APPENDIX D SOIL STIFFNESS MODEL

To model the non-linear elastic response of the Dunkirk a constitutive model of the form described by Jardine (1985) was used. The secant stiffness expressions that describe this behaviour are as follows:

$$3.G/p' = A + B.\cos\{\alpha.[\log_{10}(\epsilon_D/(\sqrt{3}.C))]^{\gamma}\}$$

$$K/p' = R + S.\cos\{\delta.[\log_{10}(|\epsilon_v|/T)]^{\mu}\}$$

where

G is the secant shear modulus

K is the secant bulk modulus

p' is the mean effective stress given by

$p' = (\sigma_1' + \sigma_2' + \sigma_3')/3$

ϵ_D is the deviatoric strain invariant given by

$\epsilon_D = [(2/3).(\epsilon_1-\epsilon_2)^2 + (\epsilon_2-\epsilon_3)^2 + (\epsilon_3-\epsilon_1)^2]^{1/2}$

and related to the axial strain ϵ_a in an undrained triaxial test by the expression

$\epsilon_D = \sqrt{3}.\epsilon_a$

ϵ_1, ϵ_2 and ϵ_3 are principal strains

ϵ_v is the volumetric strain, and

A, B, C, R, S, T, α, γ ,δ and μ are all constants.

In the analysis tangent stiffness expressions are used which can be derived from the above expressions by differentiation. Throughout the analysis the stiffness at a particular point is continually updated. It depends on the current strain, ϵ_D, and the current mean effective stress, p', at that point. Until a specified minimum strain ($\epsilon_{D,min}$ or $\epsilon_{v,min}$) is exceeded the stiffness varies only with the mean effective stress, p'. This also applies once a specified upper strain limit ($\epsilon_{D,max}$ or $\epsilon_{v,max}$) is exceeded. In the analysis the calculated stiffness is prevented from falling below specified minimum values (G_{min} or K_{min}).

$$3.G^{sec}/p' = A + B.\cos\{\alpha.[\log_{10}(\varepsilon_D/(\sqrt{3}.C))]^{\gamma}\}$$

Stratum	A	B	C (%)	α	γ	$\varepsilon_{D,min}$ (%)	$\varepsilon_{D,max}$ (%)	G_{min} (kPa)
Looser Dunkirk sand	1495	1543	$7.0x10^{-4}$	1.349	0.6385	$5.196x10^{-4}$	0.433	1600
Dense Dunkirk sand	1,869	1,929	$7.0x10^{-4}$	1.349	0.6385	$5.196x10^{-4}$	0.433	2,000

Table D.1 Coefficients and limits for non-linear elastic small-strain shear modulus stiffness

$$K^{sec}/p' = R + S.\cos\{\delta.[\log_{10}(|\varepsilon_v|/T)]^{\lambda}\}$$

Stratum	R	S	T (%)	δ	μ	$\varepsilon_{v,min}$ (%)	$\varepsilon_{v,max}$ (%)	K_{min} (kPa)
Looser Dunkirk sand	470	330	$7.0x10^{-4}$	1.4	0.797	$3.0x10^{-3}$	0.2	4000
Dense Dunkirk sand	587	412	$7.0x10^{-4}$	1.4	0.797	$3.0x10^{-3}$	0.2	5000

Table D.2 Coefficients and limits for non-linear elastic small-strain bulk modulus stiffness

APPENDIX E - PHOTOCOPIES OF LETTERS FROM WS-ATKINS

APPENDIX E - PHOTOCOPIES OF LETTERS FROM WS-ATKINS

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FACSIMILE TRANSMISSION

Destination Fax Number:	0171 225 2716	00

To: Professor R. Jardine

From: Mark Manzocchi

Pages: 8 Ref: AM3499/MM Date: 27/11/98

Re: Application of cyclic soil model to piles

With reference to our meeting yesterday, please find attached the results of some new analyses I have examined on the cyclic degradation of a single pile. I have divided the main block up into 10, 5 and 1 sub-blocks and applied an "incremental" deterioration at the end of each sub-block. The "incremental" deterioration I applied is a modification of what we discussed. Basically I derived a scheme that, when applied repeatedly to a single soil block that is fully mobilised in both tension and compression will give exactly the same result as the application of a single block. Deterioration between sub-blocks is calculated according to the following scheme:

N_{tot}: Total number of cycles to date, including the present sub-block
N_s: Number of cycles in the present sub-block of cycles

$$r = A\left(\frac{\tau_{cy}}{\tau_{\max static}} + B\right)$$

$$\frac{\Delta\sigma'_{rcyclic}}{\sigma'_{r0}} = \frac{r\left(N_{tot}^{C} - \left(N_{tot} - N_s\right)^{C}\right)}{1 + r\left(N_{tot} - N_s\right)^{C}}$$

The degradattion in radial stress, $\frac{\Delta\sigma'_{rcyclic}}{\sigma'_{r0}}$, approximately equals the degradation in shear capacity. Succesive application of this updating scheme will result in the same overall degradation in those areas that are fully mobilised in both tension and compression as the application of a single block of N_{tot} cycles.

There follows a table summarising the results for three cases and showing percentage degradation

Fav (MN)	Fcy (MN)	N	10 Sub-Blocks		5 Sub-Blocks		1 Sub-Block	
			Fshaft comp (MN)	Fshaft tens (MN)	Fshaft comp (MN)	Fshaft tens (MN)	Fshaft comp (MN)	Fshaft tens (MN)
25	15	100	41.5 (12%)	30.2	41.6 (12%)	30.2	42.1 (11%)	30.6
30	20	100	39.1 (17%)	28.4	39.3 (17%)	28.6	40.1 (15%)	29.1
30	20	400	32.3 (31%)	23.6	33.0 (31%)	24.0	35.6 (24%)	25.9

F_{tip} =15.2 MN

Plots of accumulated degradation and shear capacity are given on the next pages. It appears that the method requires a reasonably small amount of sub-blocks (5) to achieve a stable state. The effect of the migration of the fully mobilised region can be seen but is reasonably small for the lower levels of loading but increases as the loading increases.

I hope this is O.K.

