 % ELONGATION SD	NUMBER OF TESTS
Fabric from 1980 stock	234	4.8	8.58	0.19	148	5.2	10
Fabric fully embedded in sand	227	8.8	8.56	0.19	144	7.6	10
Fabric fully embedded in clay	219	14.1	8.21	0.46	145	6.3	10
Fabric taken from the north side							
sand fill, no vegetation	172	13.1	7.1	1.03	143	2.8	2
sand fill, with vegetation	208	2.3	8.2	0.55	139	19.1	2
clay fill, no vegetation	179	13.8	7.9	0.56	126	11.3	6
clay fill, with vegetation	217	9.1	8.4	0.38	135	3.3	6
Fabric taken from the south side							
sand fill, no vegetation	127	9.9	6.6	0.21	117	6.3	2
sand fill, ivy grown	198	23.9	7.5	0.51	150	16.9	2
sand fill, no protection layer	112		5.9		110		1
clay fill, no vegetation	151	10.9	7.4	0.49	116	13.1	10
clay fill, ivy grown	204	16.3	7.9	0.29	143	4.2	2

construction were removed (Troost et al., 1990). A fraction of the loss may be due to UV-radiation, however.
The residual strength and modulus pattern of yarns removed from the samples is similar to that for the fabric (see Figure 8).

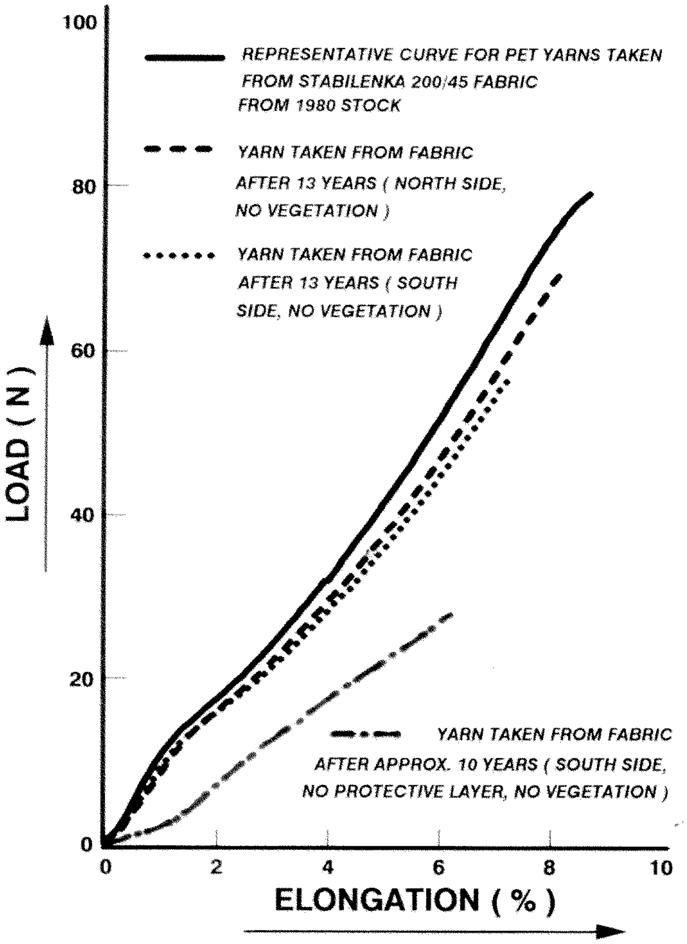

Fig. 8 Load - elongation curves of yarns taken from fabric samples from the outside of the dam without vegetation, compared with the original curve

Yarns taken from a bald spot on the south side (see Figure 9) were wide open to UV-radiation and lost 60 % of the breaking strength and 55 % in modulus.

5.3 Chemical analyses of the yarn polymer

As reported in 5.1, the reinforcing fabric in the dam was always surrounded by moisture to such an extend that hydrolysis ought theoratically to have occurred.
Hydrolytic attack makes PET molecules smaller, an effect that can be detected by measuring the relative solution viscosity, the carboxylic end-group content and the molecular weight distribution (Schmidt et al.,1994).

Samples prepared from fabric from inside the dam, from the outside on the north (with protective layer but without vegetation and from the outside on the south (without any protection at all) were tested for these properties.

Fig. 9 Unprotected spot on the south side

The values found, compared with those for yarn from stock, are presented in the table below.

Property	Description of sample			
	DIOLEN 770 from stock	Inside of the dam	North side, covered with hydroseeding layer	South side, unprotected
Relative solution viscosity	1.77	1.78	1.77	1.71
Carboxylic end-group content (meq / kg)	23	23	23	45
Number-average molecular weight Mn (g / mole)	12400	12600	11700	10300
Weight-average molecular weight Mw (g / mole)	33000	33600	32600	30600

Figure 10 illustrates the relative change in molecular weight distribution curves, compared with that of yarns from stock.

