A C S Smith and T Vadron

The durability of Reinforced Earth reinforcing strips in Southern Africa

Synopsis

This note describes the results of the monitoring of steel reinforcing strips placed in 13 Reinforced Earth™ projects constructed in Southern Africa before 1982. The results confirm that Reinforced Earth structures will meet their required service lives provided that the backfill complies with Reinforced Earth specifications. Durability problems were encountered on three projects. These problems are briefly discussed in an addendum.

Samevatting

Hierdie nota beskryf die uitslag van die kontrolering van metaalversterkingsbande in 13 Gewapende Grond™ -projekte wat in Suid-Afrika voor 1982 gebou is. Die uitslae bevestig dat Gewapende Grond-projekte die vereiste dienstydperk sal bereik mits die opvulling aan die Gewapende Grond-spesifikasies voldoen. Duursaamheidsprobleme is op drie projekte teëgekom. Hierdie probleme word kortliks in 'n addendum uiteengesit.

A C S Smith *PrEng graduated from the University of the Witwatersrand in 1968 with a BSc (Eng) degree. After working with C J Reid, a firm of road and earthworks contractors, for four years, he received a bursary from the SA Institute of Steel Construction to study structural engineering at Imperial College, where he completed an MSc (DIC) in 1973. After a year with Dorbyl and six months with consulting engineers Shepherd and Shepherd, he joined Reinforced Earth (Pty) Ltd in 1975. He is a Fellow of SAICE and a member of both ICE and ASCE.*

Vladimir (Taffy) Vadron *is the Construction Manager for Reinforced Earth. Since joining the company in 1976 he has been personally responsible for the supply of materials to and the provision of technical assistance in the construction of over 200 000 m² of Reinforced Earth structures in Zimbabwe, Malawi, Botswana, Lesotho and throughout South Africa. He recently played a major role in the development and production of a new medium tensile reinforcing strip, which is currently being exported to Europe and the Far East and will soon be incorporated into Southern African structures.*

Introduction

Reinforced Earth was introduced into Southern Africa in 1975. As at December 1991 190 projects had been completed, comprising over 420 structures and over 200 000 m² of facing area.

All reinforcing strips have been either black or galvanized steel. These have been buried in a wide variety of Southern African backfill materials. Since 1978 all Reinforced Earth structures have included special test strips installed for the purpose of monitoring the evolution of corrosion of the strips.

Service life design philosophy

Without an impressed cathodic protection system it is not possible to stop the on-going corrosion of metals buried in the ground. To ensure that the structure meets its required service life, the loss of strength of the metal through corrosion in the particular backfill over the service life of the structure is estimated and a sacrificial thickness of metal is provided.

Research on the durability of Reinforced Earth reinforcing strips

This is documented in the reference given. The results of the research have led to the formulation of specifications for Reinforced Earth backfill (Fig 1) and reinforcing strips, as well as envelopes for the corrosion rates of galvanized steel reinforcing strips in Reinforced Earth backfill.

These envelopes are as follows:

Dry land structures: $P = 25\ T^{0,65}$ (1)

Structures in fresh water: $P = 50\ T^{0,6}$ (2)

where P = loss of thickness of zinc and steel per side in microns and T = time in years.

The loss of thickness and the loss of strength are related by the following equation:

$$T = To\ (1 - K\ \Delta\ e/e_o) \quad (3)$$

$$\text{where } To = e_o\ b\ \sigma\ r \quad (4)$$

To = initial tensile strength
T = tensile strength remaining
e_o = initial thickness
Δe = average total thickness of steel and zinc lost (on both sides)
K = constant = 1 for perfectly uniform corrosion
= 2 for galvanized steel
b = width of reinforcing strip
$\sigma\ r$ = ultimate stress

The design purposes nominal sacrificial thicknesses, factors of safety and load factors are specified.

$$Tm = \frac{1}{\lambda \gamma_f} (e_o - e_s)\ b\ \frac{\sigma\ r}{1,5} \quad (5)$$

where

Tm = maximum allowed design force
γf = load factor equal to 1,35 for dead loads and 1,6 for live loads and between these two values for combinations of dead and live load
λ = additional factor of safety for high security structures
e_s = nominal sacrificial thickness for design purposes

Example

A bridge with the following criteria:

- Service life 100 years
- Dry structure
- High security structure
- 60 mm x 5 mm high adherence reinforcing strips; $\sigma\ r$ = 360 N/mm²; b = 60 mm; e_o = 5 mm; zinc thickness = 80 microns

From the guidelines e_s = 1,5 mm

$To = 360 \times 60 \times 5 \times 10^{-3} = 108{,}0$ kN
$P = 25 \times 100^{0,65} = 0{,}5$ mm
$\Delta e = 2 \times 0{,}5 - 2 \times 0{,}08 = 0{,}84$ mm
$T = 108{,}0\ (1 - 2 \times 0{,}84/5{,}0) = 71{,}7$ kN

Chemical requirements

		Out of water	*In water*			*Out of water*	*In water*
Resistivity	(Ohm.mm)	> 10 000	> 30 000	Sulphates	(ppm)	< 1 000	< 500
pH		5 to 10	5 to 10	Sulphides	(ppm)	< 300	< 100
Chlorides	(ppm)	< 200	< 100				

The resistivity shall be determined in accordance with the method prescribed by the patentee

Material suitable in Reinforced Earth structures

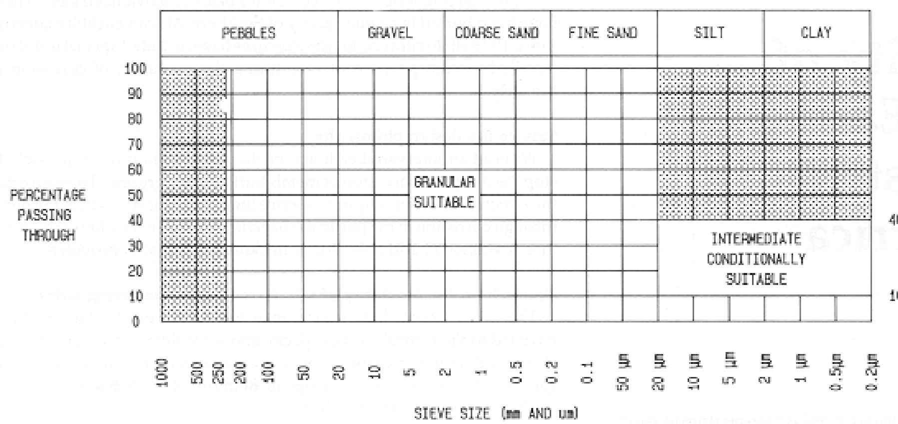

Fig 1: Specification for fill material

$$Tm = \frac{1}{1,1 \times 1,35}(5,0 - 1,5)\ 60 \times \frac{360}{1,5} \times 10^{-3} = 33,9 \text{ kN}$$

The factor of safety at the end of the service life assuming the most aggressive Reinforced Earth backfill (upper envelope) is the ratio of T to Tm. In this case it is 71,7/33,9 = 2,12.

Monitoring of Reinforced Earth structures

With regard to monitoring, two basic categories of Reinforced Earth structures have been built in Southern Africa:

1. Those that do not include monitoring strips – constructed prior to 1978.
2. Those that include special monitoring strips – constructed after 1978.

Special quality control procedures for monitoring both categories include the preparation of test strips and the testing thereof after their removal from structures. The initial mechanical and geometric properties are estimated for the first category and are known for the second category.

Since 1986 the special monitoring strips have been cut from a length of reinforcing strip that is analysed for all mechanical and geometric properties. This is done in order to give an accurate estimate of the initial strength of the placed strip.

Sufficient strips are installed in the structures to allow regular testing over the service life of the structure. Fig 2 illustrates the detail for installation of special monitoring strips for Reinforced Earth structures with concrete cladding elements. Figs 3(a), (b) and (c) show the installation and extraction of the monitoring strip.

Where test strips have not been included in a structure, it becomes necessary to cut out a section of an actual reinforcing strip and then replace this section.

The testing of the samples is undertaken by the SABS in accordance with Reinforced Earth procedures.

Results obtained from the monitoring of 13 Southern African projects

The project details as well as the monitoring results for each project are set out in Table 1. A graphical illustration of the results is given in Figs 4, 5 and 6.