Regards

Mark

WS Atkins

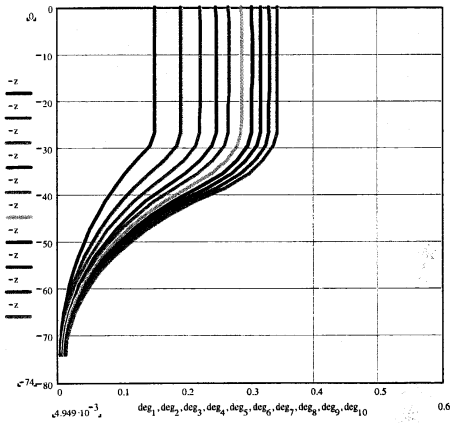
Cyclic Degradation in Piles
Assessment of Analytical Model

AM 3499
27/11/98
M.Manzocchi

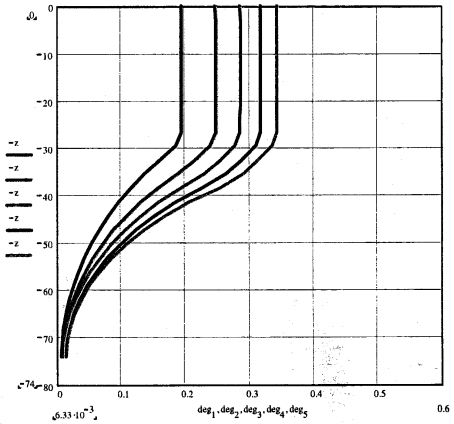
100 Cycles

ABC parameters as Appendix A

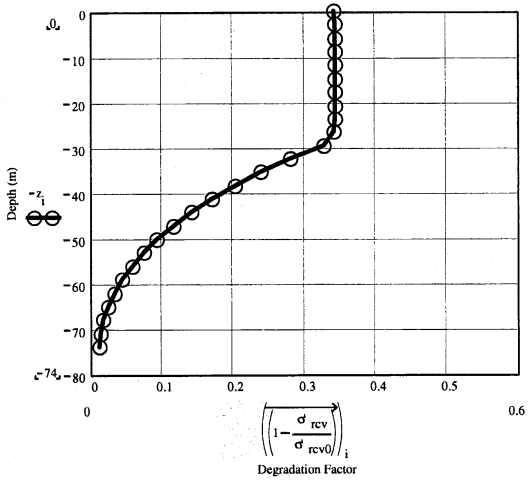
Fav=25 MN
Fcy=15 MN



10 Blocks of 10
Fcomp=56.7
Ftens=30.2



5 Blocks of 20
Fcomp=56.8
Ftens= 30.2
Degradation of σ'_{rc}



1 Blocks of 100
Fcomp=57.3
Ftens= 34.1

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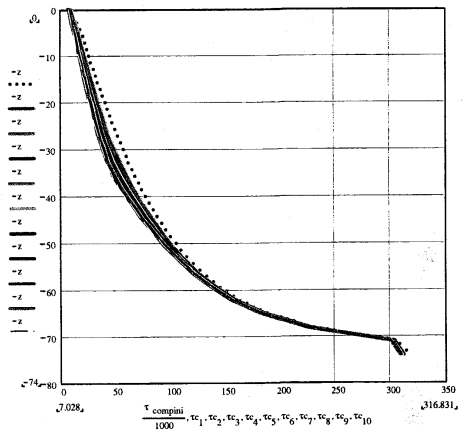
Cyclic Degradation in Piles
Assessment of Analytical Model

AM 3499
27/11/98
M.Manzocchi

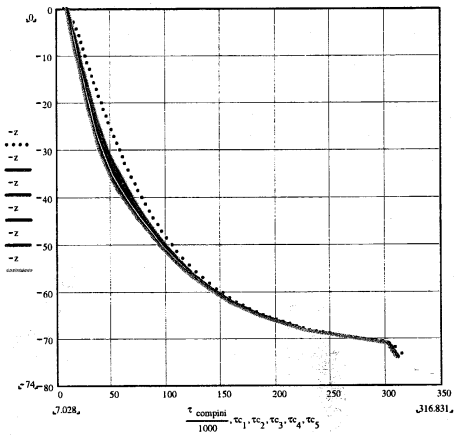
100 Cycles

ABC parameters as Appendix A

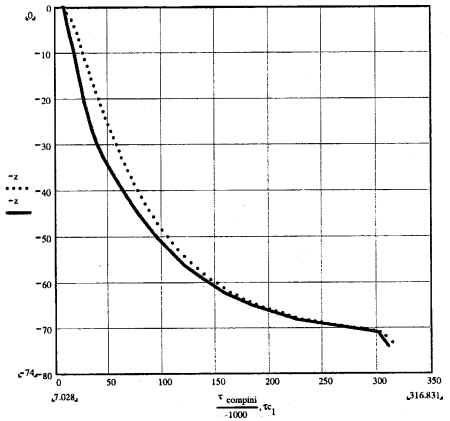
Fav=25 MN
Fcy=15 MN



10 Blocks of 10
Fcomp=56.7
Ftens=30.2



5 Blocks of 20
Fcomp=56.8
Ftens= 30.2
Compressive Skin Friction



1 Block of 100
Fcomp=57.3
Ftens= 30.6

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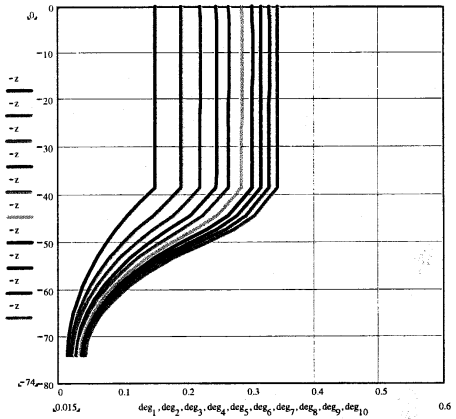
Cyclic Degradation in Piles
Assessment of Analytical Model

AM 3499
27/11/98
M.Manzocchi

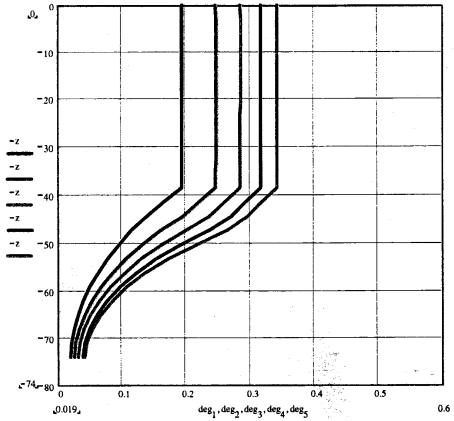
100 Cycles

ABC parameters as Appendix A

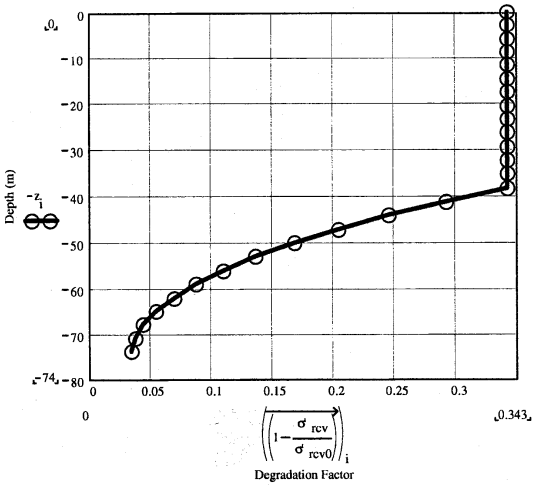
Fav=30 MN
Fcy=20 MN



10 Blocks of 10
Fcomp=54.3
Ftens=28.4



5 Blocks of 20
Fcomp=54.5
Ftens= 28.6
Degradation of σ'_{rc}



1 Block of 100
Fcomp=55.3
Ftens= 29.1

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Cyclic Degradation in Piles
Assessment of Analytical Model

