SRI LANKAN GEOTECHNICAL SOCIETY

ANNUAL CONFERENCE

SRI LANKAN GEOTECHNICAL SOCIETY

SLGS

1986

"GEOTECHNICS FOR INFRASTRUCTURE DEVELOPMENT"

30th September 2013

At the ICTAD Auditorium

SLGS ANNUAL CONFERENCE 2013

"GEOTECHNICS FOR INFRASTRUCTURE DEVELOPMENT"

PROGRAMME

1:00 - 1:30	Registration
1:30 - 2:15	Presentation 1: **"Micropile Foundation Systems for Railway Bridge Structures"** ***Eng. K. L. S. Sahabandu & Dr. J. S. M. Fowze*** *General Manager & Specialist Engineer (Geotech.)* *Central Engineering Consultancy Bureau(CECB)*
2:15 - 3:00	Presentation 2: **"Tunnelling for Railway Infrastructure Development"** ***Eng. C. J. Medagoda & Dr. J. S. M. Fowze*** *Design Engineer & Specialist Engineer (Geotech.)* *Central Engineering Consultancy Bureau(CECB)*
3:00 - 3:45	Presentation 3: **"Application of Geosynthetics in Railway Projects"** ***Eng. Mike Dobie & Eng. Richard Ong*** *Regional Manager(Asia-Pacific) & Area Manager-Asia* *Tensar International Ltd*
3:45 - 4:10	Discussion and Concluding Remarks
4:10 - 4:30	Tea Break
4:30 - 6:00	**17th Annual General Meeting of the SLGS**

SRI LANKAN GEOTECHNICAL SOCIETY

Executive Committee for 2012/2013

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Past Presidents	:	Prof. B L Tennekoon
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Eng. S H U de Silva

SECRETARIAT : National Building Research Organisation

99/1, Jawatte Road
Colombo 05

Message from the President - SLGS

On behalf of Sri Lankan Geotechnical Society I cordially welcome all the participants to the Annual Conference - 2013. This year Sri Lankan Geotechnical Society has completed 27 years of service to the nation. Over the last twenty seven years the Sri Lankan Geotechnical Society (SLGS) has provided a forum for disseminating new knowledge in the field of geotechnical engineering and promoting research. Numerous Conferences and Workshops were organized and Newsletters and Journals were published in this context. Two events; "Project Day" and "Young Geotechnical Engineers Conference" were organized annually to promote research culture among undergraduates and young engineers.

As one of its member societies, SLGS has published in all the International and regional conferences organized by the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE).

SLGS is planning to organize an International conference on 10th and 11th August 2015. It is already registered with the ISSMGE and we expect active participation of our membership in this event. We look forward to publish a large number of research papers from Sri Lankan institutions that are involved in the field of Geotechnical Engineering. There is sufficient time now to plan a good research paper. SLGS welcome your innovative ideas to make this conference a success. Details of the conference are published in the August Newsletter.

Sri Lankan engineers encounter many challenges in the field of Geotechnical Engineering. In numerous instances these challenges were successfully overcome by careful planning with a clear understanding of the fundamentals and execution with great dedication and commitment. However, there is a shortage of competent professionals in the field of geotechnical engineering and many malpractices are taking place. It is our duty to educate the public on such events so that they can be vigilant and culprits are exposed.

This annual conference includes three papers under the theme "Geotechnics for Infrastructure Development "by Eng. K L S Sahabandu, Eng. Dr. J S M Fowze, and Eng. C J Medagoda from Central Engineering Consultancy Bureau and Eng. Mike Dobie and Eng Richard Ong from Tensar International Ltd. I sincerely believe that this will be a great opportunity for you to interact with them and enhance your knowledge.

Prof. Athula Kulathilaka
President - SLGS

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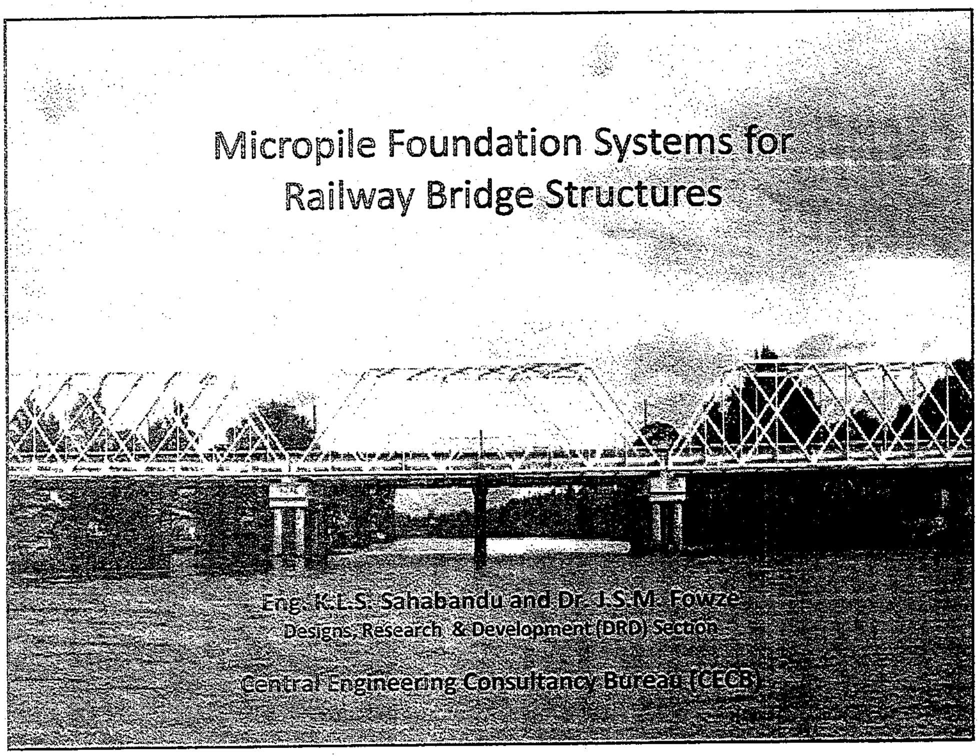

Micropile Foundation Systems for
Railway Bridge Structures
Eng. K.L.S. Sahabandu and Dr. J.S.M. Fowze
Designs, Research & Development (DRD) Section
Central Engineering Consultancy Bureau (CECB)

Contents

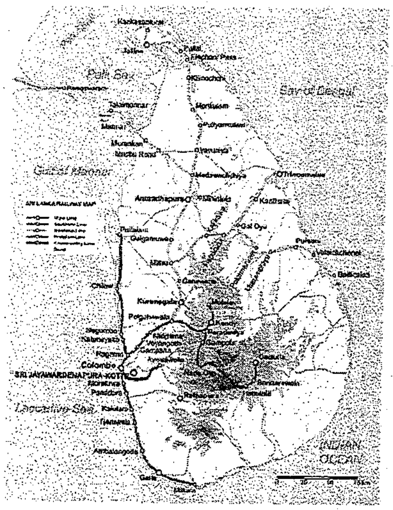
Introduction

Sri Lanka's transportation network comprises road and rail, sea and air modes....

Rail: Sri Lanka's rail network of 1,438 km in 1948. With recent years this length has been reduced due to various reasons.

Railway Structures: Exceeded the life span

At present the national railway carries only 5% of passengers and 1% of freight transport which is highly inadequate.



- There is a Need for Railway Infrastructure Development

Railway Bridges Project...

Name of the Project		Construction & Replacement of Railway Bridges (SRS/F6018.1)
Employer/Purchaser		Sri Lanka Railways (SLR)
Engineer/Consultant		Central Engineering & Consultancy Bureau (CECB)
Contract Amount		Euro – 15,232,749.00
Main Contractor / Supplier		Waagner Biro Brueckenbau AG 2/F, Prince Alfred Tower No. 10, Alfred House Gardens, Colombo 03 Sri Lanka
Sub Contractors	Pile Foundations	PORR Grundbau GmbH-Austria
Sub Contractors	Civil/Erection Works	CML Edwards Construction

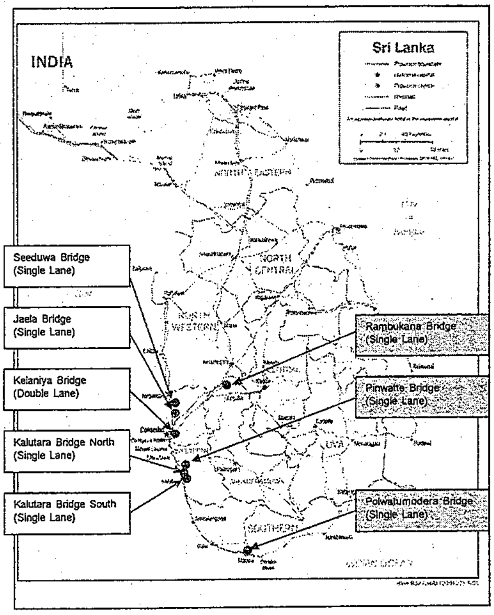
Introduction

Railway Bridge Project

New Construction

&

Replacement of Super-structure



Railway Bridges Project

8 Railway Bridges

Kelaniya Bridge	(N)	:	Double Lane (7spans-2x25m+3x52m+2x25m)
Ja –Ela Bridge	(N)	:	Single Lane (1 span- 40m)
Seeduwa Bridge	(N)	:	Single Lane(2 spans – 2x40m)
Pinwatta Bridge	(R)	:	Single Lane(1 span – 33m)
Kalutara Bridge South	(N)	:	Single Lane(4 spans – 4x50m)
Kalutara Bridge North	(N)	:	Single Lane(4 spans – 4x50m)
Rabukkana Bridge	(R)	:	Single Lane(1 span – 40m)
Polwatumodera Bridge	(R)	:	Single Lane(3 span – 33m)

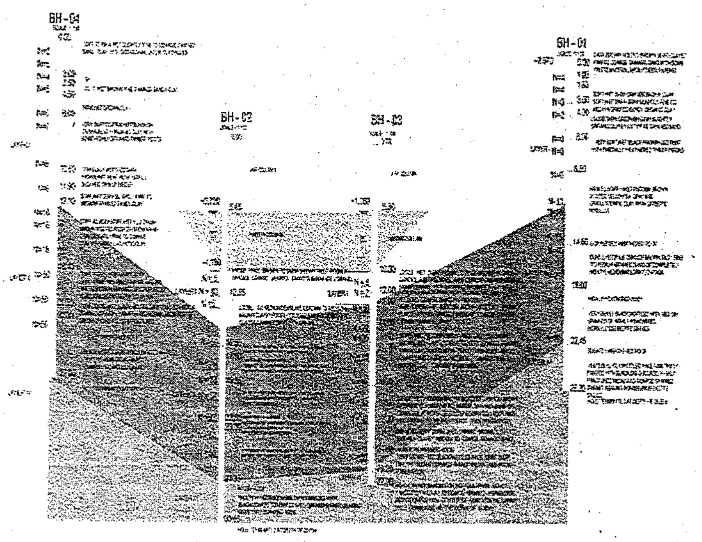
Railway Bridges Project

Subsurface Conditions at Bridge Sites

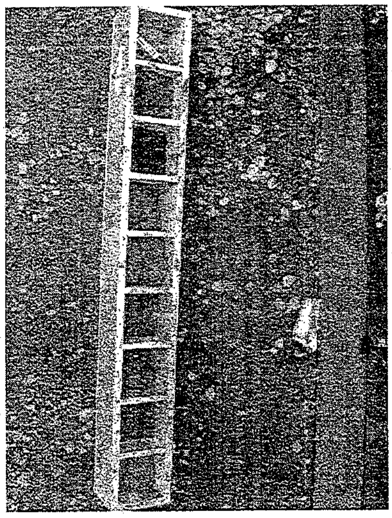
Layer	SPT	Description
I	N≤ 10	WEAK SOILS Peat, soft organic clay or loose or very loose sand.
II/III	N>10	COMPLETELY TO MODERATELY WEATHERED ROCK
IV	CR & RQD	SLIGHTLY WEATHERED / FRESH ROCK

Subsurface Conditions at Bridge Sites

At Kelaniya River (Typical)



Subsurface Conditions at Bridge Sites

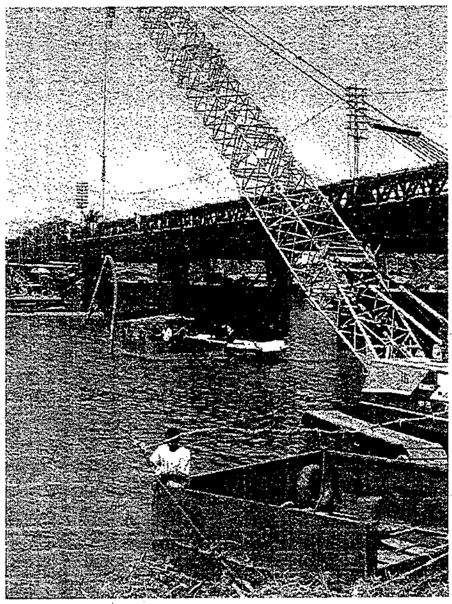


Conditions at **Kelaniya, Kalutara, Ja-Ela and Seeduwa** were demanded Deep Foundation systems!

Deep Bridge Foundations

Considerations:

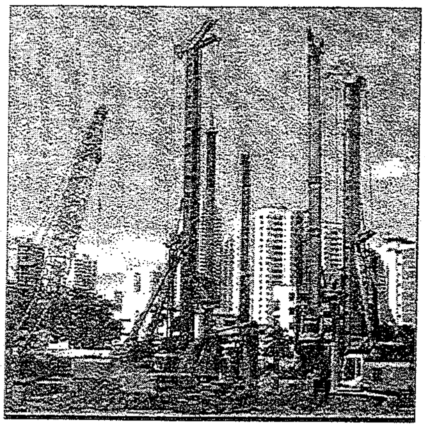
- Working Environment
- To be constructed close to existing bridge structures



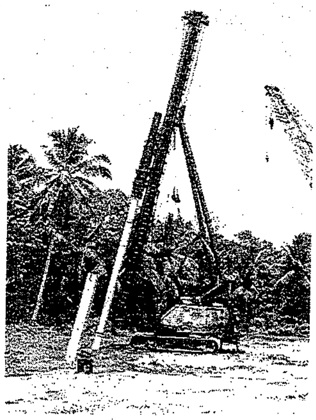
Deep Bridge Foundations

Options and Trade-off:

Bored and Cast Insitu???



Driven???



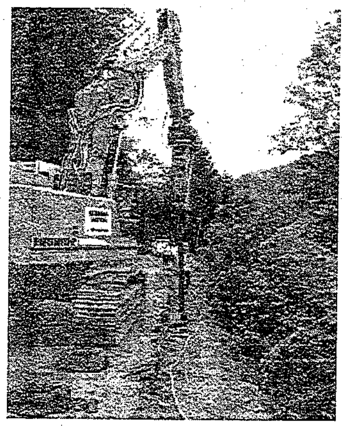
Heavy, Noise and Vibration!!!

Light, Low Noise & Vibration: OPTED

Deep Bridge Foundations

Options and Trade-off:

Ductile Iron Pipe Piles???

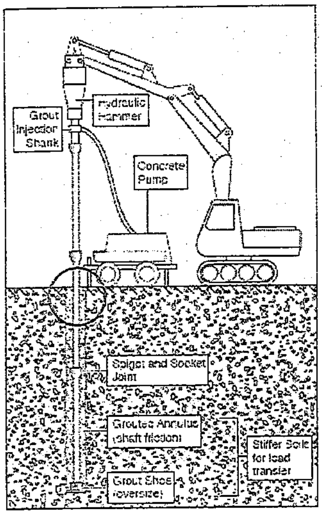


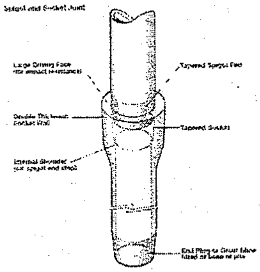
Raked piles

Deep Bridge Foundations

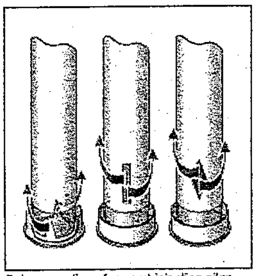
Options and Trade-off:

Ductile Iron Pipe Piles???





Tension???
Drivability???
Borehole stability???
Raking ???
Buckling???

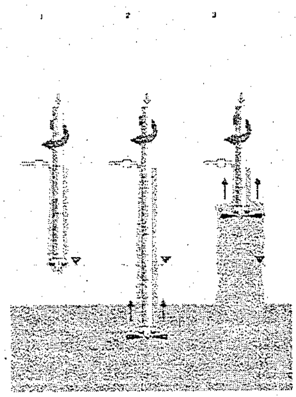


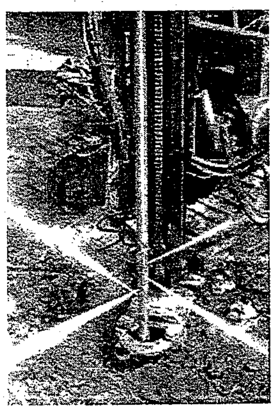
Cutaway options for grout injection piles

Deep Bridge Foundations

Options and Trade-off:

Deep Cement Mixing Piles (DCM Piles) with Jet Grouting???





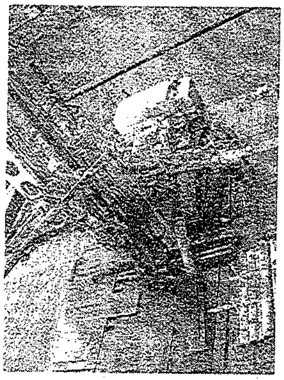
Uncertainty in peaty soils

Deep Bridge Foundations

Options and Trade-off:

Micropiles???