The maximum loss of thickness of any strip monitored during this series

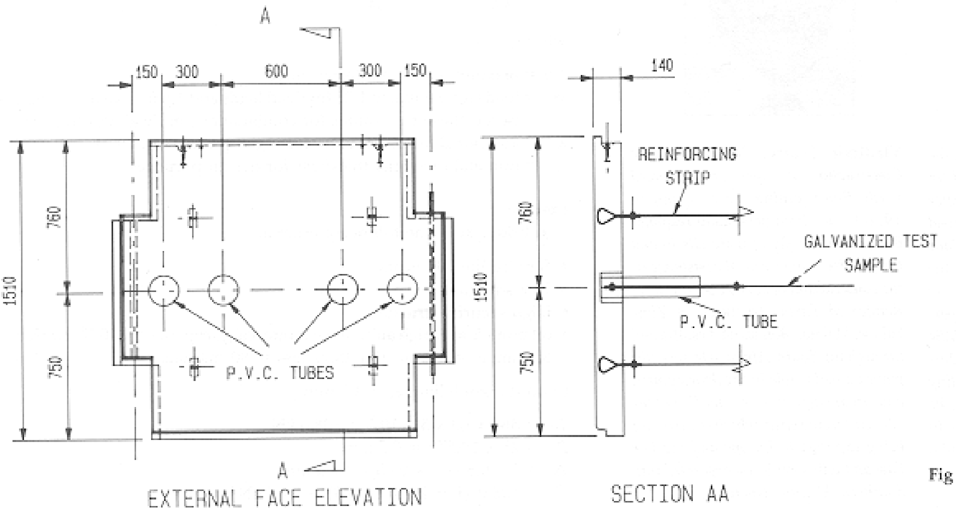

Fig 2: Details of special monitoring strips

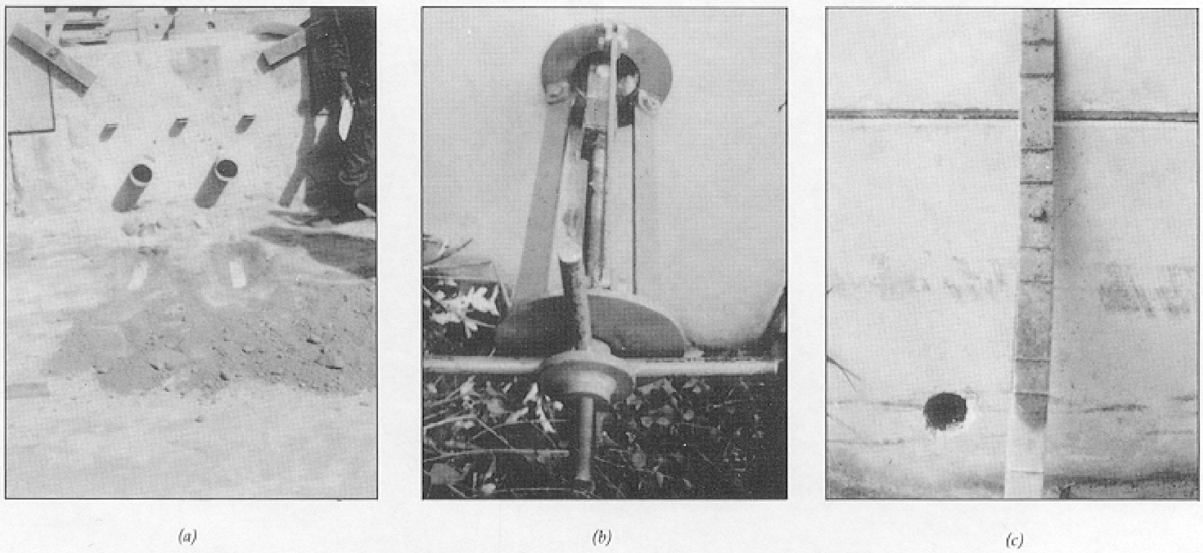

Fig 3: The installation and extraction of a monitoring strip

Reinforced Earth
South Africa

DURABILITY CONTROL REPORT

Report No	Project	Location	Year of nstruction	Details of Project	Age at test (years)	No strips tested	Test strip dimensions	Loss of thickness of zinc Coating per side	Maximum Tensile strength (kN)	Loss of strength (kN)	'ercentage of bare steel	E ongation at failure	Type of material	Grading	pH	Resistivity (cm)	Chlorides (ppm)	Sulphates (ppm)
11	Connaught Interchange	Durban Natal	1981	3 Ret walls + 2 false abutments to bridge	8½	2	40x5	i 12,5 ii 22,5	i 83,5 ii 75,5	nil nil	0	Not know n	Dwyka Tillite	Granular to intermediate	5,0 – 7,8	3250-4500(	17-87	-
12	Virginia Road over Raiul bridge	Virginia O.F.S.	1980	2 RE abutments to bridge	9½	2	60x5	i 48,9 ii 25,6	i 185,5 ii 115,5	nil nil	8	20,7	Dumprock from Mine Quartzite	Granular	5,3 - 7,4	1250-5250	70-144	720 - 159 4
13	Hoedspruit Air force Base	Hoedspruit Transvaal	1979	6 Retaining walls	10 ½	1	40x5	4	79	nil	0	19,2	Weathered Granite	Granular	5,9-7,9	1850-5500	51	66-270
14	Geldenhuis Staging Yard	Germiston Transvaal	1981	1 Retaining wall	9½	1	40x5	15,3	67,75	1,55 Rolling Tolerance	0	34	Sandstone	Granular to intermediate	4,2-5,1	20000-500(	51	618
15/ 15a	Vanguard Drive	Cape Town Cape Prov	1981/2	7 Retaining walls	8½	1	40x5	i 29 ii 12,6	i 77.8 ii 82,5	nil nil	0	26	Cape dune Sand	Granular	9,6	12500	26-53	36-272
16	East-West Bypass	Bellville Cape Prov	1980/1	4 Retaining walls	9½	1	40x5	45,4	76	nil	0,1	22,5	Cape dune Sand	Granular	7,3-8,95	10000-40000	4 - 3,9	-
17	Sir Lowry's Pass	Cape Prov.	1981	1 Retaining wall	8½	1	60x5	Not Done	126,5	nil	0	31	Sandstone	-	-	-	-	-
18	Police Bridges Diepkloof	Johannesburg TRansvaal	1980	2 RE Abutments	10	1	60x5	14,7	197	nil	0	25	Sandstone	Intermediate	5,5	20000	-	-
19	Bridge over Cairnspruit	Near Nelspruit Transvaal	1982	2 RE Abutments	8	1	60x5	8,1	113,5	nil	0	27	Not known	Granular	5,8	55000	17	-
20	Georges Valley	Near Tzaneen Transvaal	1980	5 Retaining walls	10	1	40x5	11	82,5	nil	0	23	Coarse River sand	Granular	6,5-6,9	40000-100000	-	-
21	Georges Valley	Near Tzaneen Transvaal	1978	2 Retaining walls	12	1	80x3	32,6	87,8	nil	0	25,2	Commercial Sand	Mainly Intermediate	4,75 - 7,05	22400-7500	-	-
22	Quarry Rd	Pinetown Natal	1982	1 Retaining wall	9	1	40x5	45,1	102,7	nil	1	22	Decomposed Tillite	Granular to Intermediate	4,6-6,5	8000-1000(	17-87	211 - 249
23	Wyliespoort Sibasa	Near Thohoyandu Venda	1981/2	3 Retaining walls	10	3	40x5	i 16 ii 11 iii 11	i 78 ii 80 iii 80	nil nil nil	0	22,5 - 27,5	Weathered Sandstone	Intermediate	5,0-6,6	37500 – 350000	17-52	-