AM 3499
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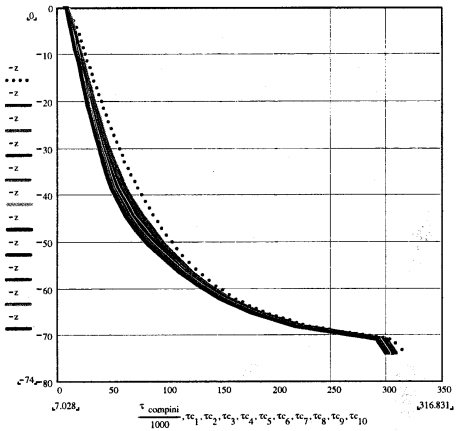
M.Manzocchi

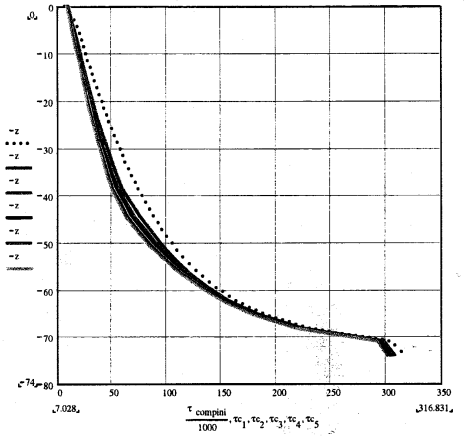
100 Cycles

AGC parameters as Appendix A

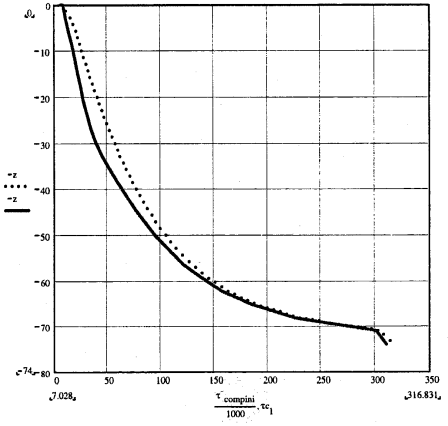
Fav=30 MN
Fcy=20 MN



10 Blocks of 10
Fcomp=54.3
Ftens=28.4



5 Blocks of 20
Fcomp=54.5
Ftens= 28.6
Compressive Skin Friction

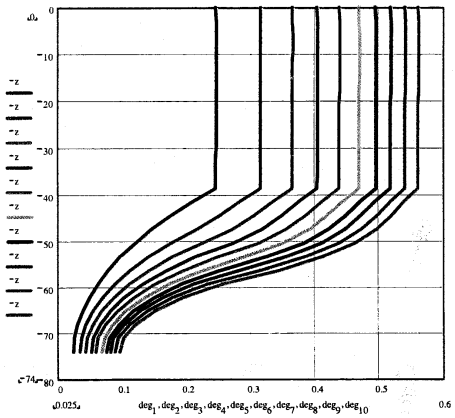


1 Block of 100
Fcomp=55.3
Ftens= 29.1

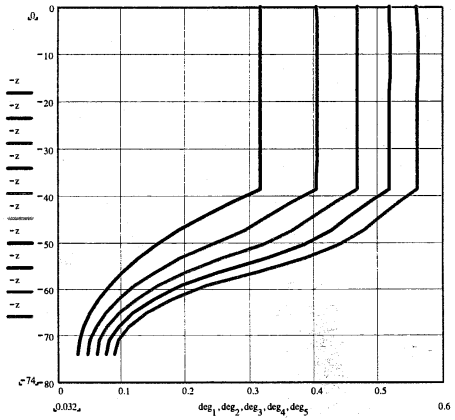
400 Cycles

ABC parameters as Appendix A

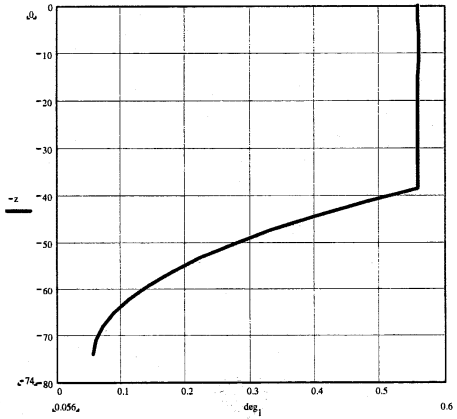
Fav=30 MN
Fcy=20 MN



10 Blocks of 40
Fcomp=47.5
Ftens=23.6



5 Blocks of 80
Fcomp=48.1
Ftens= 24.0
Degradation of σ'_{rc}

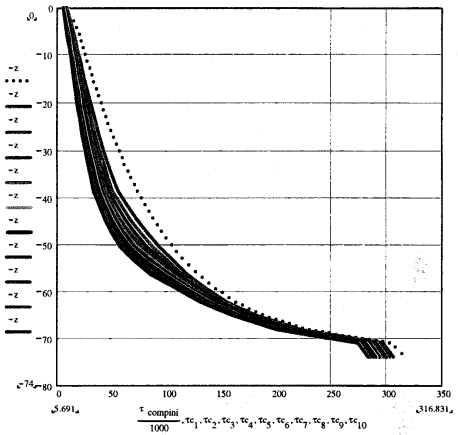


1 Block of 400
Fcomp=50.8
Ftens= 25.9

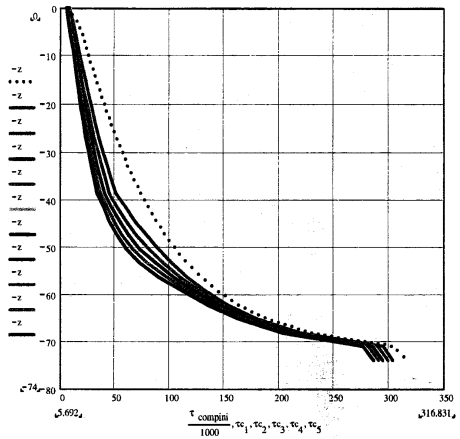
ABC Parameters as Appendix A

400 Cycles

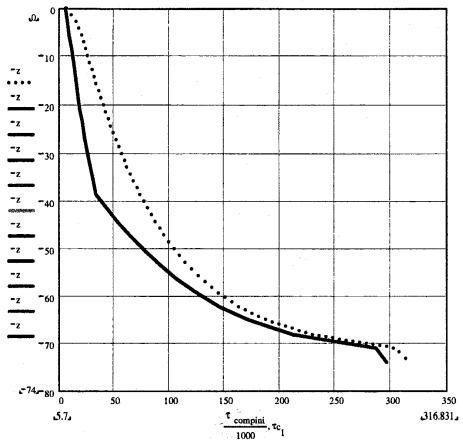
Fav=30 MN
Fcy=20 MN



10 Blocks of 40
Fcomp=47.5
Ftens=23.6



5 Blocks of 80
Fcomp=48.1
Ftens= 24.0
Compressive Skin Friction



1 Block of 400
Fcomp=50.8
Ftens= 25.9

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Your ref
Our ref AM 3499.001/GMM