- Small-diameter (typically less than 300 mm (12 in.)), drilled and grouted non-displacement pile that is typically reinforced.

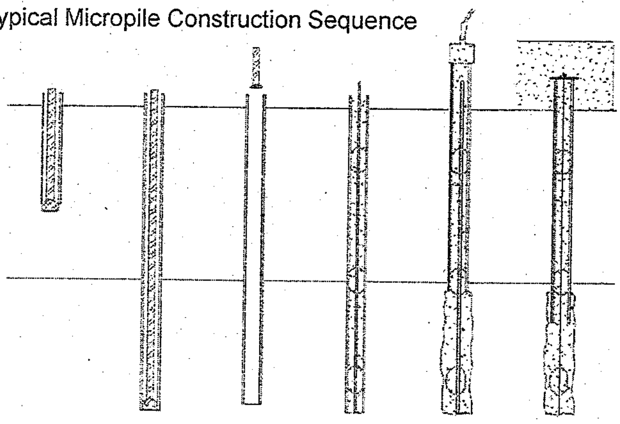


Deep Bridge Foundations

Options and Trade-off:

Micropiles???

Typical Micropile Construction Sequence



Deep Bridge Foundations

Options and Trade-off:

Micropiles???

- Appropriate for any type of ground condition (e.g.karstic areas, uncontrolled fills, boulders, rock etc.)
- Can penetrate most obstacles
- Low noise and vibration
- Drilling machines required for installation are generally lighter in weight
- Can be installed in low headroom situations and in remote areas
- Can be used in places where pile driving would result in soil liquefaction
- Can be used in places where required support system needs to be in close pile proximity to existing structures

Deep Bridge Foundation Systems

Ultimately, the Micropile Foundation System was selected as appropriate foundation solution

Load Carrying Capacity of Micropiles

Subsurface condition in general and Concrens

Layer	SPT	Description	Notes
I	N≤ 10	Not load bearing ▫ Dependent on the location it consists of peat, soft organic clay or loose or very loose sand / silt.	Pile Vulnerable to Buckling if N<3
II, III	N>10	Load bearing • Completely to Moderately Weathered Rock •Allowable shaft friction on the surface of the grout column is assumed to be τ = 90 kPa	
IV	CR & RQD	Slightly Weathered / Fresh Rock τ=300 kPa and Allowable Base Resistance 3 MPa for a minimum length of 1m within layer IV.	

Load Carrying Capacity of Micropiles

Micropile Foundation Systems with

Steel Tubes

Abutments and Piers

SINGLE TUBE

External diameter : 114.3 mm(4.5") or 127 mm(5")
Tube thickness : 10 mm / 12.5 mm
Steel quality : N80 (yield strength: f_{yk}=560 N/mm^2)

Abutments and Land Piers with Weak subsoil conditions

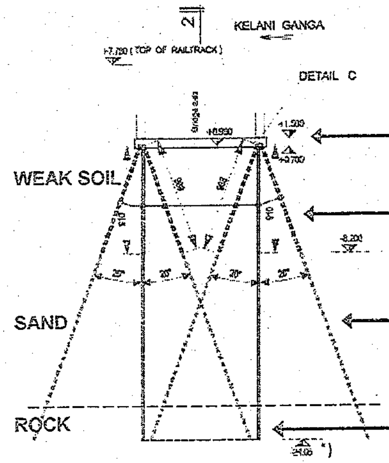
DOUBLE TUBE TO AVOID BUCKLING

External diameter of outer tube : 219.1 mm (only in top weak soil layers)
Tube thickness : 10 mm
Steel quality : S 355(St 52) – (yield strength: f_{yk}=355 N/mm^2)

External diameter of inner tube : 114.3 mm(4.5")
Tube thickness : 10 mm
Steel quality : N80 (yield strength: f_{yk}= 560 N/mm^2)

Load Carrying Capacity of Micropiles

General Arrangement of Micropile Foundation Systems



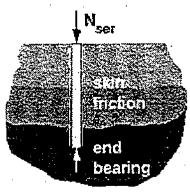
Abutment Structure

Outer tube **219/10 mm** in weak soil layers
Steel Quality = S275 / S 355

Bearing Pile **114/10 mm** or **127/12,5 mm**
Steel Quality = N80 / S 355

Embedded in the rock
1,0 – 5,0 m

Load Carrying Capacity of Micropiles



Allowable Geotechnical Capacity

Compression		Tension
1.Shaft friction Layer II,III Layer IV	$A_s \times f_{s,all}$	50% of Shaft friction for pile under compression Layer II, III Layer IV
2. End bearing	$A_{end} \times p_{end,all}$	

Design Basis

Layer II & III - Diameter of grout column = Approx. 1.4 x Diameter of Borehole for Clay; for Sands Even More

Layer IV- Diameter of grout column =1.0 x Diameter of Borehole

Load Carrying Capacity of Micropiles

Allowable Structural Capacity

Without regard to Buckling

Pile type: Tube dia.114.3mm
Thickness 10mm
Steel quality N80

Considering Buckling

1.Pile type: Tube dia.114.3mm / 127 mm
Thickness 10mm
Steel qualityN80

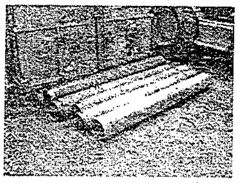
2.Composite pile types
Type 1
Type 2
Type 3
Type 4

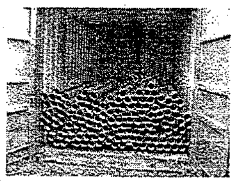
Design codes: DIN 18 800 part 1- Structural steel work
DIN 18 800 part 2- Analysis of safety against buckling of linear members and frames

Load Carrying Capacity of Micropiles

PILE TYPES

Composite Type	Outer tube	Inner tube	Inner tube Material
1	219.1mm x 10mm	114.3mm x 10mm	N80
2	219.1mm x 10mm	114.3mm x 10mm	S 355(St 52)
3	219.1mm x 10mm	127.0mm x 12mm	N80
4	219.1mm x 10mm	127.0mm x 12mm	S 355(St 52)





Load Carrying Capacity of Micropiles

Allowable structural capacity – Without regard to buckling

1.Compression
Design parameters

Partial safety factors according to DIN 18800-1
Load(γ_F) = 1.4
Material(γ_M) = 1.1

$$P_k \leq \frac{A \times f_{yk}}{\gamma_F \times \gamma_M}$$

Where,
P_k is the characteristic value of the axial force in the pile(working load)
A- Area of the tube

2.Tension capacity= 50% of compression capacity because of threads (~50% of section Area)

Load Carrying Capacity of Micropiles

Allowable structural capacity – Where buckling may occur(SPT<3)

Design Parameters

$$\lambda_k = \frac{L}{i} \quad i = \sqrt{\frac{I}{A}} \quad \lambda_a = \pi\sqrt{\frac{E}{f_{y,k}}} \quad \overline{\lambda}_K = \frac{\lambda_K}{\lambda_a}$$

$$\overline{\lambda}_K \leq 0.2 : \chi = 1$$

$$0.2 < \overline{\lambda}_K < 3.0 : \chi = \frac{1}{k + \sqrt{k^2 - \overline{\lambda}_k^2}}$$

$$\overline{\lambda}_K > 3.0 : \chi = \frac{1}{\overline{\lambda}_k(\overline{\lambda}_K + \alpha)}$$

$$k = 0.5[1 + \alpha(\overline{\lambda}_k - 0.2) + \overline{\lambda}_k^2]$$

External diameter –d1
Internal diameter – d2
Area – A
Moment of inertia – I
Radius of gyration – i
Material strength-f_{yk}
Partial safety factor for material -γ_M
Effective Length - L
Slenderness ratio-λ_k
Reference slenderness ratio-λ_α
Reduction factor according to the standard buckling curves- χ

Load Carrying Capacity of Micropiles

Allowable structural capacity – Where buckling may occur(SPT<3)

Page 8 DIN 18800 Part 2

Bow imperfections need not be assumed if members satisfy the criteria specified in item 739 of DIN 18 800 Part 1.

Table 3. Bow imperfections

	Type of member	Bow imperfection, w_0, v_0
	Solid member, of cross section with following buckling curve	
1	a	l/300
2	b	l/250
3	c	l/200
4	d	l/150
5	Built-up members, with analysis as in subclause 4.3	l/500

Page 10 DIN 18 800 Part 2

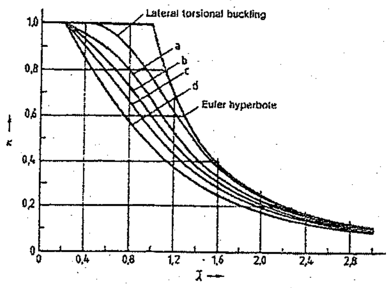


Figure 10. Reduction factors κ for lateral buckling (buckling curves a, b, c and d) and κ_M for lateral torsional buckling, obtained by equation (18) with n equal to 2.5

l: Thickness of the weak layer in m

Buckling curve	a	b	c	d
α	0.21	0.34	0.49	0.76

Load Carrying Capacity of Micropiles

Allowable structural capacity – Where buckling may occur(SPT<3)

N_{pl} Axial force in perfectly plastic state

$$\frac{N_d}{\chi \times N_{pl,d}} \leq 1$$

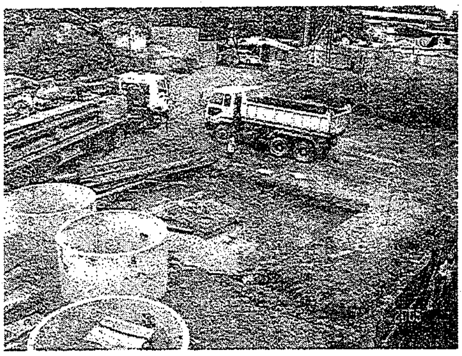
$$\max N_d = \chi \times N_{pl,d}$$

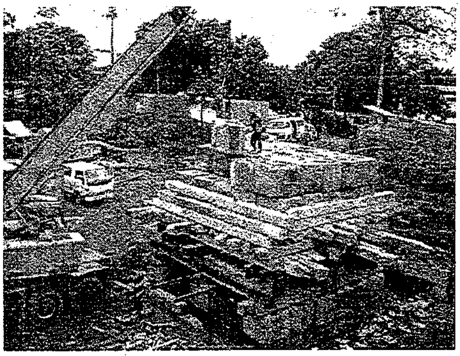
$$perm\ N = \max N_d / \gamma_F$$

Load Carrying Capacity of Micropiles

Verification of Load Bearing Capacity

Static Pile Load Testing at Land Pier 5 of Kelaniya Bridge

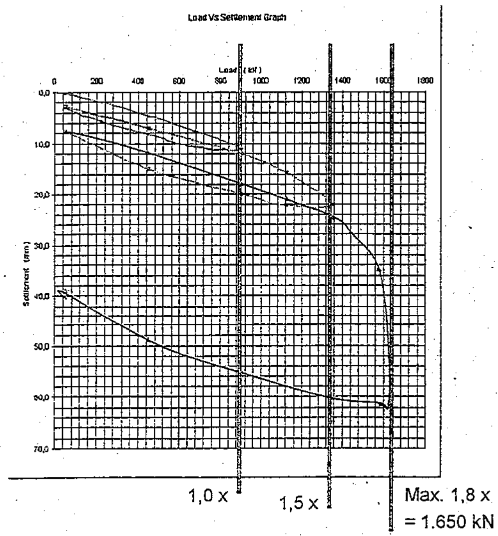


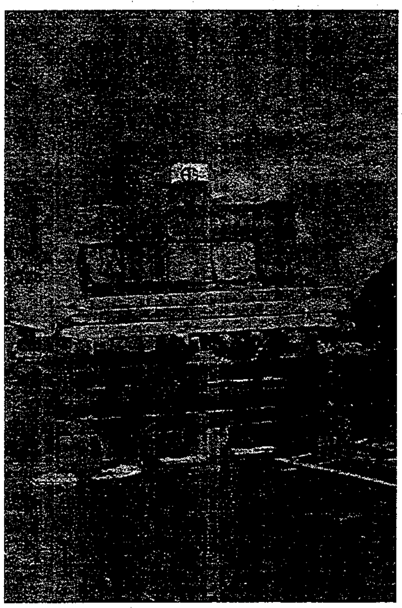


Working Load 921 kN = 92 t

Load Carrying Capacity of Micropiles

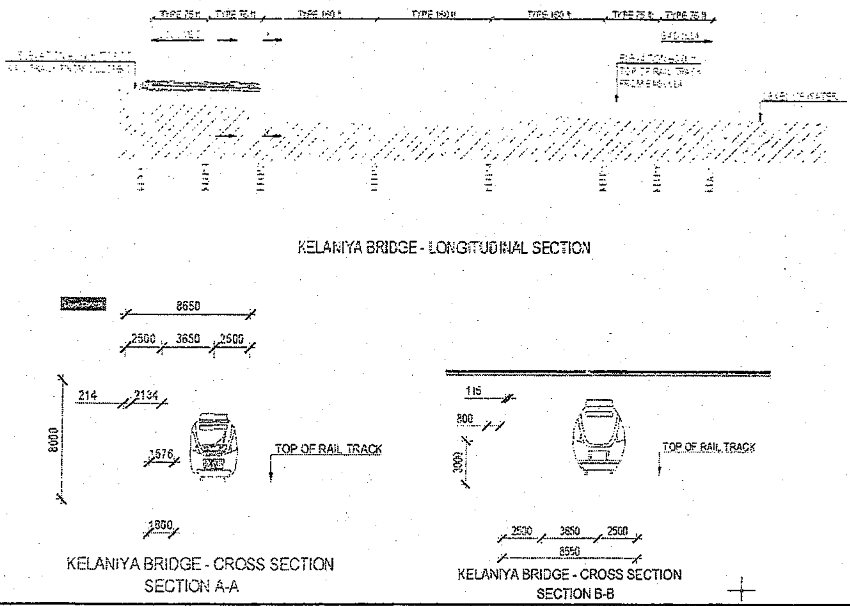
Results of Pile Load Test





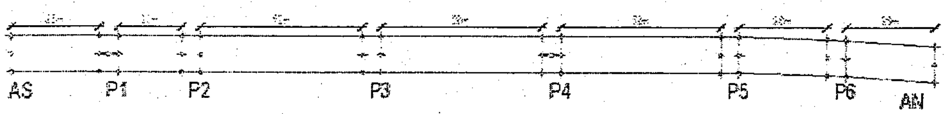
Design of Micropile Foundation System

Kelaniya Railway Bridge



Design of Micropile Foundation System

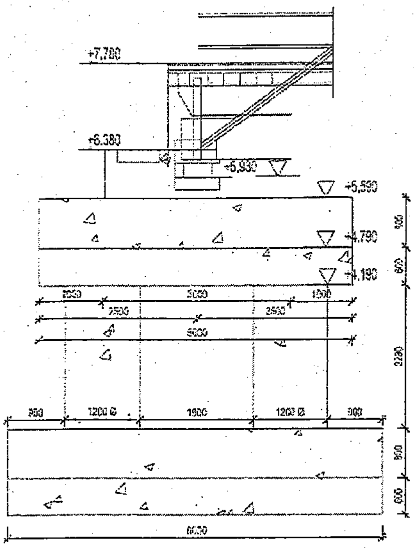
Kelaniya Railway Bridge

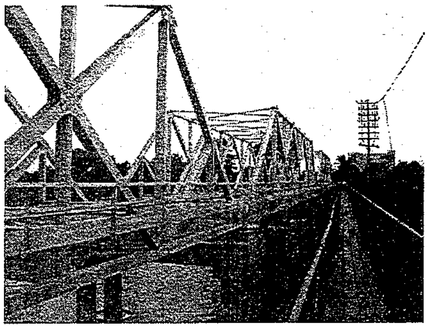


- Crosses the Kelaniya River
- Overall length - 268 m
- Comprising three internal spans of 52 m, two internal spans of 28m and end spans of 28 m
- AN and AS are abutments
- P1, P2,P5 and P6 are land piers
- P3 and P4 are river piers

Design of Micropile Foundation System

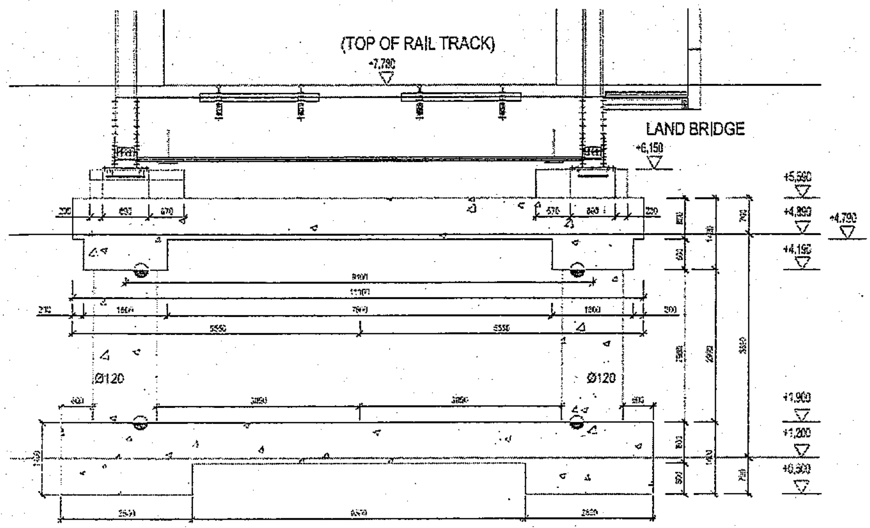
Longitudinal Elevations of Kelaniya Land Pier 5
(Pier 1,2 and 6 similar to Pier 5)