24	Dunswart Bridge	Boksburg / Benoni	1987	2 Retaining walls	5	1	40x5	18	89.4	nil	2	22	Slag from Dunswart iron & steel	Granular	8.2-12.4	800-3000	7-28	432 - 122 9
25	Norton	Zimbabwe	1982/83	Bridge approach Ramps	10. 1/2	1	40x5	11	81.5	nil	0	24	laterite	Silty granular	6.8	32500	7	50
26	Grotegeluk	Ellisrus	1977	Retaining Walls	16	1	80x3	0	79.5	nil	0	27	Aeolian sand	Silty Granular sand	6.3	5575	44	
27	Sandton City	Sandton	1982	Retaining Wall	11	1	60x5	0	160	nil	0	22	Decomposed granite	Intermediate	5.2-5.9	12667	35	
28	Tombo Port St. Johns	Transkei	1990	Retaining Walls	2 1/2	1	60x1 0	Black	262	nil	N/A	29	Weathered Dolorite	Granular	7.33	4700	25	28
29	Tweepad Stage 2	North West Cape	1987	Retaining Walls	6.5	2	40x5 60x5	7 5	92.7 104.4	nil nil	0 0	6.8 22.5	Dune Sand	Fine-medium sand	8.9	6758	69	33
30	Faerie Glen	Pretoria	1983	Retaining Wall	11 1/2	1	60x5	54	152.9	nil	7 1	23	Blast Furnace slag	granular	10.7	1800	35	168 0
31	Remedial works	Krugersdorp	1978/79	Retaining Wall	15 1/2	1	60x5	10	146.4	nil	0 0	23.5	Sand - Washed decomposed granite	-	-	-	-	-
32	Mabopane Bridge	Pretoria north	1980/81	Bridge Abutments	14 1/2	1	60x5	10	134.3	nil	0 0	24	Sandy gravel	Granular	6.6	16000	-	-
33	Donegal Road	Durban	1981	Retaining Wall	13	1	40x5	10	84.5	nil	0 0	24.4	Unknown	-	-	-	-	-
34	OK Bazaars	Empangeni	1982	3 Retaining Walls	12	1	40x5	10	101.9	nil	1 0	20.2	Sandy Gravel	Granular	5.4	6500	42	31
35	Connaught Bridge	Durban	1982	Retaining Walls & Abutment	12	1	40x5	16	96.7	nil	0 0	13.2	Unknown	-	-	-	-	-
36	Water Wonderland	Durban	1983	Retaining Wall	11	1	60x5	12	159.1	nil	0 0	20	Sandy Gravel	Granular	8	29200	17	216
37	Elandsriver Bridge	Eastern Transvaal	1984	2 Bridge Abutments	10	1	40x5	2	92.2	nil	0 0	16.8	Unknown	-	-	-	-	-
38	Phoenix Bridge	Durban	1983	2 Bridge Abutments	11	1	40x5	45	128.6	nil	0 0	25.6	Sandy Gravel	Granular	-	-	-	-
39	Umhlatuzan a to Mkhondeni	Natal	1983	3 Retaining Walls	11	1	40x5	18	116.0	nil	0 0	20.8	Unknown	-	-	-	-	-
40	Auchas 1 & Auchas 2	N. W. Cape	1989 ,90,91,9 2	Tip Wall to Crusher	4 1/2	2	50x5	0 0	151.8 152.2	nil nil	1 4 1 9	18.8 20.0	Boulders Remaining on a 19.2mm screen	Granular	Not done	3700	15	165
41	Koingnass	W. Cape	1977	8 Retaining walls	17	2	60x3 80x3	23.18 28.83	84.8 93.6	nil nil	45 6 80 10	19.6 15.0	Fine single sized sand	nil	7.31	650/800	82 0	150
42	Tombo Port St. Johns	Transkei	1990	Retaining Walls Grid	4 1/2		60 x10	Black	275	nil	N/A	29.4	Weathered Dolorite	Granular	7.5	4680	-	-
43	Tombo Port St. Johns	Transkei	1990	Retaining Walls Concrete	5	1	40x4	3	86.1	nil	-	22.0	Unknown	-	7.0	7600	-	-
44	Middelftn	Eastern Transvaal	1985	Road over Rail Bridge	10	1	40x5	5	96.2	nil	0 0	27	Dark Red sand	Intermediate	7.0	15300	-	-
45	Richards Bay Minerals	Natal	1991	4 Grid Walls	4	1	40x4	4	86.1	nil	0 0	26	Dune sand / top soil	Granular	6.1	29750	21	32
46	Iscor	Vanderbijlpar k	1983	Storage slot & wall	12 1/2	1	60x5	0	149.2	nil	0 0	21	Blast furnace slag	Granular	8.2	-		432 0