Date 18/12/98

Ext no 4534

Professor R.J. Jardine
Dept. of Civil & Environmental Engineering
Imperial College of Science, Technology and Medicine
London SW7 2BU

Dear Richard,

Please find enclosed colour copies of the calibration results sheets for the two Dunkirk tests and the test analyses on the synthetic pile for inclusion into your report. Please let me know if you require any more figures.

Yours Sincerely,

for and on behalf of
WS Atkins Science and Technology

Mark Manzocchi

WS Atkins

Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R3

AM 3499
01/12/98
M.Manzocchi

Predictions with ABC values from Appendix A

Dunkirk Cyclic Degradation Model: Test of Analysis
Pile R3: Cyclic Tension Test
Stage 1:
F_{cy} = -0.7MN
F_{av} = -0.7MN
N=200
5 Sub-Blocks of 40 Cycles

After 200 Cycles:

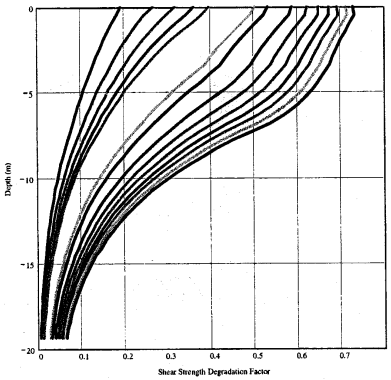
Tensile Capacity=2.26 MN
Degradation = 7.4%

Stage 2:
F_{cy} =-0.95MN
F_{av} = -0.95MN
Cycle until Collapse
2 Sub-Blocks of 15 Cycles Followed by Sub-Blocks of 50 cycles until collapse

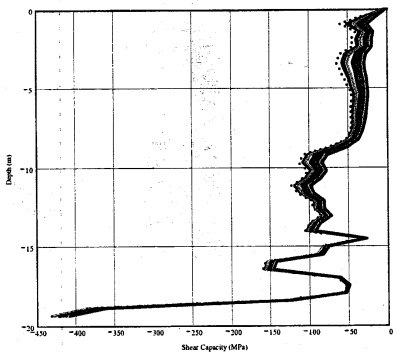
Collapse after 380 Cycles in Stage 2

After 30 Cycles
Tensile Capacity=2.13 MN
Total Degradation = 13% (Including Stage 1)

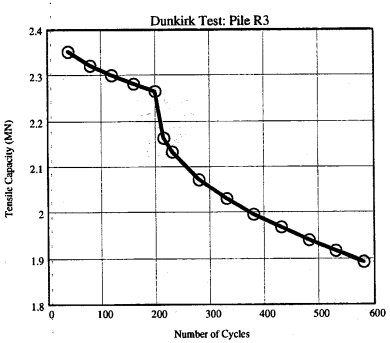
After 300 Cycles
Tensile Capacity=1.93 MN
Degradation = 21% (Including Stage 1)



Degradation Factor Variation with Depth:



Shaft Shear Capacity



Progressive Strength Degradation

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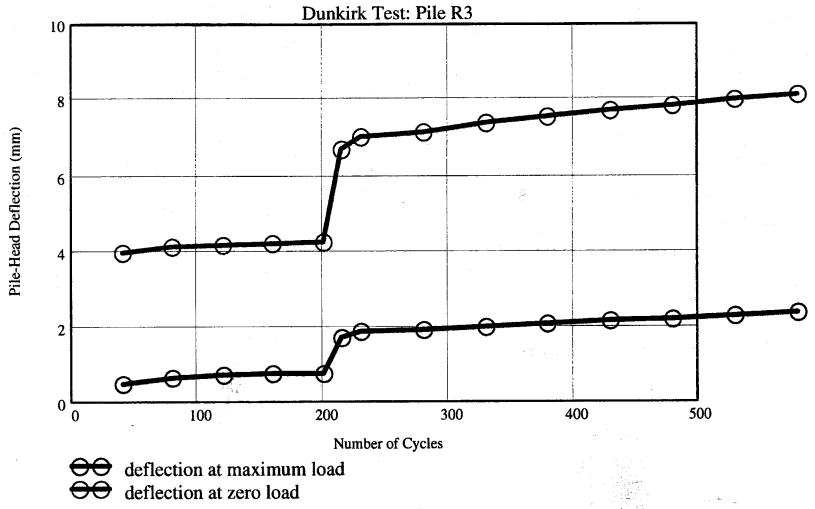
Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R3

AM 3499
01/12/98
M.Manzocchi



Predictions with ABC parameters from Appendix A

Dunkirk Cyclic Degradation Model: Test of Analysis

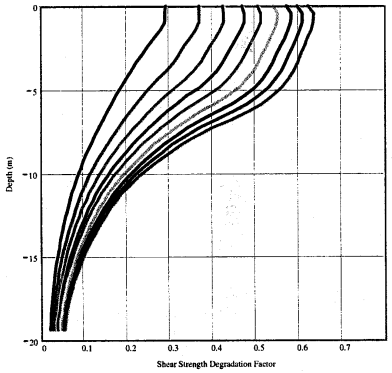
Predictions with ABC parameters from Appendix A.