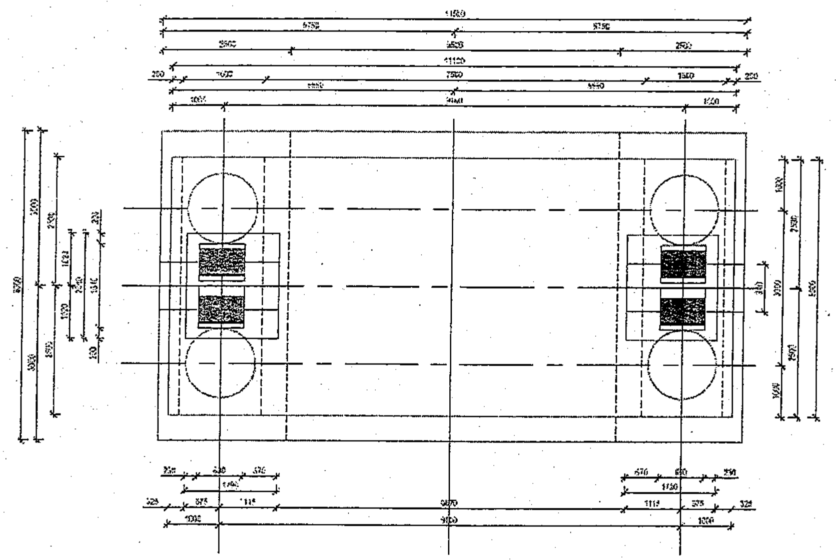
Design of Micropile Foundation System

Transverse Elevations of Pier 5 (Pier 1,2 and 6 similar to Pier 5)



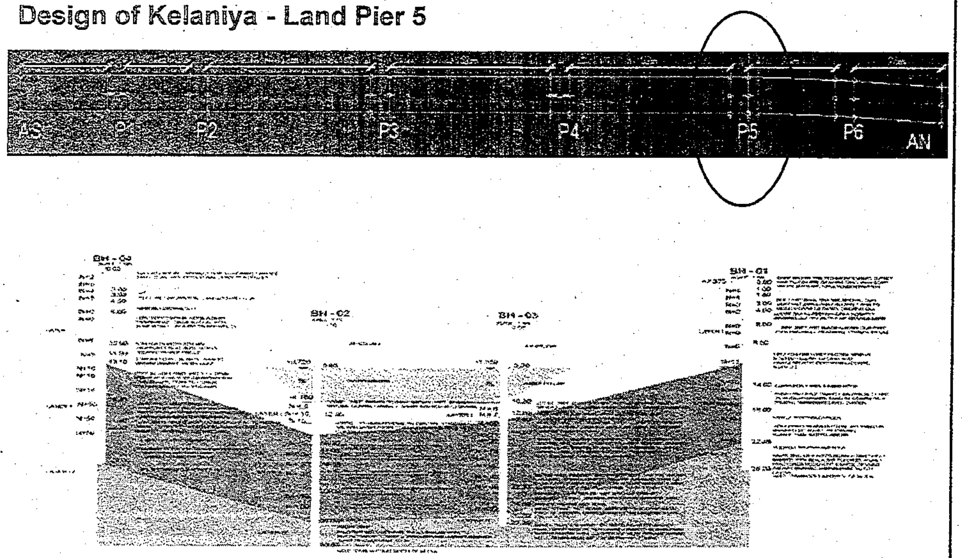
Design of Micropile Foundation System

Plan view of Pier 5 at Bearing Pad Level



Design of Micropile Foundation System

Design of Kelaniya - Land Pier 5



Design of Micropile Foundation System

Subsurface condition at Kelaniya – Land Pier 5

Pile data

N<3 ;Considering buckling effect of pile due to soft soil

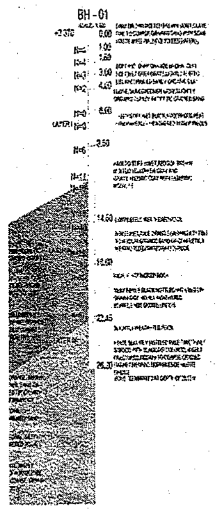
Type: Composite Type 3
Composite Type 4

Length: 18.5m

Allowable Load Carrying Capacity:1000kN

Ultimate Geotechnical capacity =
2 x Allowable Axial load = 2x1000 =2000 kN

Ultimate Structural Capacity
Composite Type 3- 1700 kN
Composite Type 4- 1300 kN



Design of Micropile Foundation System

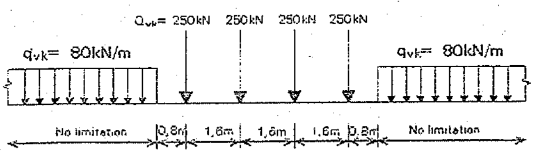
Load Evaluation on Pile cap

As per the specifications of BS5400: Part 2: 1978.

Load Categories:

1. Dead + Superimposed Dead loads
2. Dead + Superimposed Dead + Live loads
3. Dead + Superimposed Dead + Live loads + Tractive forces

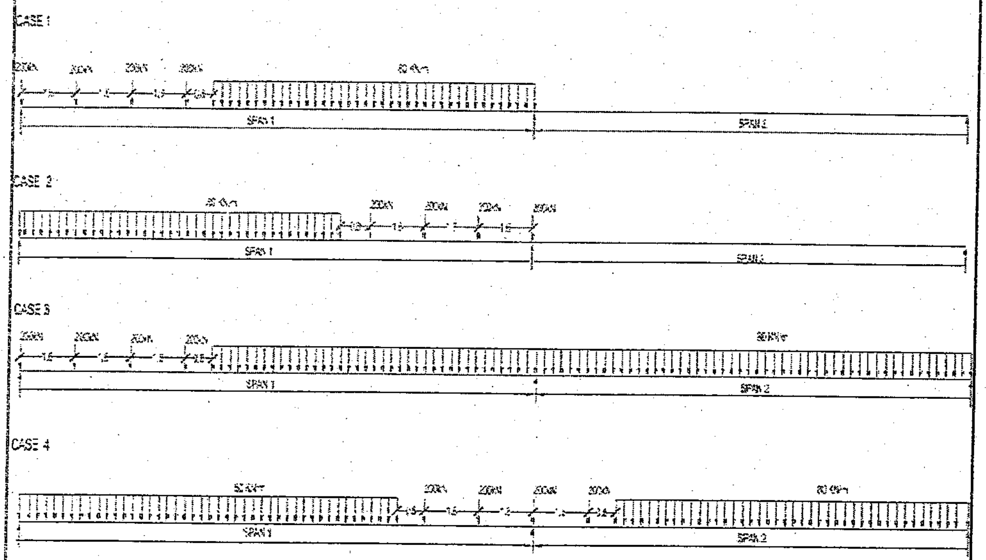
Traffic loading-RU loading



In Sri Lanka Q_{vk} is consider as 200kN

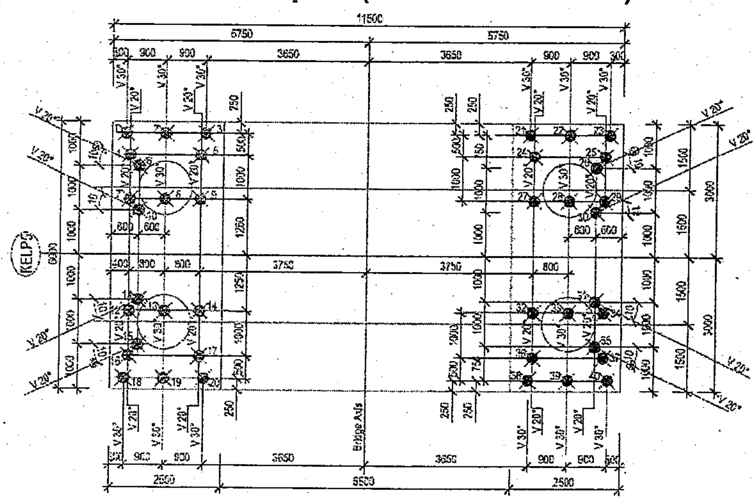
Design of Micropile Foundation System

Traffic load-Load Cases



Design of Micropile Foundation System

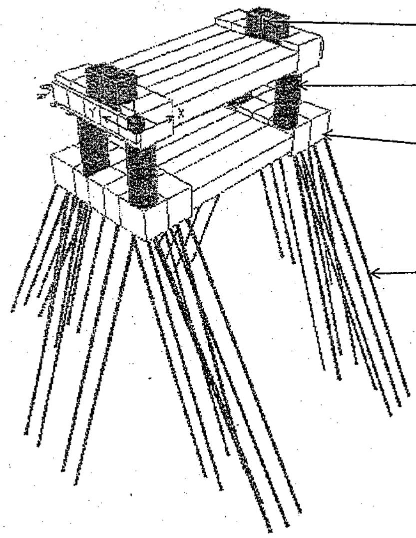
Load distribution on individual pile? (Kelani – Land Pier 5)



Design of Micropile Foundation System

Load distribution on individual pile (Kelani – Land Pier 5)

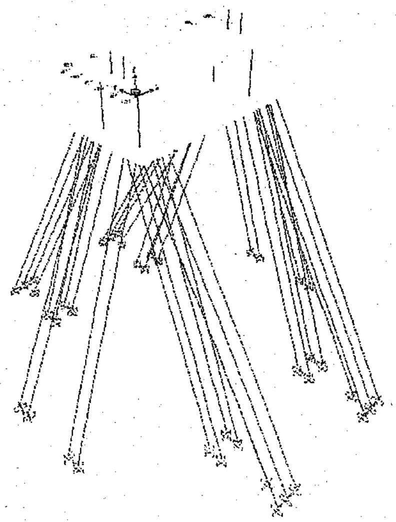
FEM-SAP 2000-3D model



Design of Micropile Foundation System

Load distribution on individual pile (Kelaniya – Land Pier 5)

FEM-SAP 2000



Element	Dimensions
Pile	127mm(dia)
Pile cap	2.5m x6mx1.4m
	7.1m x 6m x 0.8m
Pier	1.2m(dia)
Bearing	0.9m x 0.8m
Pile top cap	1.6m x5mx1.4m
	8.5m x 5m x 0.8m

Design of Micropile Foundation System

Load distribution on individual pile

FEM-SAP 2000

Soil Spring Constants

Making use of the correlation by Toshida and Yoshinaka (1972),

Modulus of elasticity of Soil, E_s = 650N kPa

According to Vesic (1961a, 1961b)
Modulus of sub grade reaction, ks

$$k_s = \frac{E_s}{b((1-\nu^2)}$$

Where, b is the width of the projected area of pile, b= 0.4 m
Poisson's ratio, v=0.3

Soil spring constant, K

By End Area Rule,

$$K = \frac{b.\Delta L(2k_{s,i} + k_{s,i-1})}{6}$$

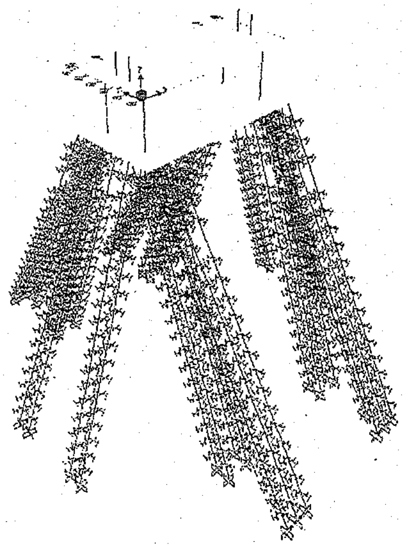
$$K' = \frac{b.\Delta L(2k_{s,i} + k_{s,i+1})}{6}$$

where, (b.ΔL) is the area of bearing of the element

Design of Micropile Foundation System

Load distribution on individual pile

FEM-SAP 2000-Spring Constants

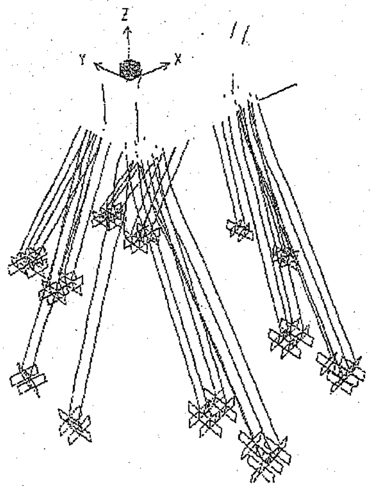


Ele. #	DL	Node	Depth m	SPT N	Es, kPa	ks, kN/m³	K	K'	K=K+K'
1	1	1	0.0	3	1950	1500		667	**667**
2	1	2	1.0	2	1300	1000	583	571	**1155**
3	1	3	2.0	2	1300	1429	643	476	**1119**
4	1	4	3.0	0	0	0	238	0	**238**
5	1	5	4.0	0	0	0	0	0	**0**
6	1	6	5.0	0	0	0	0	714	**714**
7	1	7	6.0	6	3900	4286	1429	2738	**4167**
8	1	8	7.0	11	7150	7857	3333	4524	**7857**
9	1	9	8.0	16	10400	11429	5119	5714	**10833**
10	1	10	9.0	16	10400	11429	5714	5714	**11429**
11	1	11	10.0	16	10400	11429	5714	8571	**14286**
12	1	12	11.0	40	26000	28571	11429	14286	**25714**
13	1	13	12.0	40	26000	28571	14286	12976	**27262**
14	1	14	13.0	29	18850	20714	11667	10357	**22024**
15	1	15	14.0	29	18850	20714	10357	10357	**20714**
16	1	16	15.0	29	18850	20714	10357	12857	**23214**
17	1	17	16.0	50	32500	35714	15357	17857	**33214**
18	1	18	17.0	50	32500	35714	17857	17857	**35714**
19	1	19	18.0	50	32500	35714	17857	17857	**35714**
	1	20	19.0	50	32500	35714	17857	11905	**29762**

Design of Micropile Foundation System

Load distribution on individual pile

FEM-SAP 2000-Deformed shape

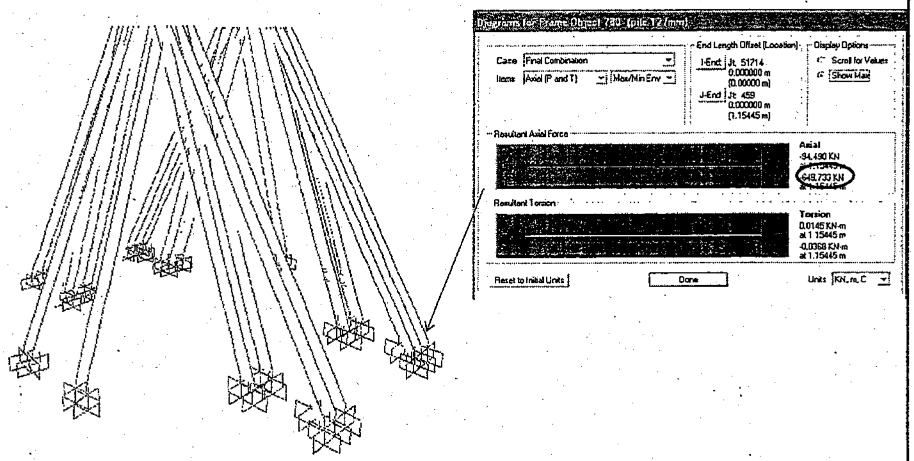


Joint Displacement			
Joint	U1	U2	U3
Text	m	m	m
157	0.020934	0.014079	-0.00966
160	0.020935	0.014521	-0.01005
162	0.020936	0.014964	-0.01044
163	0.020976	0.018844	-0.00863
165	0.020975	0.019332	-0.00776
168	0.020976	0.019822	-0.0069
170	0.020679	0.014125	-0.01231
173	0.02068	0.014913	-0.01299
176	0.020714	0.018897	-0.01115
179	0.020712	0.019766	-0.00962
183	0.020554	0.01422	-0.0129
190	0.020578	0.019654	-0.01094
194	0.020165	0.014118	-0.01322
196	0.020165	0.014515	-0.01354
197	0.020169	0.014906	-0.01386
200	0.020192	0.01889	-0.01246
201	0.020196	0.019328	-0.01182
203	0.020192	0.019759	-0.01117
207	0.020041	0.014212	-0.01343
214	0.020056	0.019646	-0.01146
217	0.020932	0.01401	-0.0087
220	0.020933	0.014462	-0.009
222	0.020934	0.014909	-0.0095
223	0.020981	0.018794	-0.0075
225	0.020981	0.019275	-0.0066
228	0.020982	0.019742	-0.0057
230	0.020677	0.014065	-0.0122
233	0.020679	0.014864	-0.0129
236	0.020719	0.018853	-0.0109
239	0.020718	0.019698	-0.0093
243	0.020552	0.014172	-0.012
250	0.020583	0.019601	-0.0109
254	0.020164	0.014075	-0.0132
256	0.020164	0.014478	-0.0135
257	0.020168	0.014874	-0.0138
260	0.020194	0.018862	-0.0124
261	0.020199	0.019289	-0.0118
263	0.020195	0.019712	-0.0111
267	0.02004	0.014182	-0.0134
274	0.020059	0.019613	-0.0114