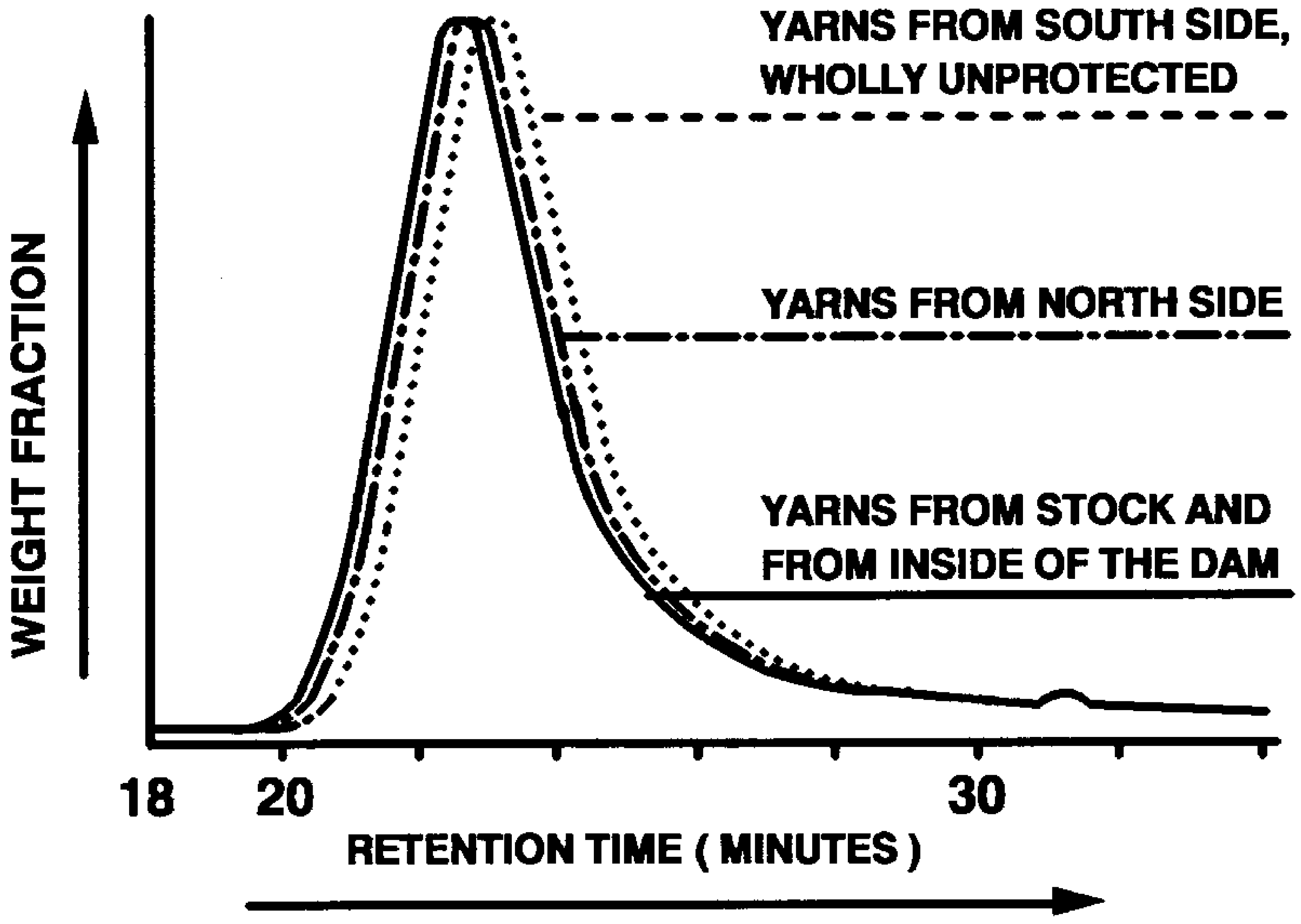

Fig. 10 Size exclusion chromatography curves

Based on the results produced by measurement of relative solution viscosity, carboxylic end-group content and size exclusion chromatography the following conclusions can be drawn:

= For yarns taken from the inside of the dam (13 years at +10°C and 100% R.H.)

  - Zero hydrolytic degradation

= For yarns taken from the north side covered by hydroseeding layer only (13 years at -10°C to + 20°C and 100% R.H.)

  - Approximately 5% strength loss, based on Mn and Mw values, due to degradation factors such as UV-radiation in the first 6 weeks of construction, before application of the hydroseeding layer.

= For yarns taken from the south side, wholly unprotected to out door weathering (approximately 10 years at -10°C up to +40°C)

  - Significant strength loss as a result of degradation caused by such factors as UV-radiation.

6 CONCLUSIONS AND RECOMMMENDATIONS

= Mechanical damage, as found inside the dam, causes strength losses in between 3 % (sand) and 6 % (clay).
These values are within the limits applied in current design practice (Voskamp,W.,1989).

= Hydrolytic attack did not operate inside the dam despite the continuous presence of moisture round the fabric.

= Hydroseeding plus planting with ivy is very effective in protecting the fabric against UV-radiation (no loss of modulus whatsoever).

= Hydroseeding,even if it fails to establish vegetation cover, gives a fairly effective protection against UV-radiation.

= A recommended greening system for European conditions is hydroseeding with herbs and planting with ivy (Hedera). Any permanent vegetation cover requires some maintenance (including watering) during the first two years.

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