Pile R4: Cyclic Tension Test

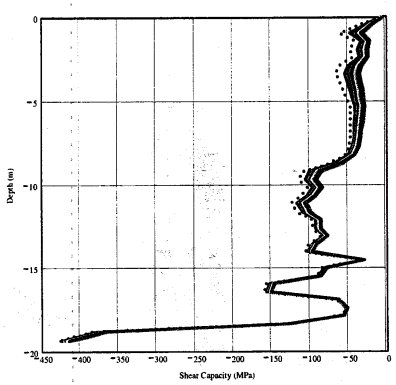
Maximum Tension = 2.0 MN
Minimum Tension = 0.0 MN

F_{cy} = -1.0MN
F_{av} = -1.0MN

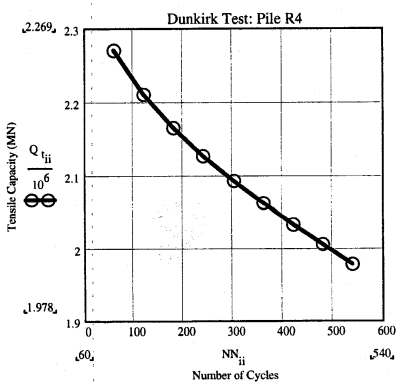
Cyclic Loading Model is Applied in sub-blocks of 60 cycles until collapse occurs



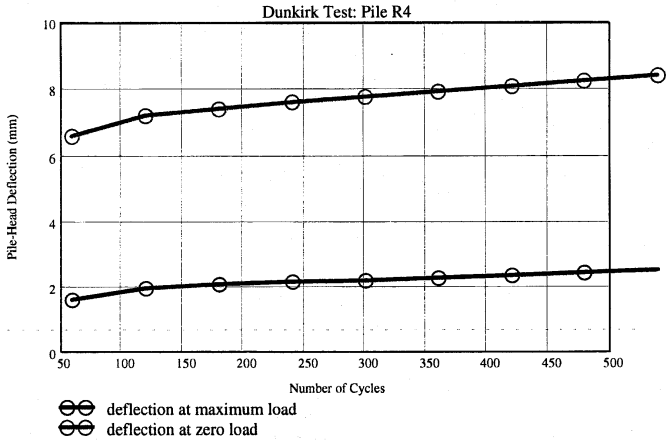
Degradation Factor Variation with Depth: Sub-Blocks of 60 Cycles



Shaft Shear Capacity Sub-Blocks of 60 Cycles



Progressive Strength Degradation



Pile-Head Deflection

Predictions with ABC parameters from Appendix A.

Number of Cycles To Failure: 500

Tensile Capacity after 300 Cycles: 2.09 MN
Initial Tensile Capacity: 2.44 MN

Percentage Capacity Loss after 300 Cycles: 14%

ABC Parameters up graded

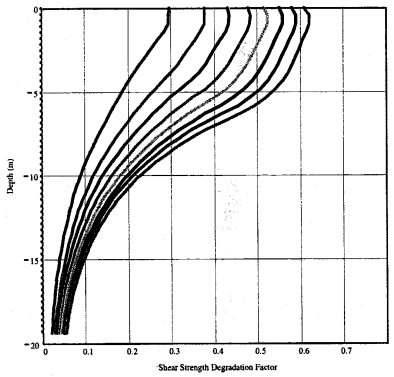
Dunkirk Cyclic Degradation Model: Test of Analysis

Pile R4: Cyclic Tension Test

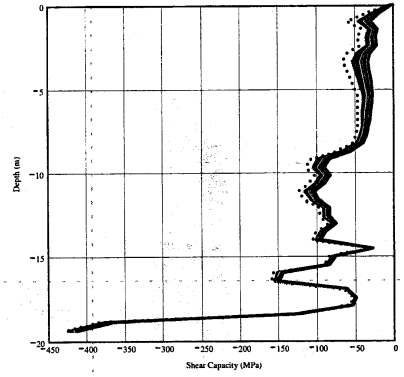
Maximum Tension = 2.0 kN
Minimum Tension = 0.0 kN

F_{cy} = -1.0kN
F_{av} = -1.0kN

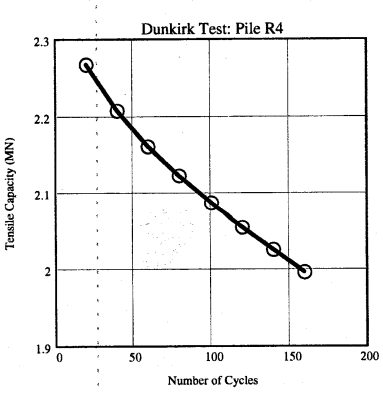
Cyclic Loading Model is Applied in sub-blocks of 20 cycles until collapse occurs after 160 cycles



Degradation Factor Variation with Depth:
8 Sub-Blocks of 20 Cycles



Local shaft Frictional Resistance with Depth
8 Sub-Blocks of 20 Cycles



Progressive Strength Degradation

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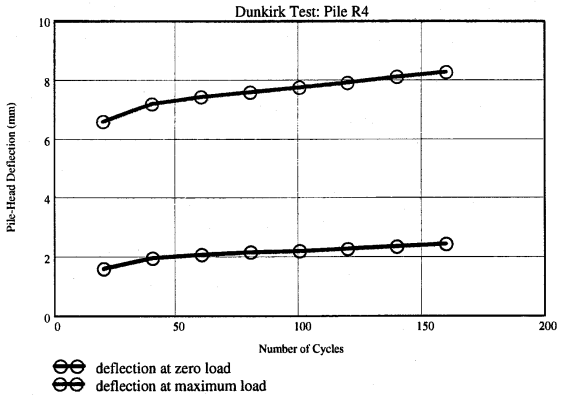
Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R4

AM 3499
01/12/98
M.Manzocchi

ABC parameters upgraded.



Pile-Head Deflection History

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Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R3

AM 3499
01/12/98
M.Manzocchi

Dunkirk Cyclic Degradation Model: Test of Analysis
Pile R3: Cyclic Tension Test

Stage 1:
F_{cy} = -0.7MN
F_{av} = -0.7MN
N=200
5 Sub-Blocks of 40 Cycles

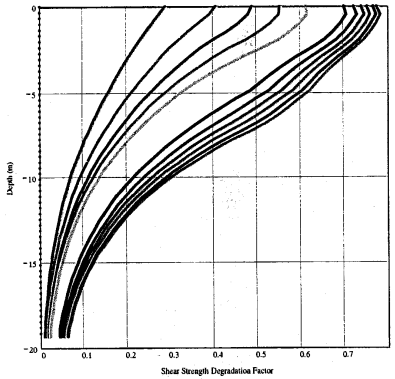
After 200 Cycles:

Tensile Capacity=2.15 MN
Degradation = 11.9%

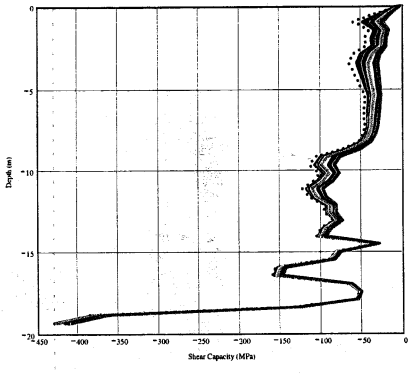
ABC Parameters upgraded

Stage 2:
F_{cy} =-0.95MN
F_{av} = -0.95MN
Cycle until Collapse+
Sub-Blocks of 10 Cycles until collapse occurs