Design of Micropile Foundation System

Load distribution on individual pile

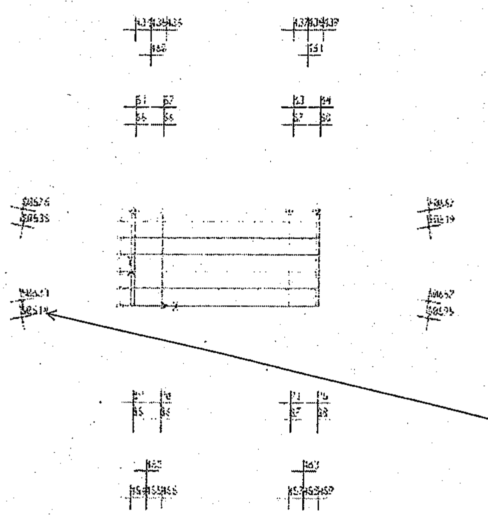
FEM-SAP 2000-Axial force of Micropiles



Design of Micropile Foundation System

Load distribution on individual pile

FEM-SAP 2000-Axial force

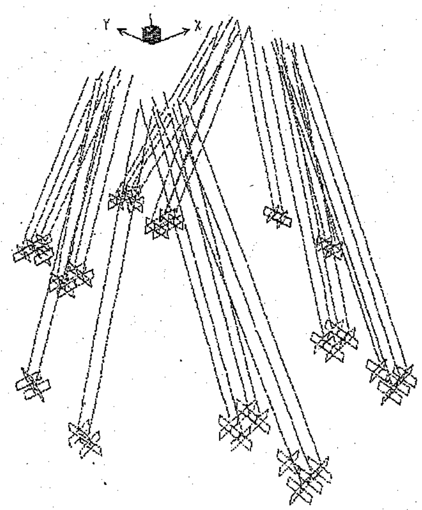


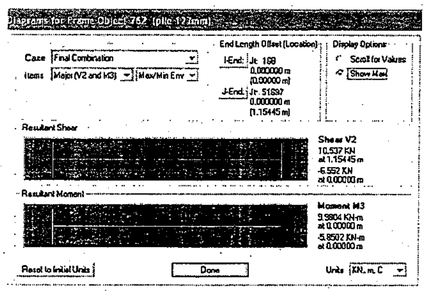
Joint	F3
Text	KN
61	646.911
62	664.681
63	657.355
64	631.805
65	621.107
66	638.457
67	629.927
68	605.024
85	691.386
86	709.234
87	701.918
88	676.207
89	621.731
90	639.118
91	630.611
95	605.622
434	533.474
435	542.747
436	551.805
437	556.904
438	546.989
439	536.465
454	560.488
455	569.814
456	578.898
457	584.016
458	574.041
459	563.422
460	512.509
461	515.444
462	488.079
463	491.029
50519	645.11
50538	673.965
50557	669.527
50576	703.113
50595	747.887
50614	781.574
50633	708.538
50652	679.634

Design of Micropile Foundation System

Load distribution on individual pile

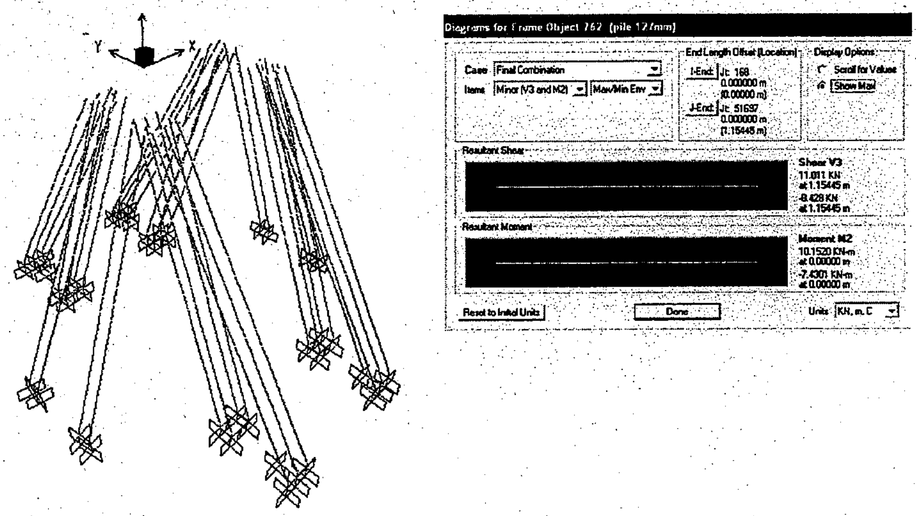
FEM-SAP 2000-Bending moment(M3)





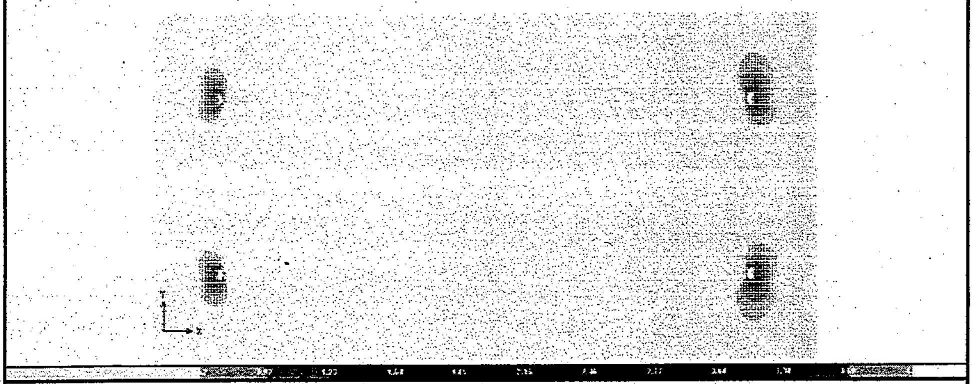
Design of Micropile Foundation System

Load distribution on individual pile
FEM-SAP 2000-Bending moment(M2)



Design of Micropile Foundation System

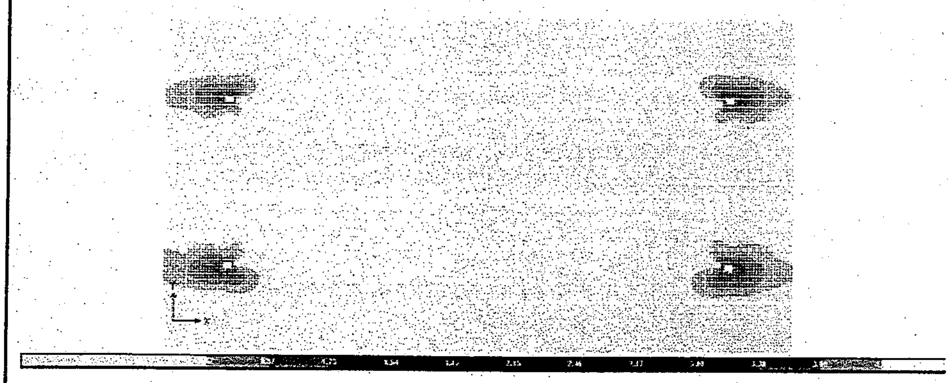
Load distribution on Pile cap
FEM-Sap 2000-Bending moment(M11)



Design of Micropile Foundation System

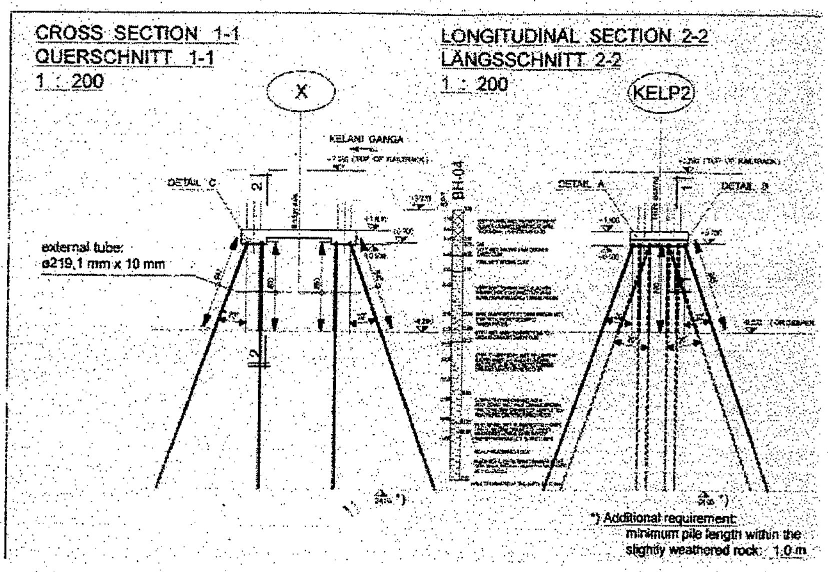
Load distribution on Pile cap

FEM-Sap 2000-Bending moment(M22)



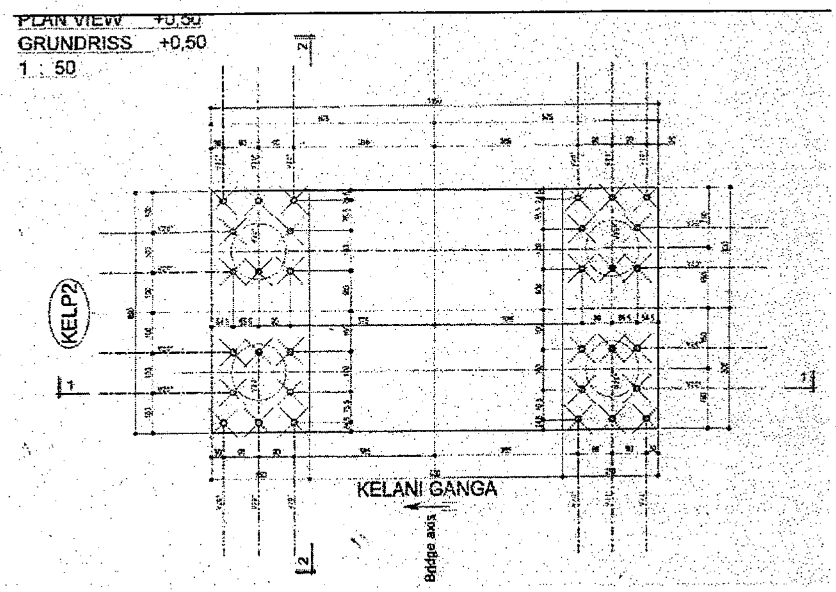
Design of Micropile Foundation System

Kelaniya Land Pier 2 GA



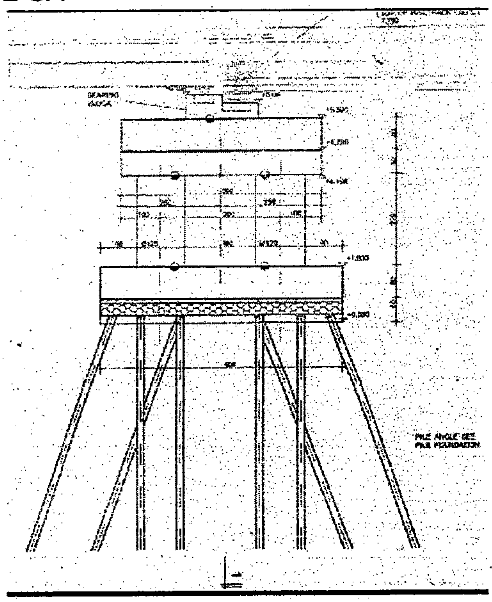
Design of Micropile Foundation System

Kelaniya Land Pier 2 GA



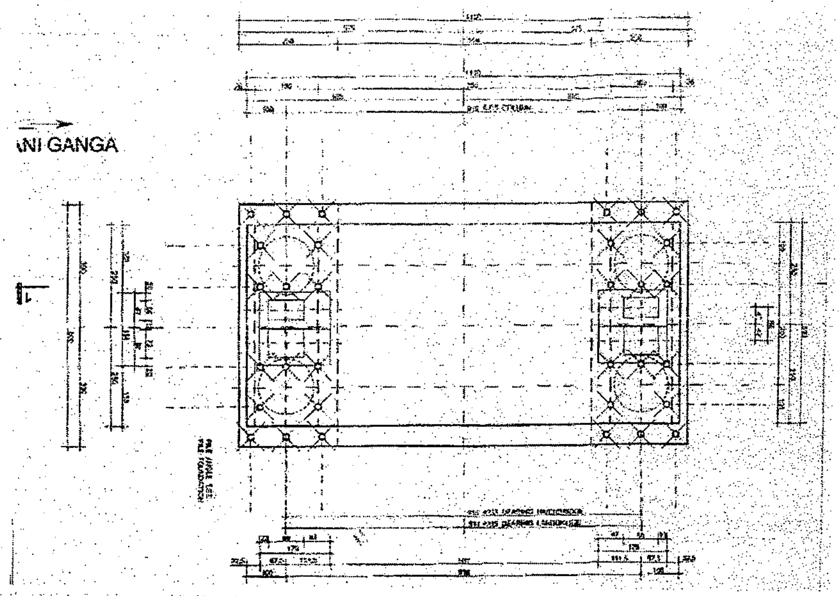
Design of Micropile Foundation System

Kelaniya Land Pier 2 GA



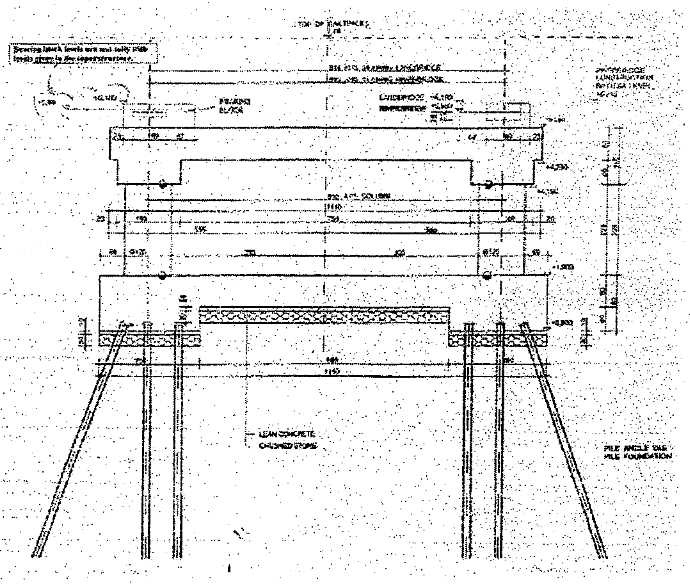
Design of Micropile Foundation System

Kelaniya Land Pier 2 GA



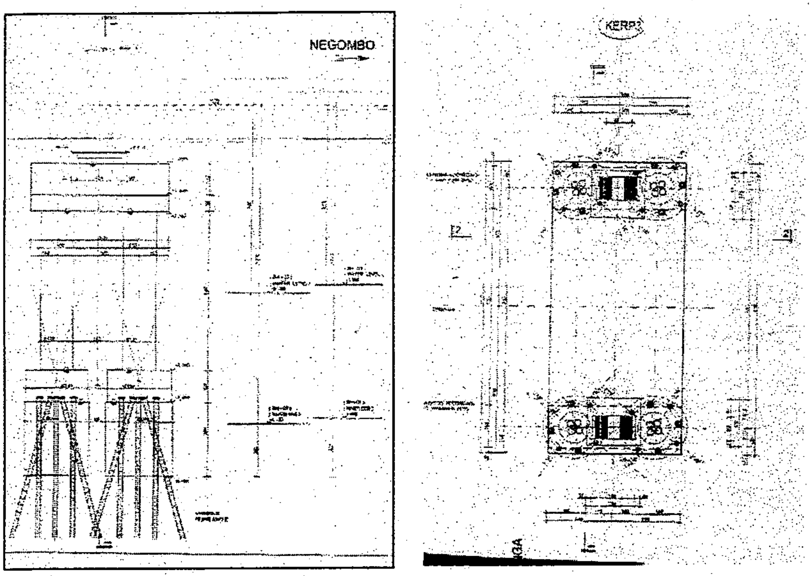
Design of Micropile Foundation System

Kelaniya Land Pier 2 GA



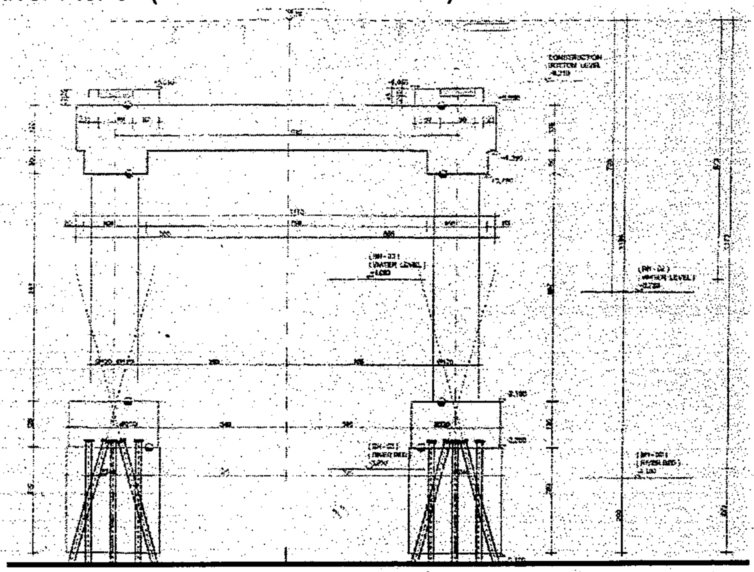
Design of Micropile Foundation System

Kelani River Pier 3 (Pier 4 is similar to Pier 3)