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47	Vulcania Link Road	Brakpan	1984	Bridge Abut. & 2 Retaining wall	11	1	40x5	8.15	114.5	nil	0 0	21	Not known	-	5.7	15000	35	556
48	Savmore Colliery	Mapumlanga	1990	2 retaining walls	5.5	1	40x4	5.21	100.10	nil	0 0	17	Not known	Conditionall y suitable	4.3	22500	4	77
49	Kromboom Parkway	Cape town	1983/84	4 Retaining Walls	12	1	60x5	6.99	170.4	nil	0 0	21	Cape Dune Sand	Granular	7.0	9000	11	45
50	Salt River Station	Cape	1983 /85	6 Retaining Walls	12	1	60x5	1.83	140.4	nil	0 0	24	Dune Sand	Granular	7.0	8600	-	-
51	Du Toitskloof	Cape	1985/86	7 Retaining Walls	10	1	40x5	14.85	127.2	nil	0 0	21	Gritty sand	Granular	7.0	4200	-	-
52	Bridge	Potgietersrus	1987	2 Abutments & wing walls, ret. wall	9	1	40x5	5.18	116.26	nil	0 0	21	Not known	-	-	-	-	-
53	Rietvlei Dam	Pretoria	1988	Retaining Wal	9	1	40x4	3.98	88	nil	0 0	24.5	Not knwn	-	-	-	-	-
54	Dunswart Bridge	Benoni	1987	2 Retaining walls	11	1	40x5	-	126	-	-	-	--	-	-	-	-	-
55	Arthur Taylor colliery	Witbank	1992	Training Wall	7	1	40x4	black	91.0	nil	0 0	-	Not known	-	-	-	-	-
56	Tombo Culvert	Tombo Port St. Johns	1989	4 Culverts	12	1	40x4	9.91	85.86	nil	0 0	19.4	Not known	-	-	-	-	-
57	Tombo Wall 4	Tombo Port St. Johns	1983	6 Retaining walls	18	1	40x5	8.43	76	nil	0 0	33.8	Not known	-	-	-	-	-
58	Tombo to Port St. Johns	Tombo Port St. Johns	1990	2 Black terra-trelRetaining walls	10	-	60x 10	black	206	-	-	-	-	-	-	-	-	
59	Verwoerdb urg Bridge	Verwoerdbur g	1984	Retaining walls	13	1	40x5	13.96	116.26	nil	0 0	30.0 0	Not known	-	-	-	-	-
60	Muldersdrif t Wall	Muldersdrift	1989	4 Retaining walls	13	1	40x4	7.14	85.52	nil	0 0	23.7 5	Not known	-	-	-	-	-
61	NIL																	
62	NIL																	
63	Potgieter St.	Pretoria	1988	Retaining Wall	15	1	40x4	16.87	96.48	nil	0 0	27.2 9	Not known	-	-	-	-	-
64																		