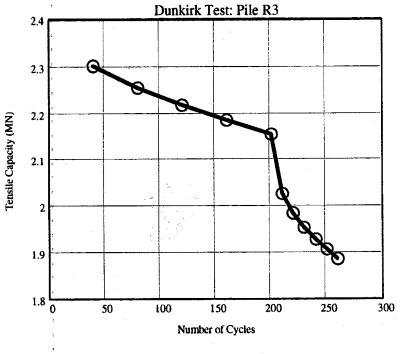
Collapse after 50 Cycles in Stage 2



Degradation Factor Variation with Depth.
Stage 1: 5 Sub-Blocks of 40 Cyscles
Stage 2: 6 Sub-Blocks 0f 10 Cycles



Local Shaft Frictional Resistance with Depth
Stage 1: 5 Sub-Blocks of 40 Cyscles
Stage 2: 6 Sub-Blocks 0f 10 Cycles



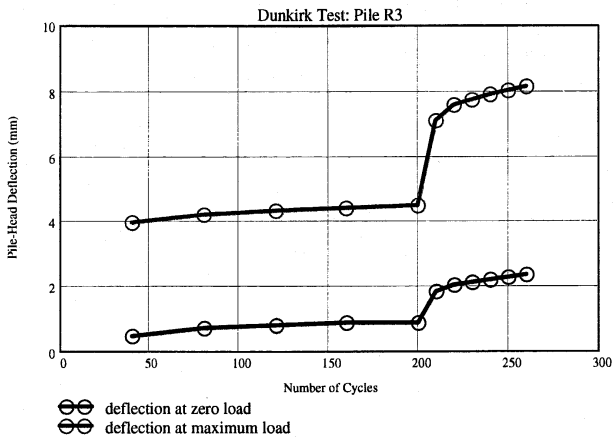
Progressive Strength Degradation

WS Atkins

Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R3

AM 3499
01/12/98
M.Manzocchi

ABC parameters upgraded



Pile-Head Deflection History

WS Atkins Science & Technology
a division of WS Atkins Consultants Limited

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Your ref

Our ref GMM/pa/02

Date 26/02/99

Ext No 4534

Professor Richard Jardine
Dept. of Civil and Environmental Engineering
Imperial College
London SW7 2BU

Dear Richard,

Please find attached plots of the shaft shear stress distribution versus depth as discussed. Please note that the synthetic pile results were analysed with the original degradation model parameters, and these plots and those sent previously use this model. The Dunkirk results have been derived using the updated degradation model.

Please contact me should you require any further information.

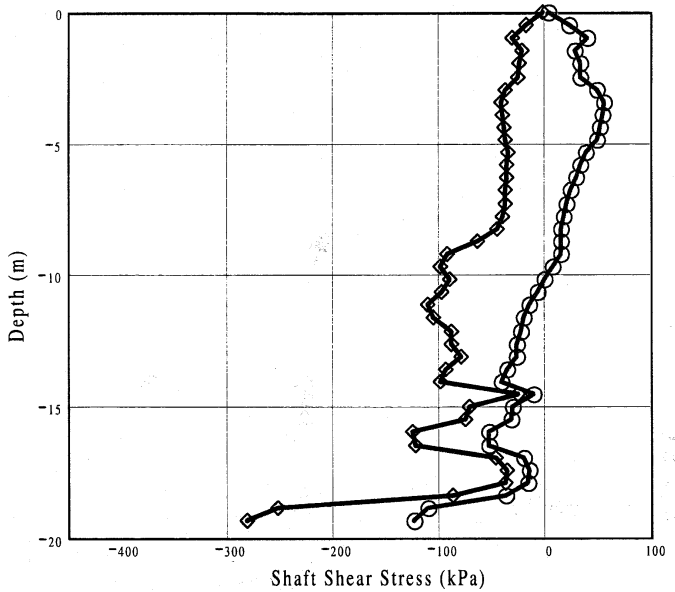
Regards,

Yours sincerely,
for and on behalf of
WS Atkins Science and Technology

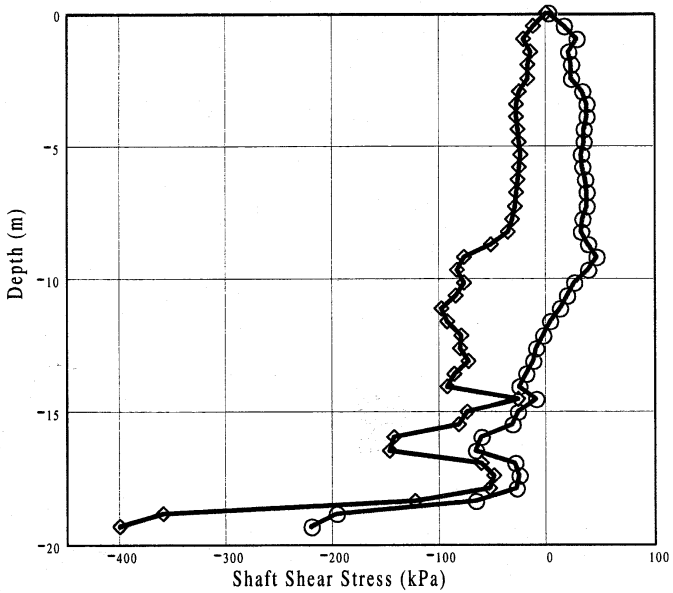
Mark Manzocchi

(up-graded ABC values)

Dunkirk Pile Test R3
Shaft Shear Stress Distributions



Beginning of Stage 2



End of Stage 2

WS Atkins

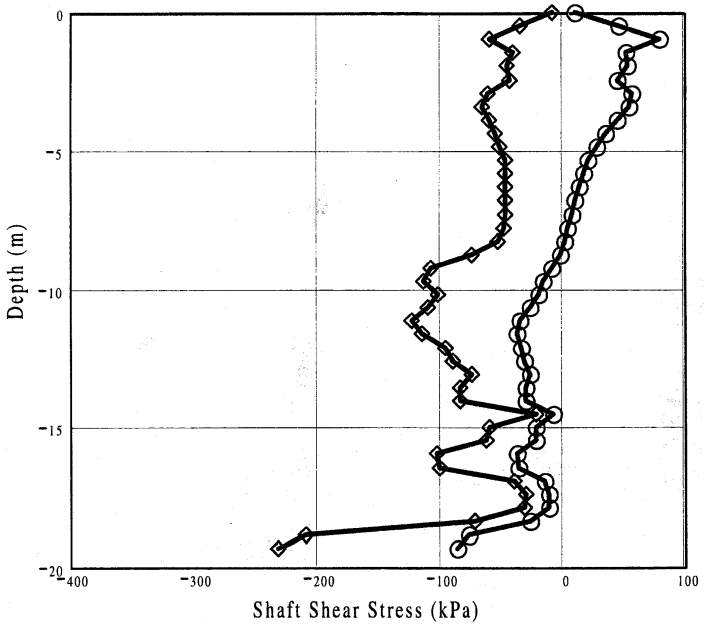
Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R4