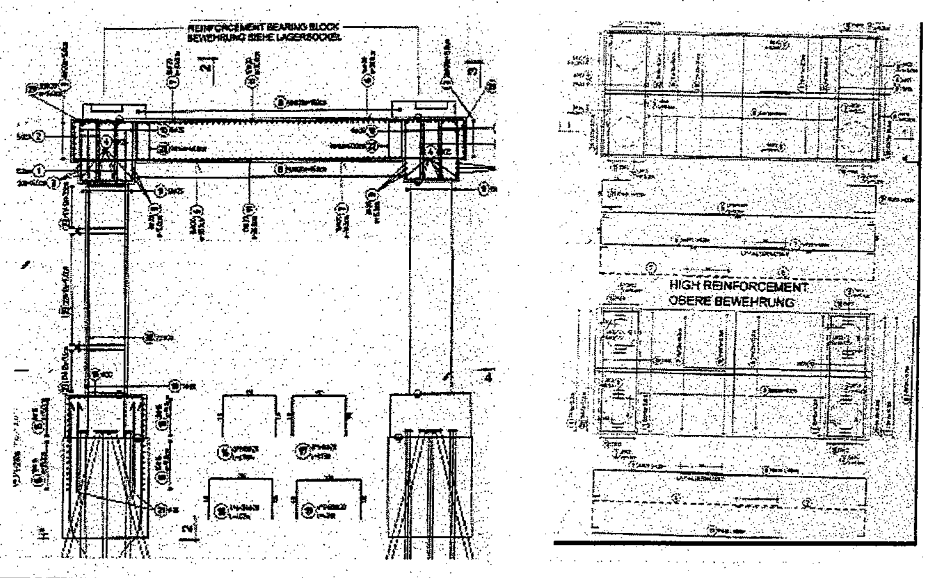
Design of Micropile Foundation System

Kelani River Pier 3 (Pier 4 is similar to Pier 3)



Design of Micropile Foundation System

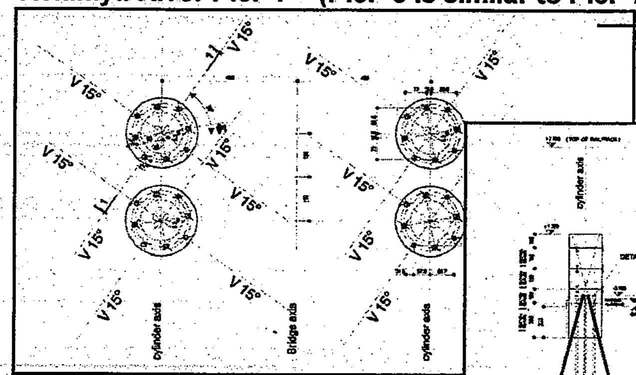
Kelaniya River Pier 3 R/F Details (Pier 4 is similar to Pier 3)

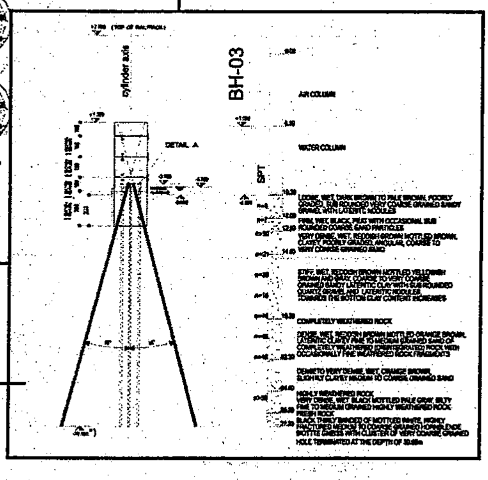


Design of Micropile Foundation System

Kelaniya River Pier 4 (Pier 3 is similar to Pier 4)

Plan View
(River Pier KELANIYA)

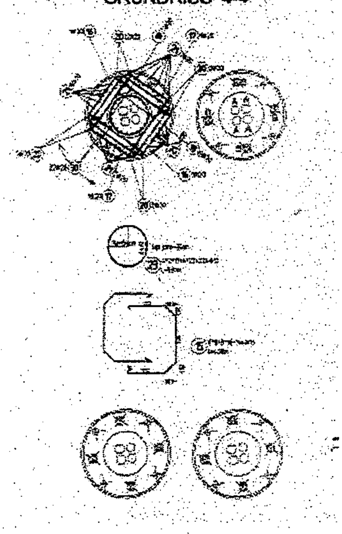




Cross Section (River Pier Kelaniya)
with soil profile

Design of Micropile Foundation System

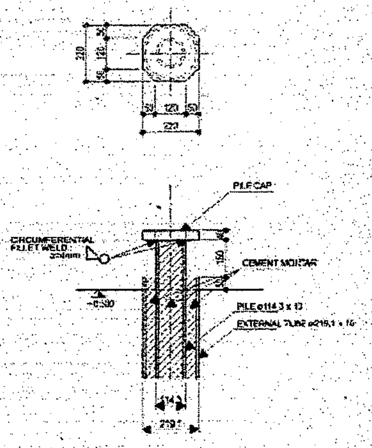
Kelaniya River Pier 3 R/F Details



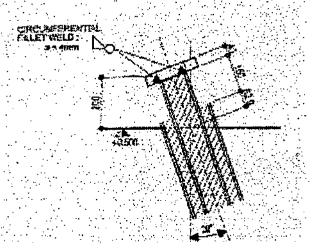
Design of Micropile Foundation System

Micropile Head Details (Typical)

DETAIL A
PILE CAP
1 : 10



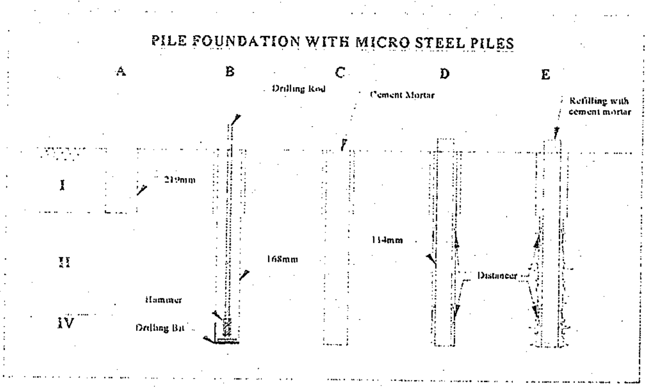
DETAIL B
PILE CAP
1 : 10



PILES (32 x)	ø 114,3 mm x 10 mm Steel : N80 filled and covered with cement mortar bore hole - diameter = 165 mm
EXTERNAL TUBES (32 x)	ø 219,1 mm x 10 mm Steel : S355JO
PILE CAPS (32 x)	steel plate 40mm x 220mm x 220mm Steel : S 355 JO
WELDING	S355JO a = minimum thickness
CONCRETE	C 25 / 30

Construction of Micropile Foundation System

Construction Procedure



A - Drilling the external tube 219.0mm Ø

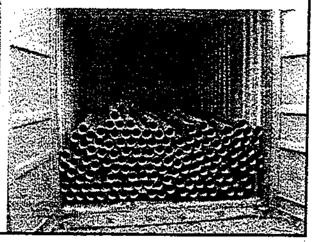
up to the required depth (very soft and organic strata) when needed.

B - Drilling the casing 168.0mm Ø up to the required depth (into the slightly weathered / fresh rock).

C - Filling the open borehole with cement mortar.

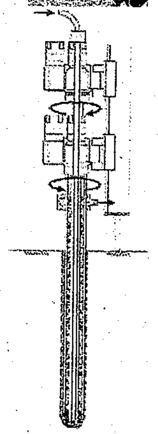
D - Installation of the bearing pile 114.0mm Ø.

E - Removing the casing 168.0 mm Ø and refill the bore hole with cement mortar when needed.



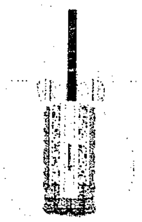
Construction of Micropile Foundation System

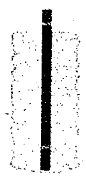
drilling



installation

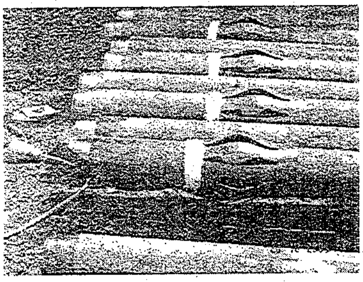
final pile

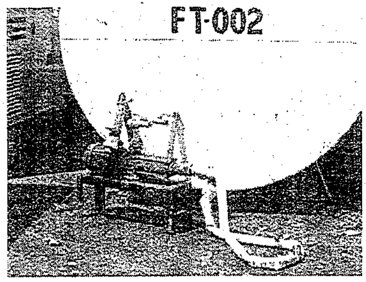




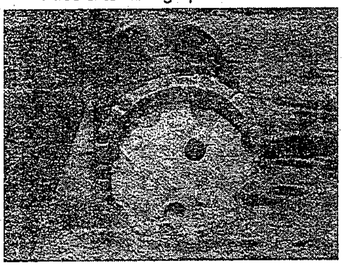
Double headed drilling

Construction of Micropile Foundation System


Piles after fixing spacers



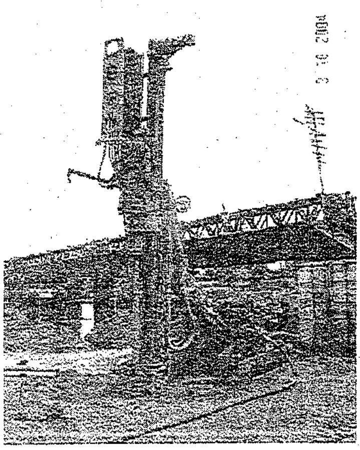
High pressure water pump

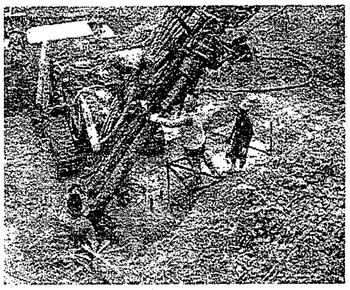

Drill pits

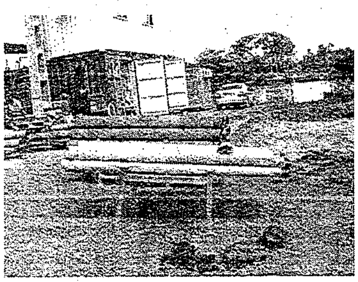

Drilling in the hard rock

Construction of Micropile Foundation System

ON LAND OPERATION

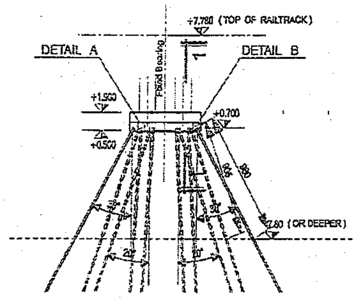

Drilling machine

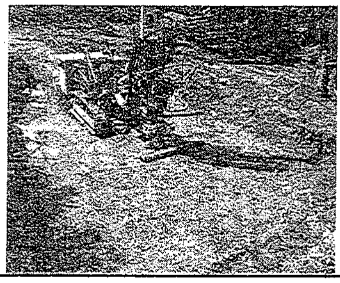

Pile Drilling along Land Piers and Abutments


Drilling rods

Construction of Micropile Foundation System

ON LAND OPERATION

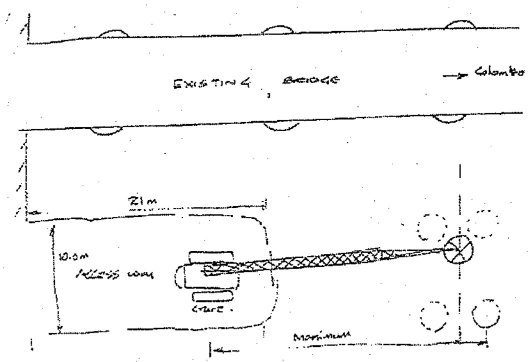


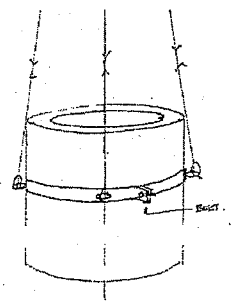


Construction of Micropile Foundation System

RIVER OPERATION

PLACING OF CONCRETE CYLINDERS

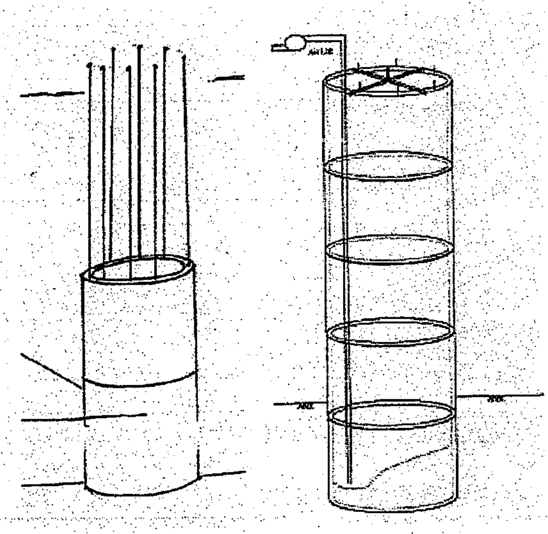


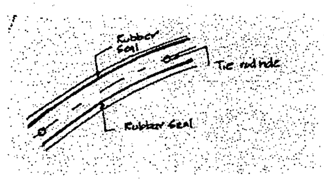


Construction of Micropile Foundation System

RIVER OPERATION

PLACING OF CONCRETE CYLINDERS & SINKING TO THE REQUIRED DEPTH BY SAND PUMP

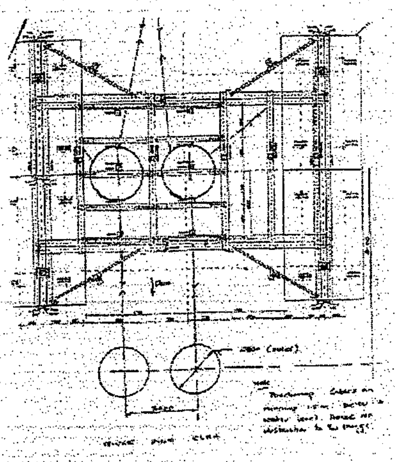




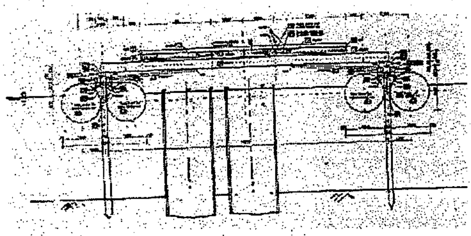
Construction of Micropile Foundation System

RIVER OPERATION

ARRANGEMENT OF CONCRETE CYLINDERS WITH PONTOON / PLATFORM



PLAN VIEW

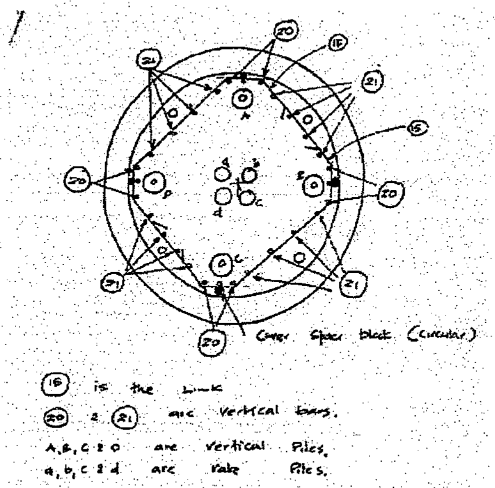


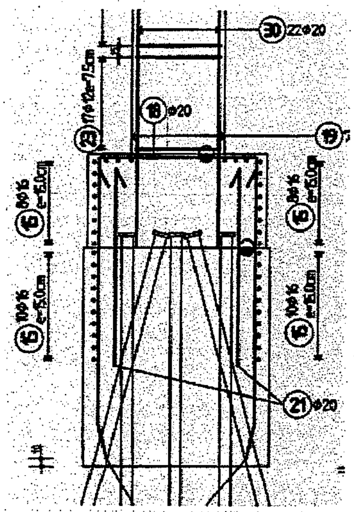
SECTION

Construction of Micropile Foundation System

RIVER OPERATION

R/F CAGE FOR PILE CAP - PLAN VIEW

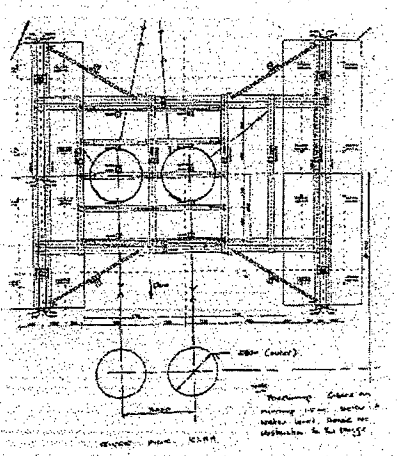




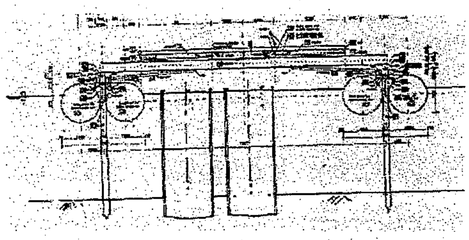
Construction of Micropile Foundation System