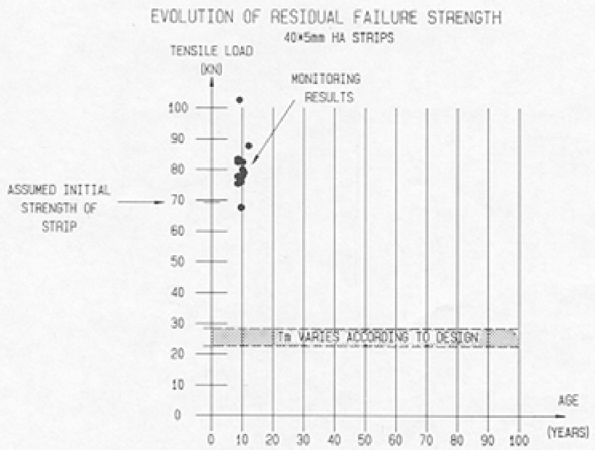

Fig 5: Evolution of residual failure strength (40 mm x 5 mm HA strips)

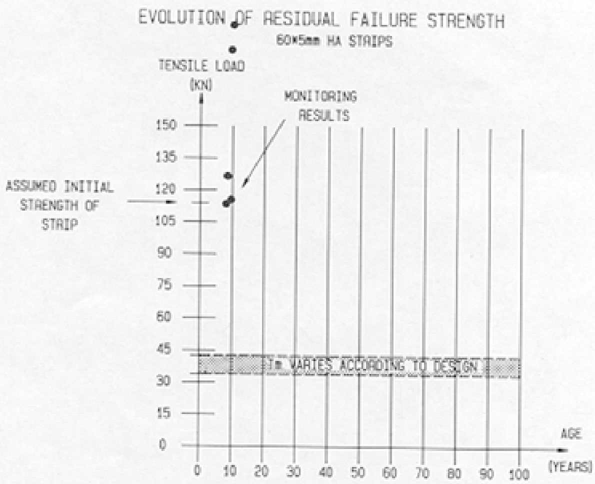

Fig 6: Evolution of residual failure strength (60 mm x 5 mm HA strips)