AM 3499
22/02/99
M.Manzocchi

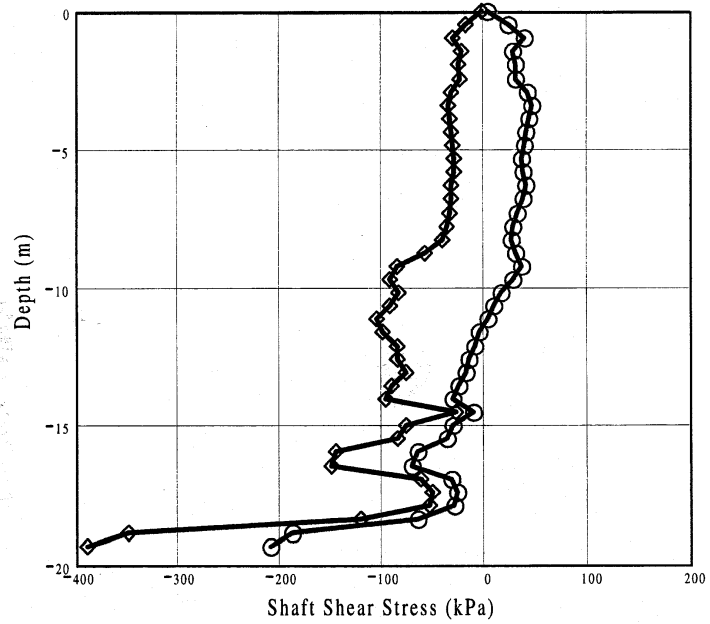
Dunkirk Pile Test R4

Degradation Parameters: A = -0.125
(Up graded values)
B = -0.06
C = 0.355

Shaft Shear Stress Distributions
Sheet 1 of 1.



Beginning of Cyclic History



End of Cyclic History (Just Prior to Failure)

WS Atkins

Cyclic Degradation in Piles
Analytical Model Verification: Dunkirk Tests
Pile R4

AM 3499
22/02/99
M.Manzocchi

Dunkirk Pile Test R4

Degradation Parameters: A = -0.125
(Up graded values)
B = -0.06
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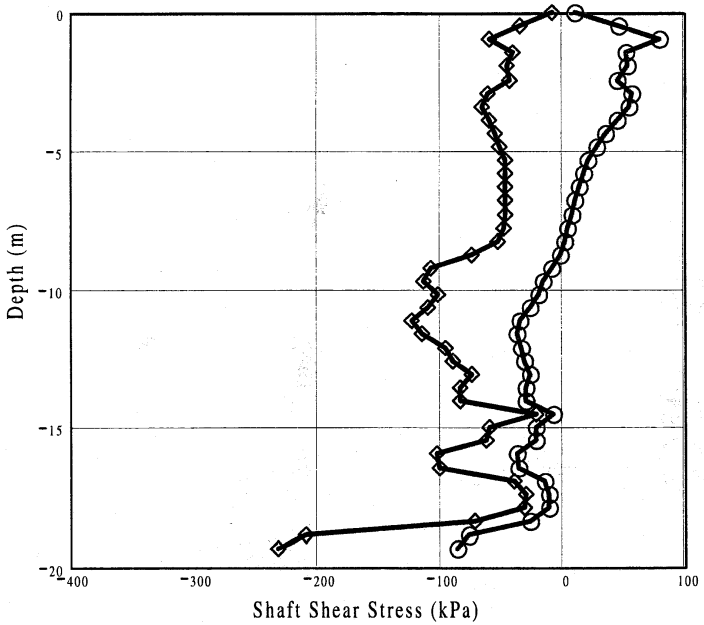
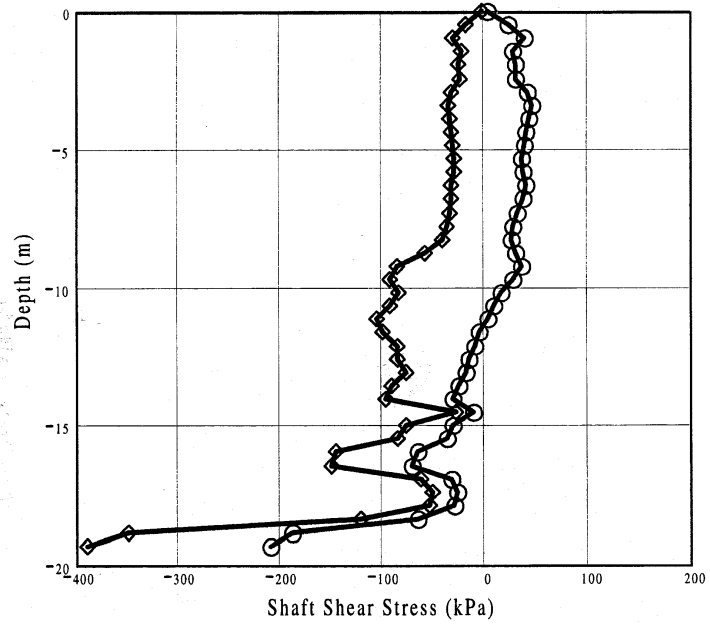
Shaft Shear Stress Distributions
Sheet 1 of 1.