RIVER OPERATION

ARRANGEMENT OF CONCRETE CYLINDERS WITH PONTOON / PLATFORM



PLAN VIEW

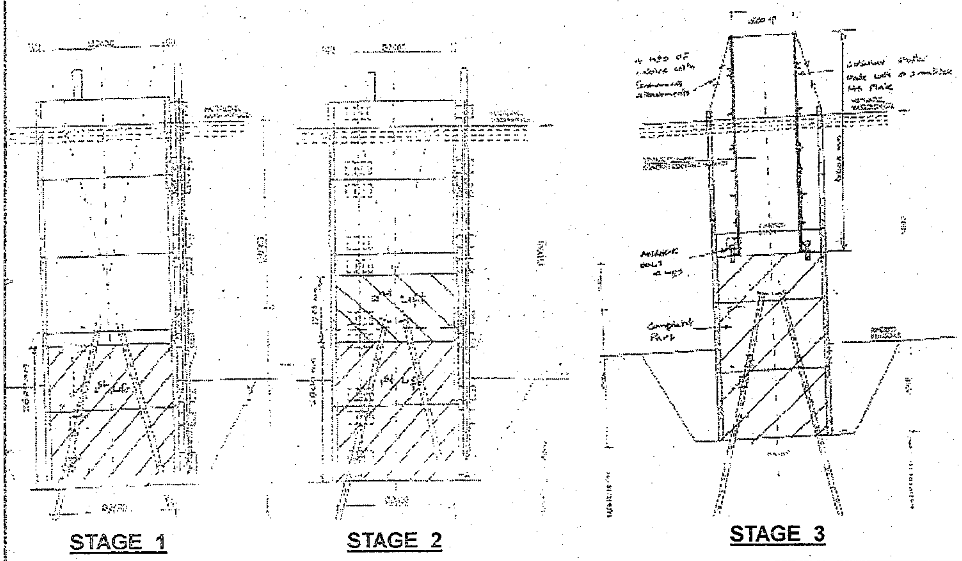


SECTION

Construction of Micropile Foundation System

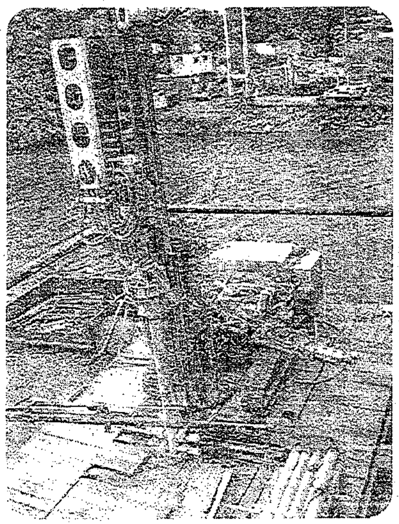
RIVER OPERATION

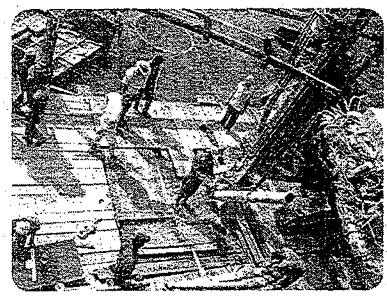
CONCRETE IN LIFTS – PILE CAP AND PIERS

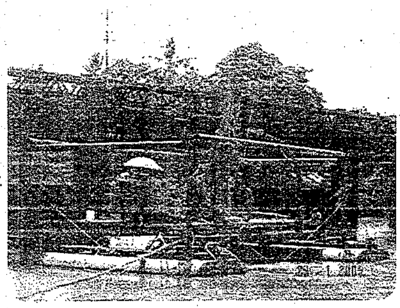


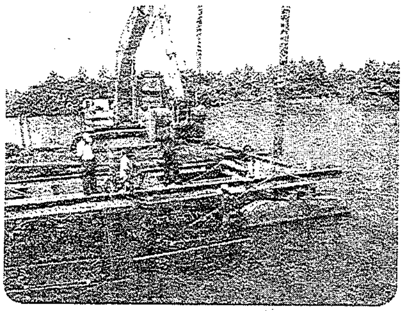
Construction of Micropile Foundation System & Erection

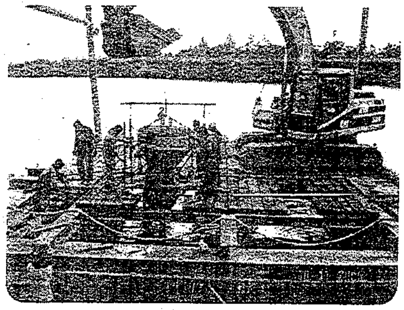
RIVER OPERATION

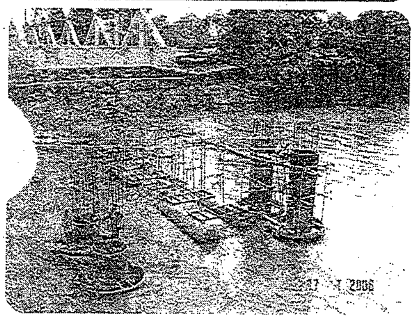






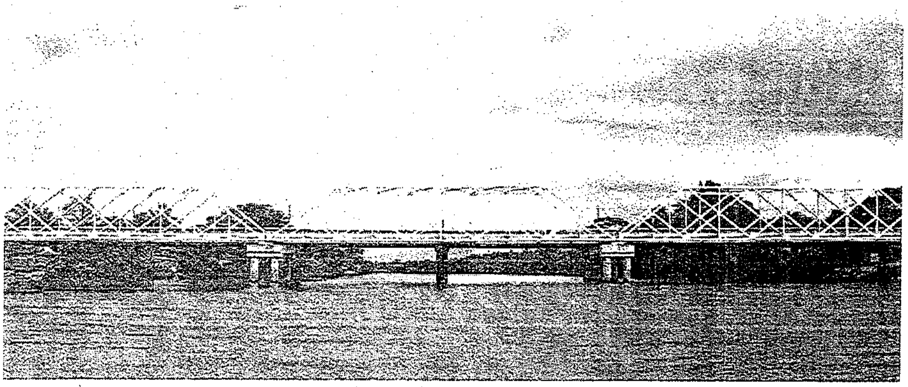






RIVER OPERATION

View of New Kelaniya Railway Bridge



Concluding Remarks

The Government of Sri Lanka undertook to replace and newly construct railway bridges in way of reinstating and developing the country's railway infrastructure

- The Program included 8 Railway Bridges of which 5 of them were new ones at Kalutara North & South, Kelaniya, Ja-Ela, and Seeduwa
- Subsurface conditions at the bridge sites demanded deep foundation systems
- Given a wide range of options for piled foundation systems, Micropile foundation systems were adopted giving due regard to site conditions and constructability issues.
- The Micropiling foundation systems were successfully implemented to put up the country's new set of major Railway Bridge structures after the colonial era.

THANK YOU

2.45

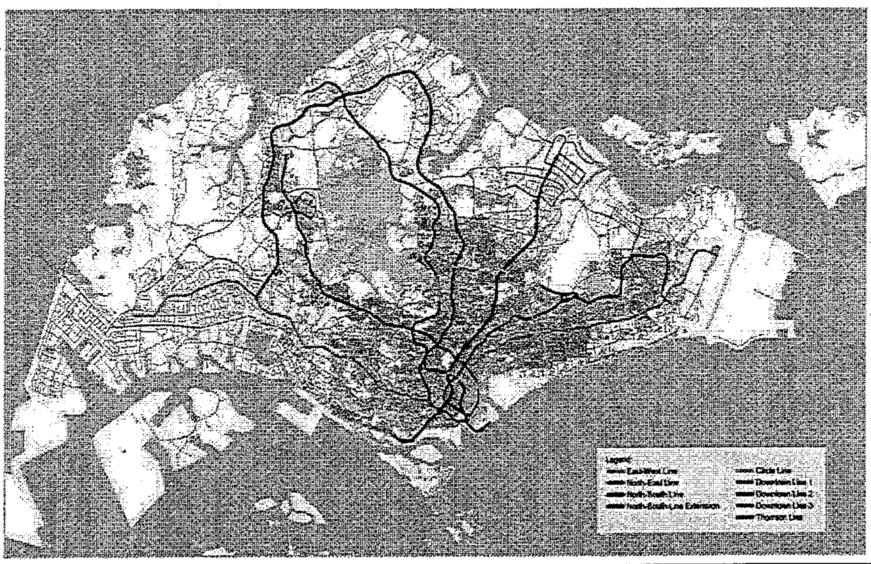
Tunnelling for Railway Infrastructure Development

Eng. C.J. Medagoda and Dr. J.S.M. Fowze
Design, Research and Development Section
Central Engineering Consultancy Bureau (CECB)

Contents

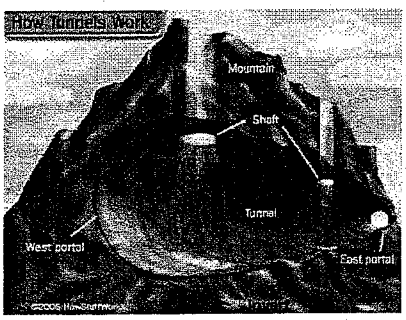
- Introduction
- Tunnelling and Tunnelling Methods
- TBM
- NATM
- DTL3 of Singapore
- A Typical Case of NATM
- Concluding Remarks

Introduction



Tunnels and Tunnelling Methods

- At its most basic, a **tunnel** is a tube hollowed through soil or stone. Or a tunnel is a man made horizontal passageway located underground.
- The opening of the tunnel is a **portal**.
- The "roof" of the tunnel, or the top half of the tube, is the **crown**.
- The bottom half is the **invert**.
- The basic geometry of the tunnel is a **continuous arch**.



Tunnels and Tunnelling Methods

Soft Ground

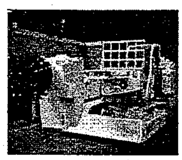
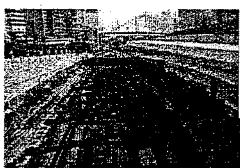
Tunnels through clay, silt, sand, gravel or mud. In this type of tunnel, **stand-up time** -- how long the ground will safely stand by itself at the point of excavation -- is of paramount importance. Because stand-up time is generally short when tunneling through soft ground, cave-ins are a constant threat. To prevent this from happening, engineers use a special piece of equipment called a **shield**. A shield is an iron or steel cylinder literally pushed into the soft soil. It carves a perfectly round hole and supports the surrounding earth while workers remove debris and install a permanent lining made of cast iron or precast concrete. When the workers complete a section, jacks push the shield forward and they repeat the process.

Hard Ground

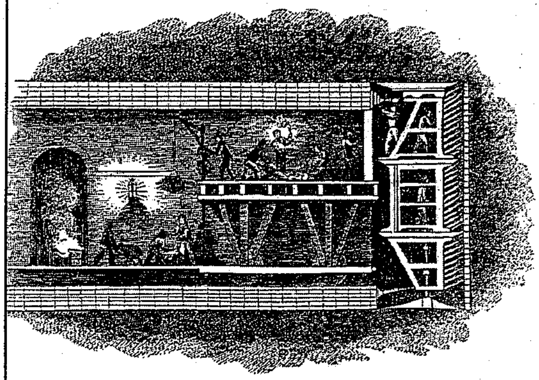
Tunnels through gneiss, shale, sandstone etc. Involves blasting, mechanical drilling & cutting or TBM. The process of digging a tunnel in rock/hard ground, however, is not simply a case of deciding where the tunnel is to go and then blasting one's way through. Rock is a very treacherous medium through which to travel. Even "solid" rock often contains innumerable cracks, faults, folds, and discontinuities, the activation of any of which may become a trigger to a collapse of the tunnel. The design and construction of a tunnel must account for the mechanical properties of the surrounding rock, which includes not only the aforementioned cracks and discontinuities, but also the weathering and deterioration of the rock, the number and type of layers in the rock, strike and dip of these layers, underground water level, overburden, etc.

Tunnels and Tunnelling Methods

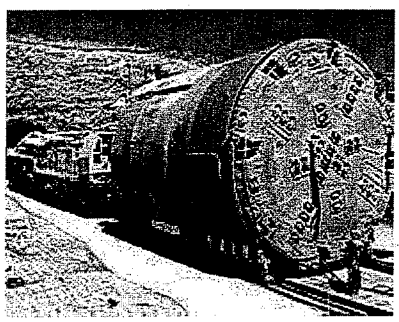
- Classical methods
- Mechanical drilling/cutting
- Cut-and-cover
- Drill and blast
- Shields and tunnel boring machines (TBMs)
- New Austrian Tunnelling Method (NATM)


TBM



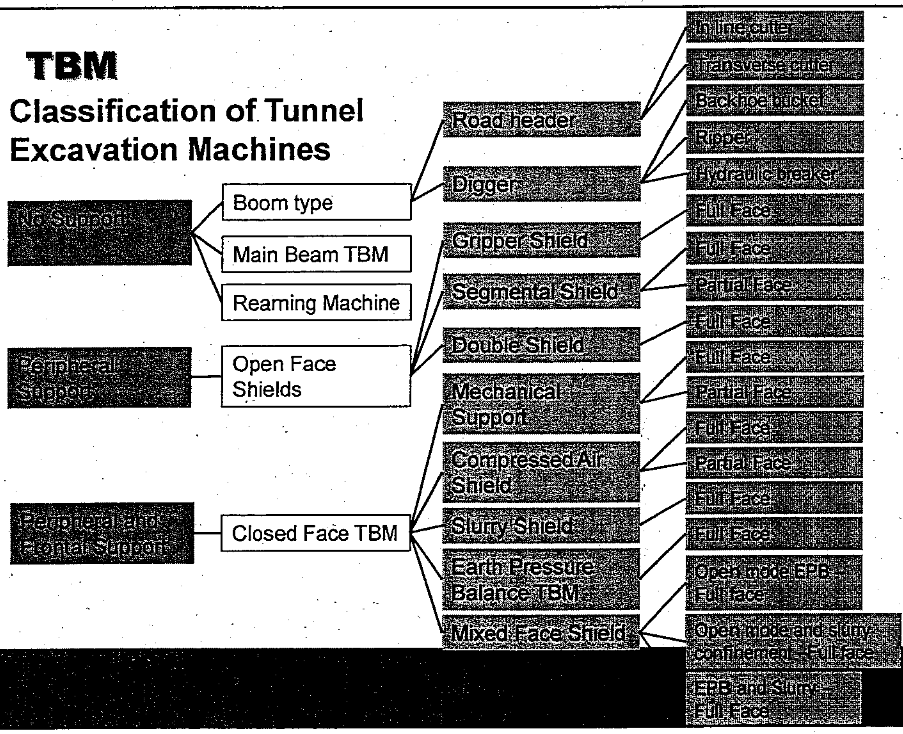
Brunel Tunnel Shield



A tunnel boring machine that was used at Yucca Mountain Nevada United States

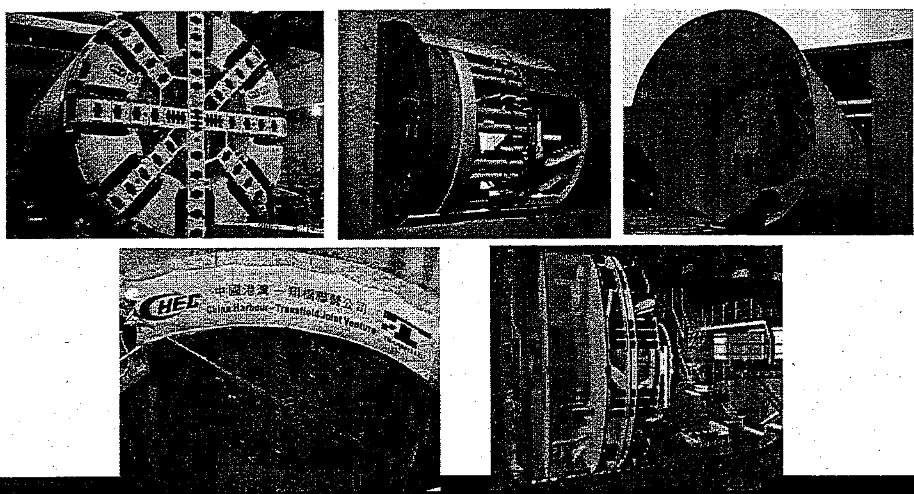
TBM

Classification of Tunnel Excavation Machines



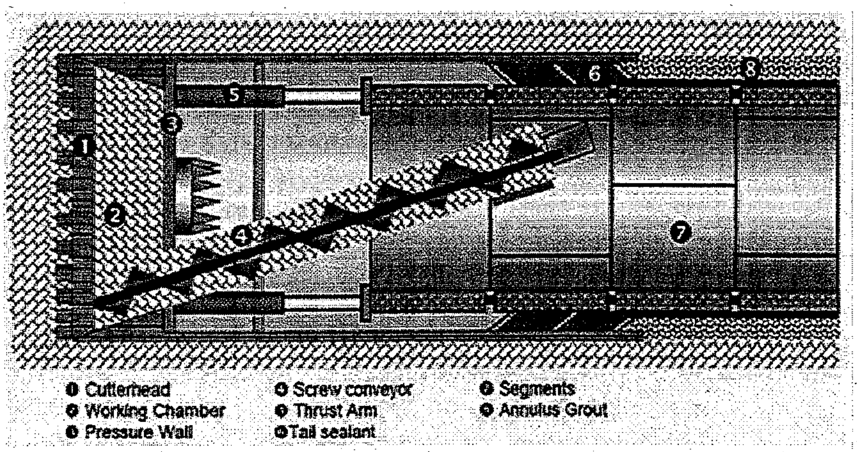
TBM

Shield Tunnel Boring Machines



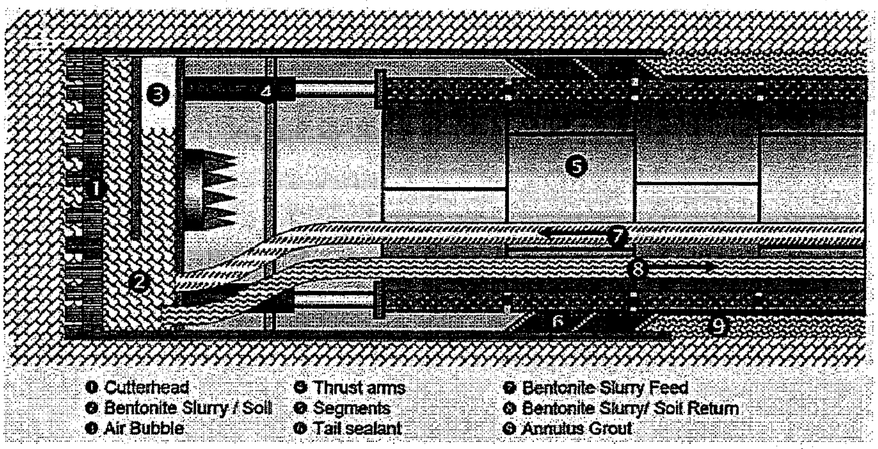
TBM

Soft Ground Shield Tunnel Boring Machines
Earth Pressure Balance Machine



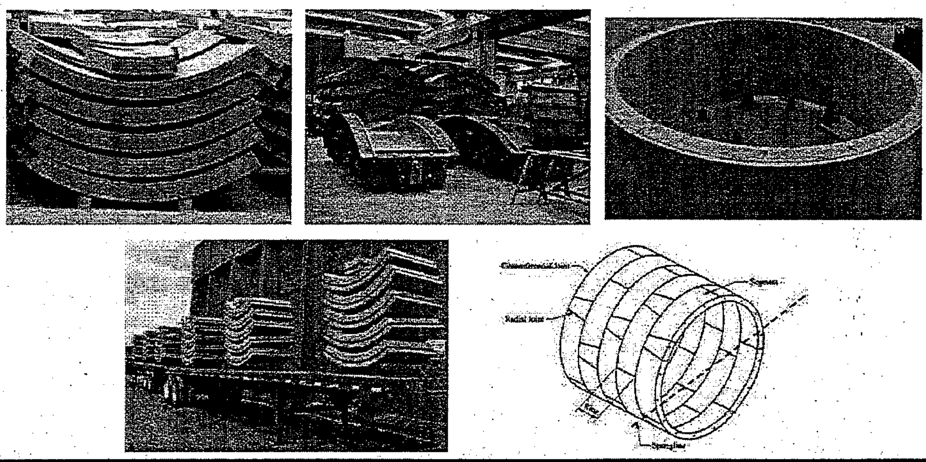
TBM

Soft Ground Shield Tunnel Boring Machines
Slurry Machine



TBM

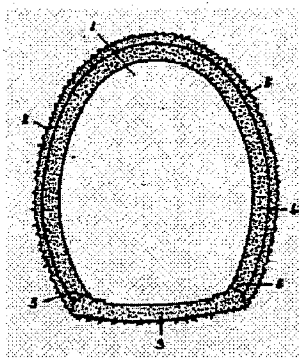
Soft Ground Shield Tunnel Boring Machines
Segmental Lining