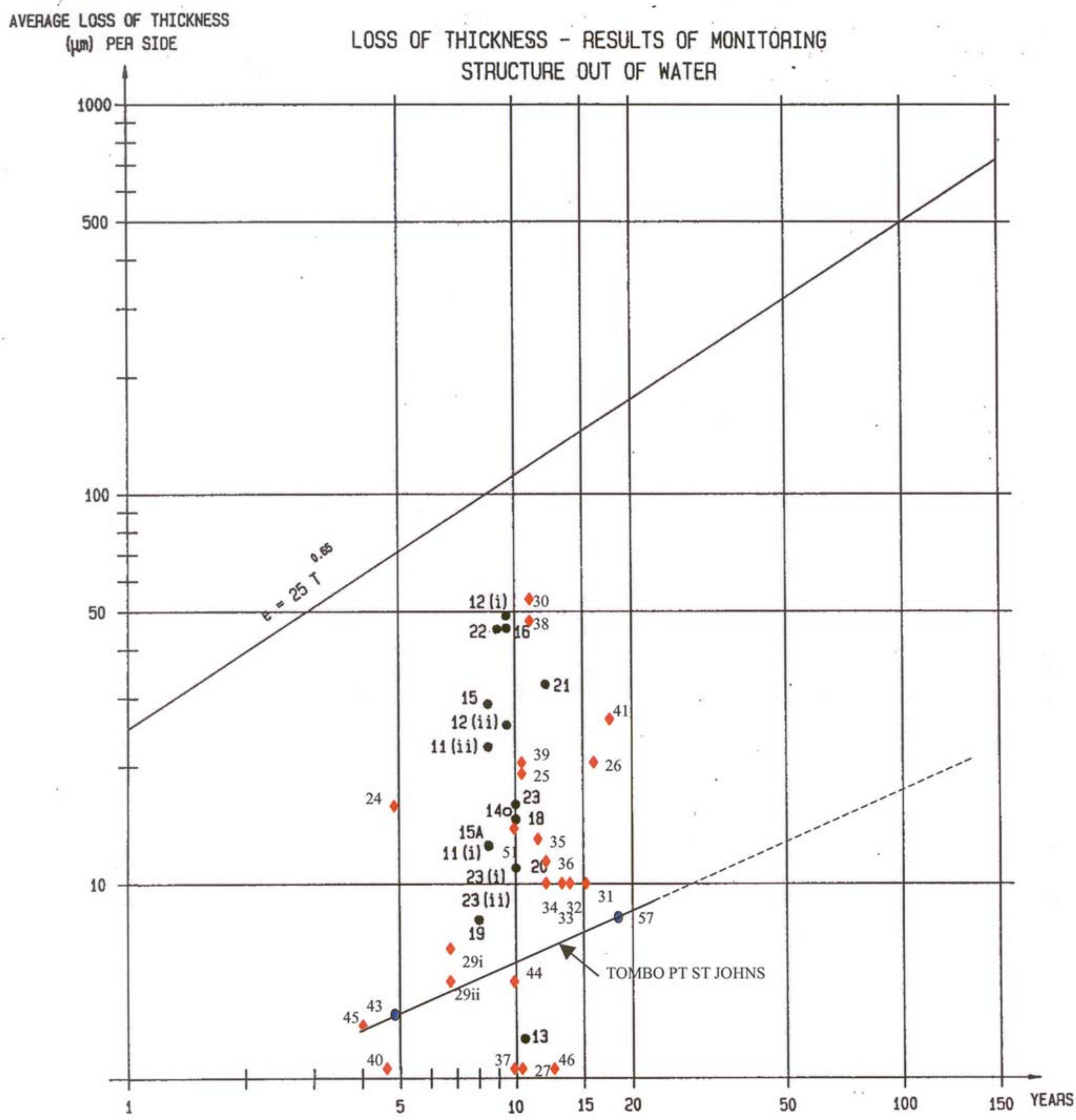

Fig 4: Loss of thickness – results of monitoring the structure out of water