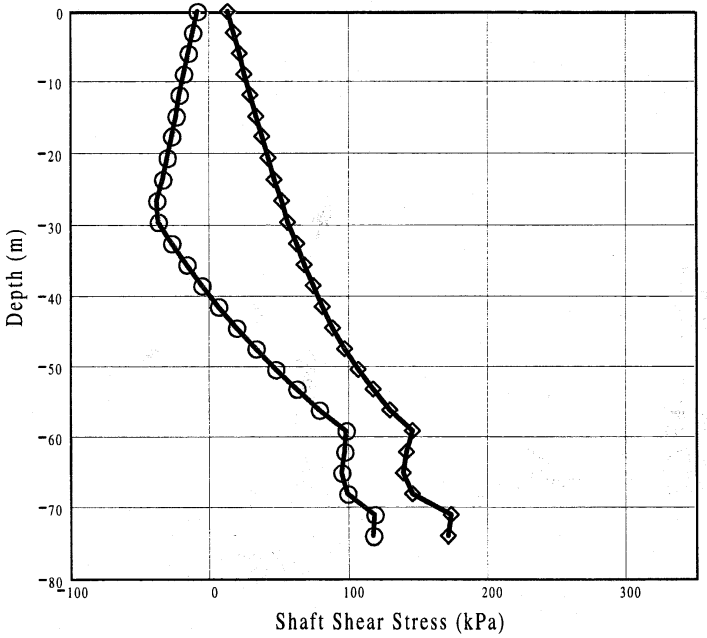
Beginning of Cyclic History



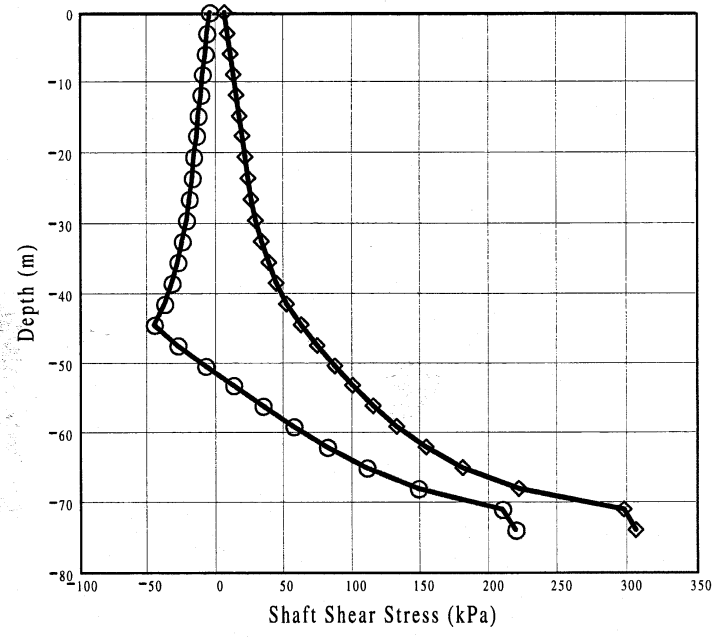
End of Cyclic History (Just Prior to Failure)

Synthetic Pile
Fav = 25 MN
Fcy = 15 MN
Shaft Shear Stress Distributions

Degradation Parameters: A = -0.083
(as per Appendix A) B = -0.06
C = 0.355



Before Cycling

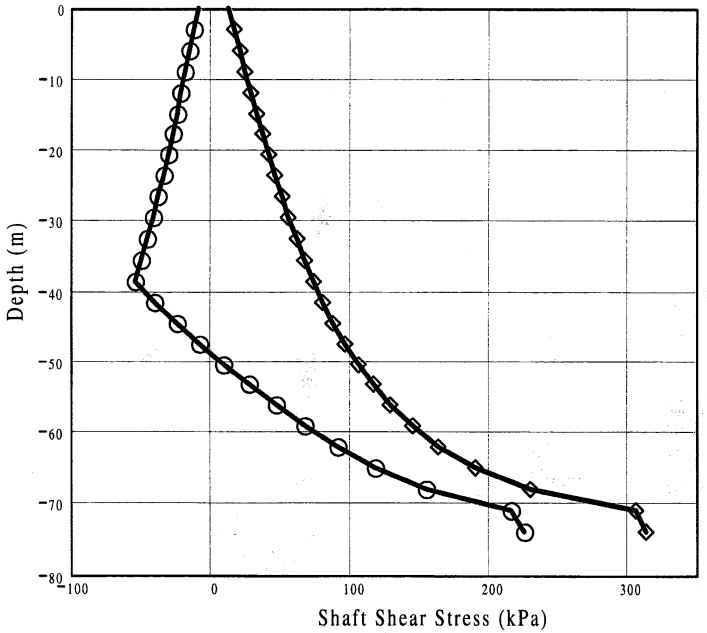


After 100 Cycles

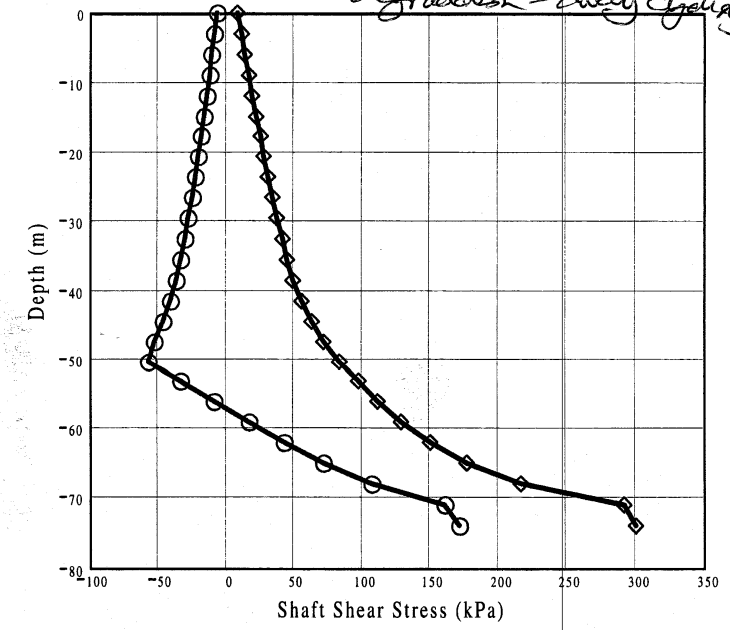
Synthetic Pile
Fav = 30 MN
Fcy = 20 MN
Shaft Shear Stress Distributions

Degradation Parameters: A = -0.083
(as per Appendix A) B = -0.06
C = 0.355

spreading wave of vertical degradation - 2 way cycling.



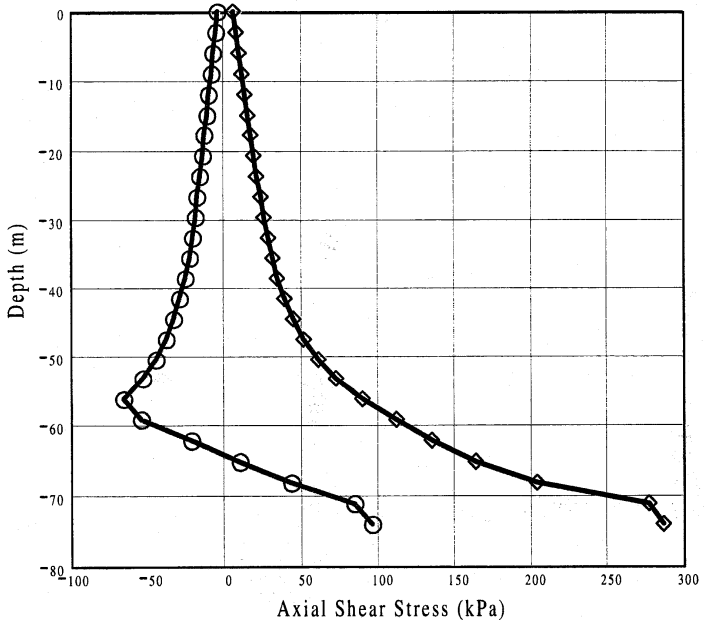
Before Cycling



After 100 Cycles

Synthetic Pile
Fav = 30 MN
Fcy = 20 MN
Shaft Shear Stress Distributions

Degradation Parameters: A = -0.083
(As Per Appendix A) B = -0.06
C = 0.355



After 400 Cycles (At failure)