New Austrian Tunnelling Method (NATM)

First Idea of NATM

- Salzburg Rabcewicz in 1948 patented a tunnelling method, which was based on a double concrete shell approach. Inner lining should be installed when deformations ceased
- Quickly installed primary lining should avoid disintegration and thus development of dead loads on lining
- Waterproofing between primary and secondary lining possible
- Design of inner lining based on measuring results



NATM

Development of Shotcrete and Bolting

- Although known and occasionally used, the systematic application of shotcrete and rock bolts started in the nineteen fifties.
- Shotcrete helped prevent disintegration of the ground, which was a problem with traditional supports.
- Rock bolts originally were used to fix single blocks, but soon systematic bolting was applied to reinforce the rock mass surrounding the tunnel.

NATM

Basic Principles of NATM

- The basic idea of the method always was that the ground, when properly treated can be used as part of the tunnel support. Precondition for this is the knowledge of the ground characteristics and its behavior during and after excavation.
- Prevent disintegration of the rock mass, thus keeping its strength
- Use rock mass as far as possible to take additional stresses resulting from excavation
  - This implies that deformations should not be completely stopped by the support right after installation
  - But deformation should be kept below critical level, where disintegration (loosening) of the rock mass occurs

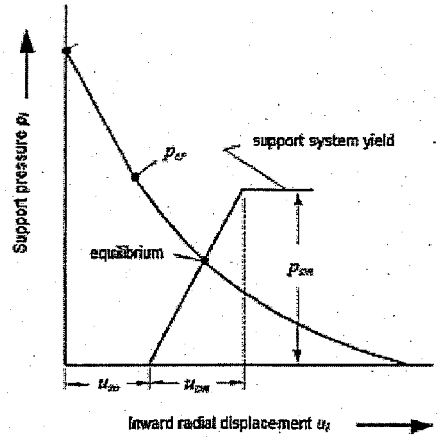
NATM

Basic Principles of NATM...

- Monitor the behavior of the system to observe stabilization process and allow for adjustments

NATM

Concept of Ground Reaction Curve



NATM

Further developments

- The approach was technically and economically so successful that the interest of the owners rapidly increased. The reduction in support quantities, as well as the increased progress, and reduced requirement for repairs led to a cost reduction of up to 50%
- In a lecture at the Geomechanics Colloquy 1962 in Salzburg Rabcewicz gave the method the name „New Austian Tunnelling Method"
- A number of tunnels with shallow overburden were successfully completed in Austria and Germany in the early 1960ies.
- The success of the method soon raised the interest of owners, designers and construction companies around the world.

NATM

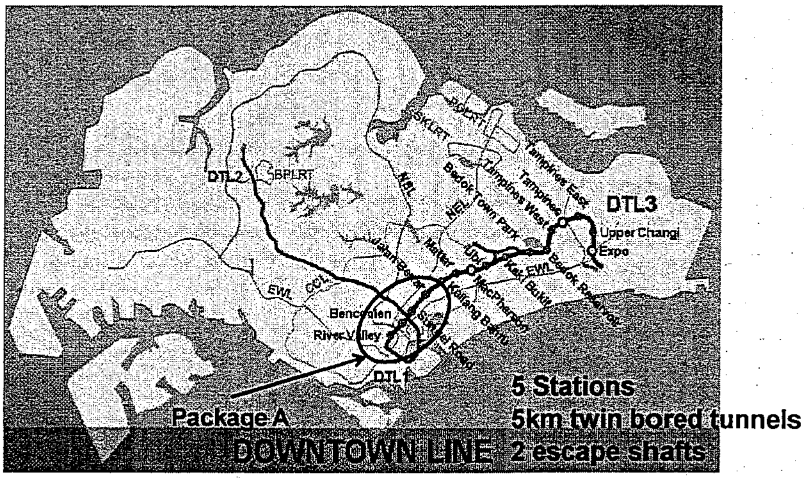
Examples of Recent Projects

Inntal tunnel, bifurcation cavern A= 320 m2

Wienerwald tunnel, Austria; sidewall galleries in built up area with shallow cover

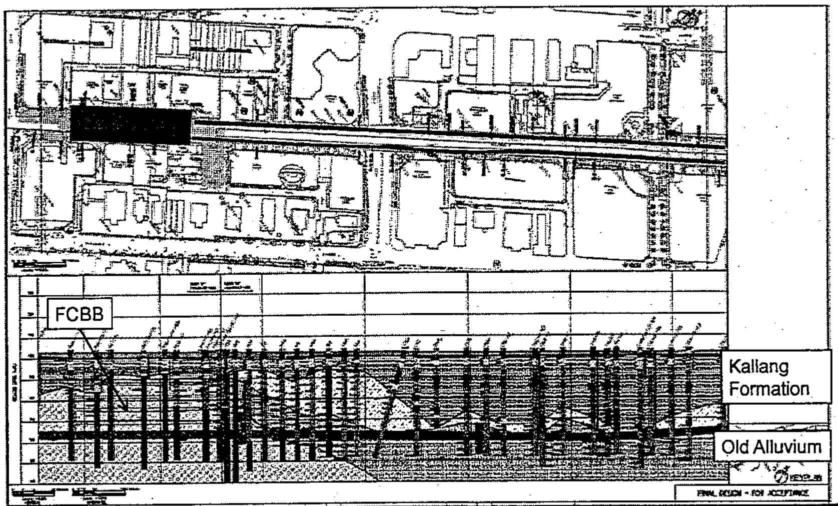
DTL3 Singapore

Downtown Line in Singapore



DTL3 Singapore

Boreholes and Soil Profile (Bencoolen St. – Sungei Rd St.)



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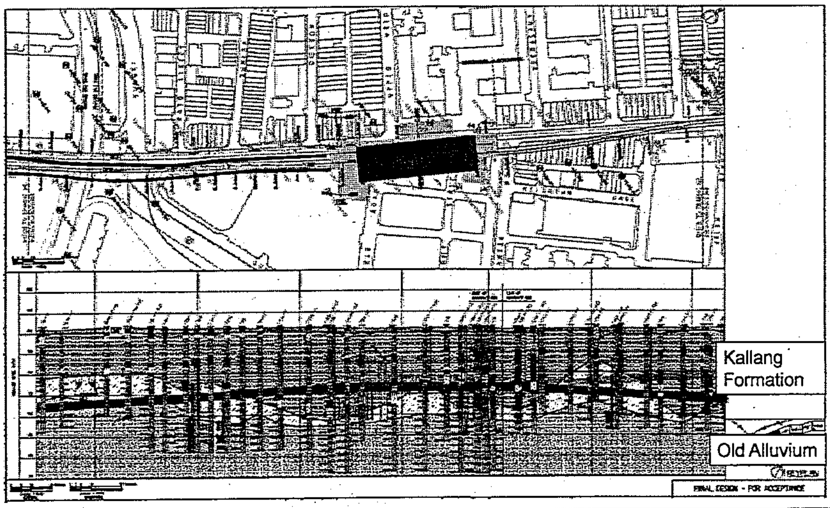
Boreholes and Soil Profile



DTL3 Singapore

Geotechnical Parameters

		Unit	Fill	KALLANG FORMATION: Marine Clay (M)	Fluvial Clay (F2)	Estuarine Clay (E)	Fluvial Sand (F1)	OLD ALLUVIUM: OA (A)	OA (B)	OA (C)	OA (D&E)	Fort Canning Boulder Bed (FCBB)
Unit Weight	γ	kN/m^3	19	16	19	15	19	20	20	20	20	21
Effective Angle of Friction	ϕ'	Deg	30	22	24	22	30	34	34	32	28	32.5
Effective Cohesion	c'	kPa	0	0	0	0	0	20	10	10	10	10
Undrained Shear Strength	c_u	kPa	30	$15+1.6z$, z from +91	$20+1.5z \le 50$, z from +90	$15+1.5z$, z from +91		250	$100+30z \le 250$, z from OA surface		$5N \le 150$	$5N \le 500$
At Rest Earth Pressure Coefficient	K_0		0.5	1.0	1.0	1.0	0.7	0.7	0.7	0.7	0.7	1.0
Young's Modulus	E_u	MPa	10	$400c_u$	$400c_u$	$300c_u$		200	$600c_u=60+18z \le 150$		$2N \le 60$	300
	E'		8	$E_u/1.2$			$10+z \le 15$, z from +90	200	$50+15z \le 150$		$2N \le 60$	$E_u/1.2$
Permeability	K_{des}	m/s	10^{-6}	10^{-9}	10^{-8}	10^{-9}	10^{-6}	10[illegible]	10[illegible]	10[illegible]	10^{-7}	10^{-8}

DTL3 Singapore

Bored Tunnel Segmental Lining Design

Geometric Design of Lining
- Ring Diameter
- Ring Length
- Ring Taper

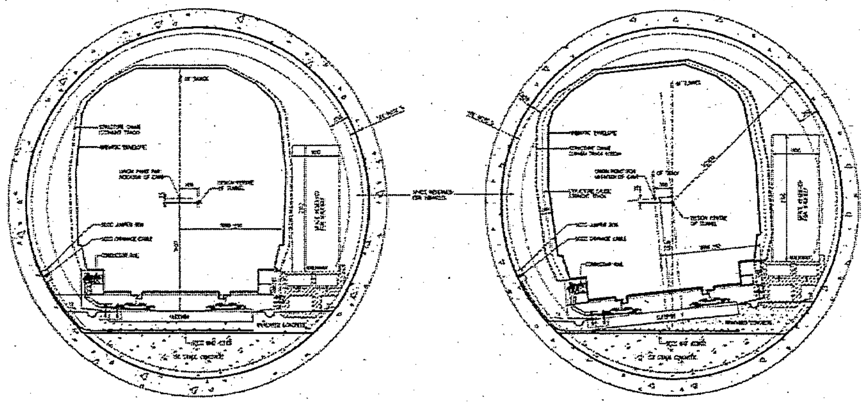
Design Check for Segment
- Demoulding
- Stacking
- Lifting/Erection
- Jacking
- Spear Bolt Design

Design Check for Ring
- Floatation
- Lining Design
- Crack Width
- Deflection

Design Check for Radial Joint
- Birdsmouthing
- Joint Checking

DTL3 Singapore

Geometric Design: Structural Gauge



LTA STANDARD
STRIGHT TRACK (SINGLE)

LTA STANDARD
BORED TUNNEL CANTED TRACK (SINGLE)
RADIUS 300m

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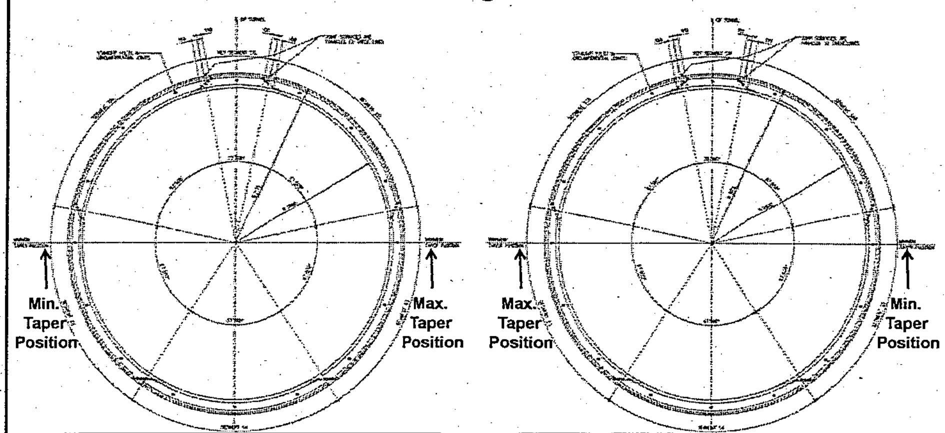
Geometric Design: RC Segmental General Arrangement



Typical Section of Left Hand Tapered Ring

Typical Section of Right Hand Tapered Ring

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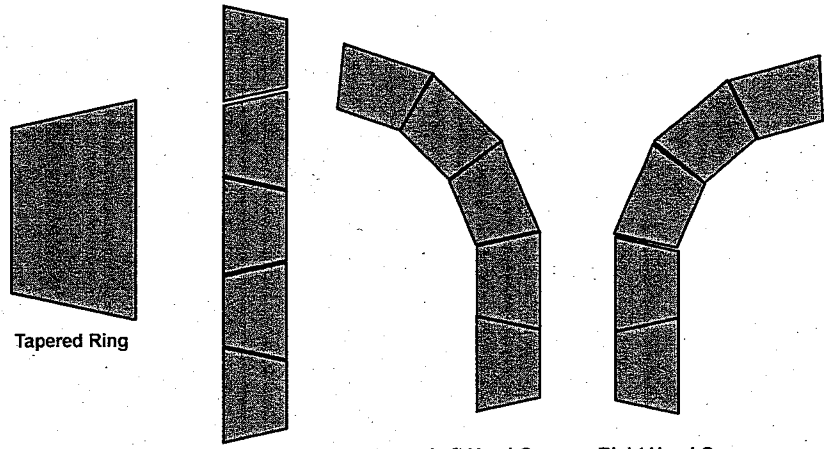
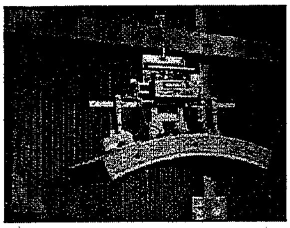
Geometric Design: Tapered Rings



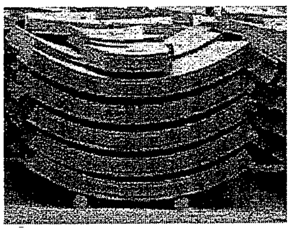
Tapered Ring Straight Left Hand Curve Right Hand Curve

DTL3 Singapore

Design Check for Segments

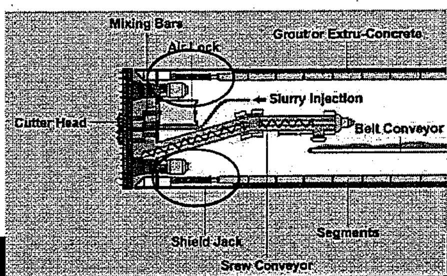


Demoulding



Stacking

Segment Erection



Jacking

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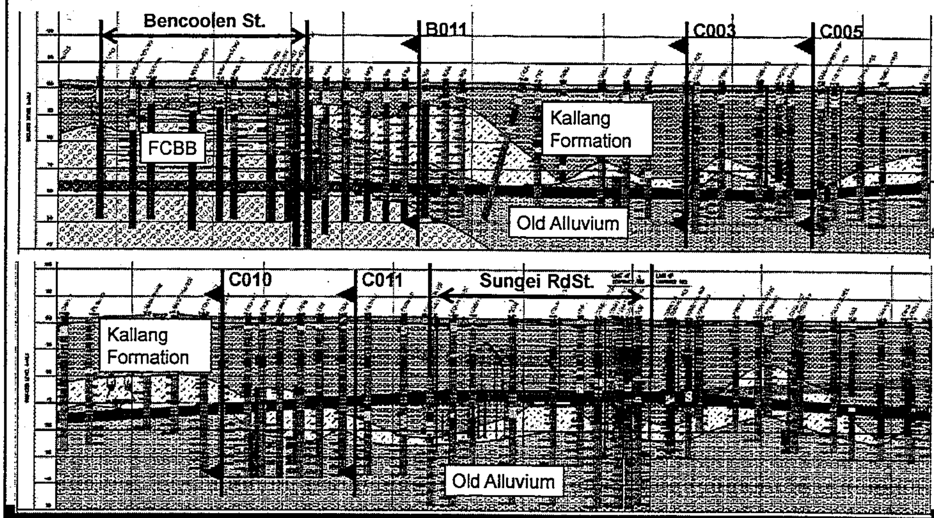
Design Check for Ring: Design Sections



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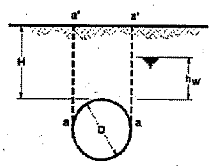
Design Check for Ring: Floatation



Uplift $U = \gamma_w \frac{\pi D^2}{4} - W$

where γ_w = specific weight of water
W = self weight of tunnel
(See Clause 7.5.4.9 below)
D = outside diameter of tunnel

Restraining Force $R = \gamma' D (h_w + \frac{D}{2} - \frac{\pi D}{8}) + \gamma_b D (H - h_w) + 2S (H + \frac{D}{2})$

where γ' = submerged weight of soil
γ_b = bulk weight of soil
S = average shear resistance along a-a'
= c_u for cohesive soils
= $\frac{1}{2} K_o \gamma' (H + D/2) \tan\phi$ for cohesionless soils

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Design Check for Ring: Lining Design

Loadings

- Overburden (i.e. effective stress)
- Groundwater pressure (based case where GWT is taken at GL and another case where GWL is taken at 3m below GL)
- Surcharge (75kPa as specified in the LTA CDC)

Additional Distortion

It is part of the design requirement to consider the effect on the lining due to an additional distortion of +/-15mm on diameter. From this additional distortion, an additional bending moment will be induced to the lining. This bending moment can be estimated using an equation relating the bending moment to a radial deformation (Morgan, 1961)

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Design Check for Ring: Lining Design

Load Combinations	ULS					SLS (crack width)					SLS (defl)	
	1	2	3	4	5	6	7	8	9	10	11	12
Load factor: 1.4/1.6	✓	✓	✓	✓	✓							
Load factor: 1.0						✓	✓	✓	✓	✓	✓	✓
$75kN/m^2$ surcharge		✓		✓	✓		✓		✓	✓	✓	✓
GWT at GL	✓	✓				✓	✓				✓	
GWT @ 3m below GL			✓	✓	✓			✓	✓	✓		✓
Full section moment of inertia	✓	✓	✓	✓		✓	✓	✓	✓			
Reduced section moment of inertia					✓					✓	✓	✓
Short term concrete Young's modulus	✓	✓	✓	✓		✓	✓	✓	✓			
Long term concrete Young's modulus					✓					✓	✓	✓
Additional distortion of 15mm on dia.					✓					✓		

DTL3 Singapore

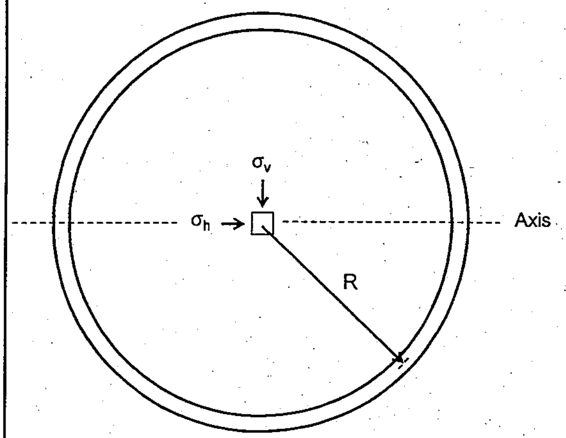
Design Check for Ring: Lining Design, Continuum Model

What is a Continuum Model?

- **A Continuum Model is...**
  A set of simple equations, that give us forces & moments in a tunnel lining.
- **Why are Forces & Moments Important?**
  The forces & moments given from Continuum Models form the basic design case for soft-ground tunnel design.
- **Why are Continuum Models important...**
  Unlike structural equations, which just consider the structural lining behavior, Continuum Equations considers the ground-soil interaction.

DTL3 Singapore

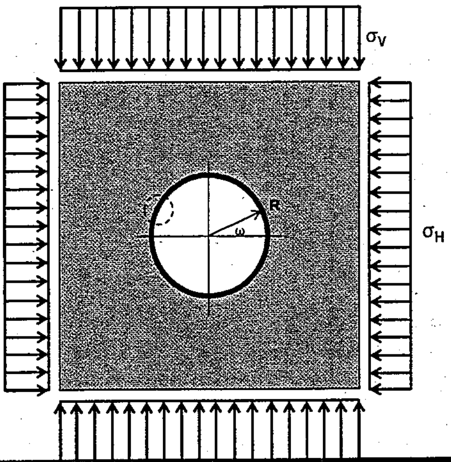
Design Check for Ring: Lining Design, Basic Continuum Model Solutions

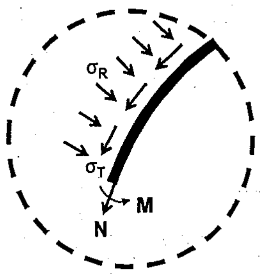


Calculate vertical & horizontal pressures by considered a block of soil at the tunnel axis. What is the soil pressure & water pressure acting on this block of soil?

DTL3 Singapore

Design Check for Ring: Lining Design, Basic Continuum Model Solutions

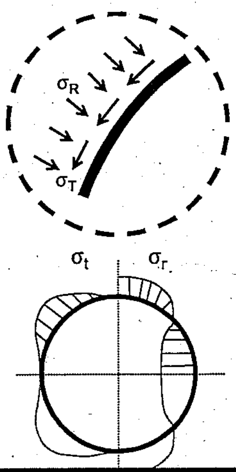




Make several Assumptions then can calculate the forces acting on the tunnel lining.

DTL3 Singapore

Design Check for Ring: Lining Design, Basic Continuum Model Solutions



Radial Stress

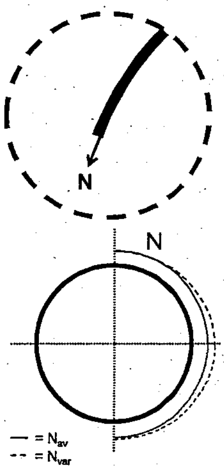
$$\sigma_r = \frac{(\sigma_v - \sigma_h)}{2}\cos 2\omega$$

Tangential Stress

$$\sigma_t = \frac{(\sigma_v - \sigma_h)}{2}\sin 2\omega$$

DTL3 Singapore

Design Check for Ring: Lining Design, Basic Continuum Model Solutions



Average Hoop Thrust

$$N_{av} = n_{av}\frac{(\sigma_v + \sigma_h)}{2}R$$

Variable Hoop Thrust

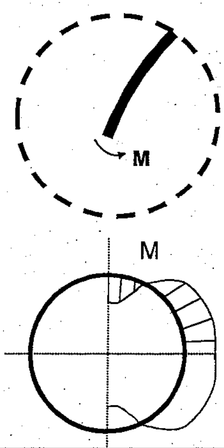
$$N_{var} = \frac{(\sigma_v - \sigma_h)}{2}n_{var}R\cos 2\omega$$

$N_{max} = N_{av} + N_{var}$ (at Axis where $\cos 2\omega = 1$)

$N_{min} = N_{av} - N_{var}$ (at Crown where $\cos 2\omega = -1$)

DTL3 Singapore

Design Check for Ring: Lining Design, Basic Continuum Model Solutions



Bending Moment

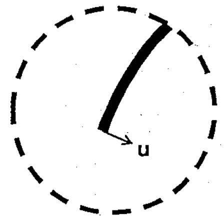
$$M_{var} = \frac{(\sigma_v - \sigma_h)}{2}m_{var}R^2\cos 2\omega$$

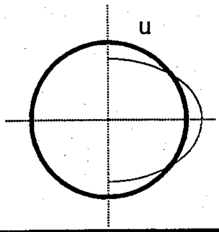
$M_{max} = M_{var}$

(at Axis or Crown where $\cos 2\omega = 1$ or -1)

DTL3 Singapore

Design Check for Ring: Lining Design, Continuum Analyses





Radial Displacement

$$u_{var} = \frac{(\sigma_v - \sigma_h)}{2} u_{var} R^4 \cos 2\omega$$

$U_{max} = u_{var}$
(at Axis or Crown where $\cos 2\omega = 1$ or -1)

DTL3 Singapore

Design Check for Ring: Lining Design, Continuum Analyses

Why use Continuum Equations?

- **Very Quick, Very Easy to Use.**
- **Internationally Recognized throughout the Soft GroundTunnel Industry.**
- **Provides Conservative Values for Forces & Bending Moments.**
- **Excellent checking tool for others work and numerical models**

DTL3 Singapore

Design Check for Ring: Lining Design, Continuum Analyses (Muir-Wood Curtis_1976)

$$M = r_0 r_e \frac{(2S_n + S_t)}{6} \cos 2\theta$$

$$N = r_0 \frac{(S_n + 2S_t)}{3} \cos 2\theta + P r_e + N_0$$

$$U = r_0 r_e \frac{(2S_n + S_t)}{18EI} \cos 2\theta + U_w + U_u$$

$$S_n = \frac{(1-Q_2)P_0}{2\left[1 + Q_2(3-2\nu)/(3-4\nu)\right]} \quad \text{(if } S_t < \text{)}$$

$$S_n = \frac{\left\{3(3-4\nu)\frac{P_0}{2} - \left[2Q_2 - (4-6\nu)\right]S_t\right\}}{\left[4Q_2 + 5 - 6\nu\right]} \quad \text{(if } S_t > \text{)}$$

$$S_t = (1-2Q_2)\frac{P_0}{2}\left[1 + Q_2\left(3 - \frac{2\nu}{3} - 4\nu\right)\right]$$

$$Q_2 = \frac{E r_0^3}{12EI(1-\nu)}$$

$$N_0 = \frac{\sigma_v(1+K)r_e}{\left[2 + \frac{2E r_0}{EA(1-\nu)}\right]}$$

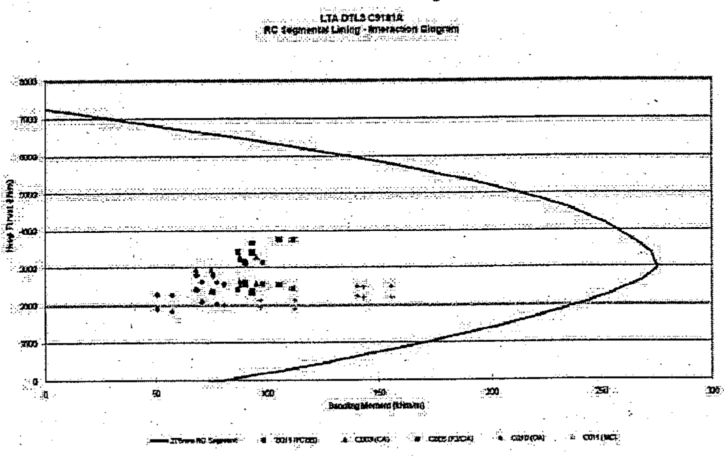
$$U_0 = \frac{r_e r_0^2(2S_n + S_t)}{18EI}$$

$$U_w = \frac{P_w r_e r_0}{EA} \qquad U_u = \frac{N_0 r_0}{EA}$$

S_n – Normal stress
S_t – Shear stress
Q_2 -Stiffness factor
N_0 – Hoop thrust due to uniform pressure
U_0 – Max. displacement due to distortional pressure
U_w – Radial displacement due to water pressure
U_u – Radial displacement due to uniform pressure
r_e – Radius of excavation (3.175m)
r_0 – Radius of lining centroid (3.0375m)
E_c – 32 Gpa (short term) 16 Gpa (long term)
Lining area – 0.275 m2/m

DTL3 Singapore

Design Check for Ring: Lining Design, Continuum Analyses



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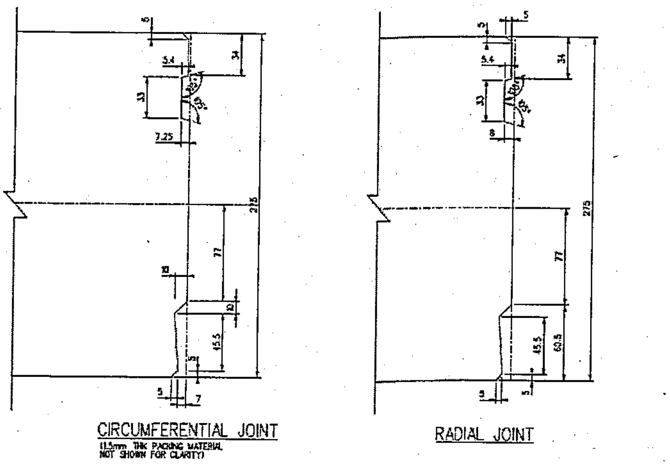
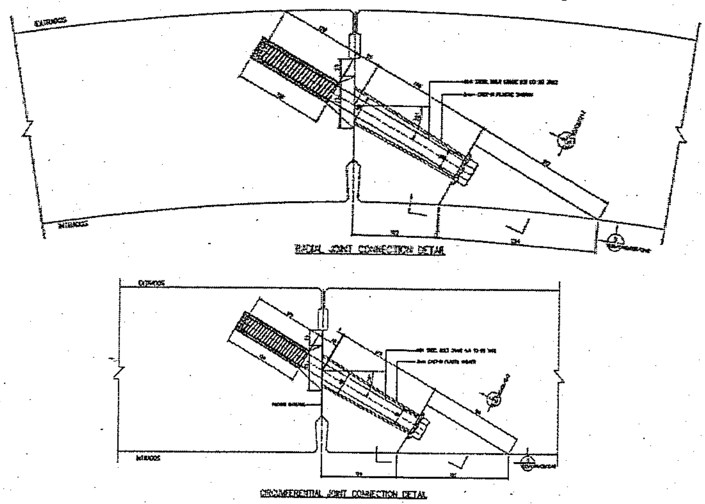
Radial and Circumferential Joint



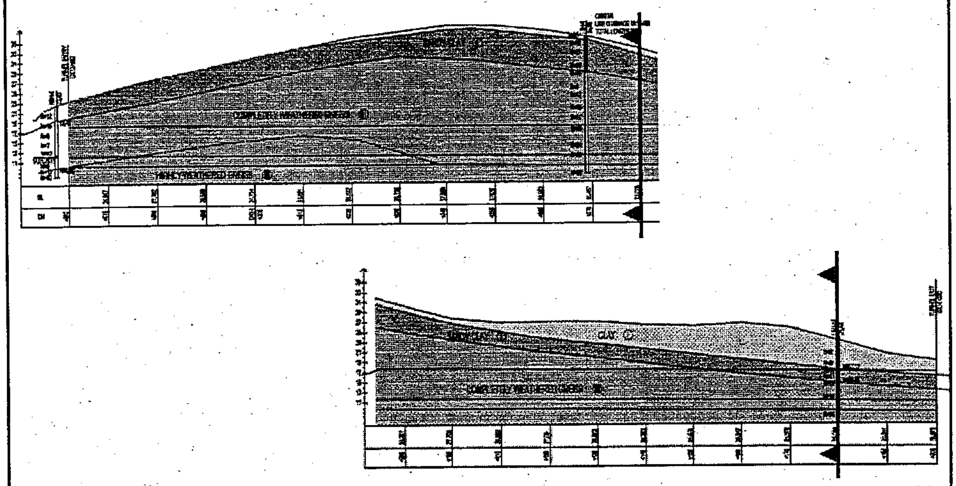
DTL3 Singapore

Radial and Circumferential Joint: Spear Bolt



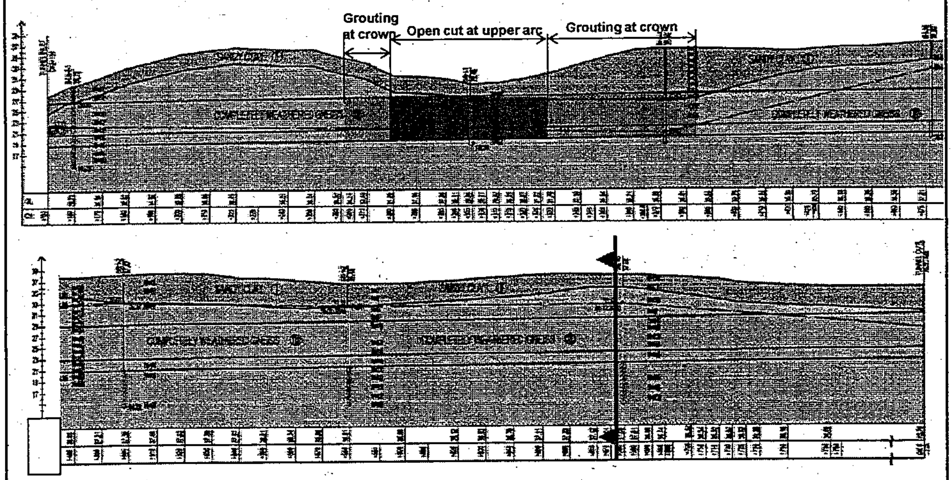
A Typical Case of NATM

Site Investigations & Design Sections (Bambarenda Tunnel)



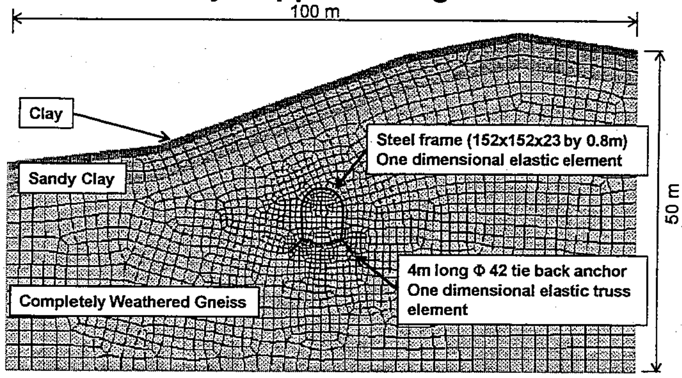
A Typical Case of NATM

Site Investigations & Design Section (Nakettiya Tunnel)



A Typical Case of NATM

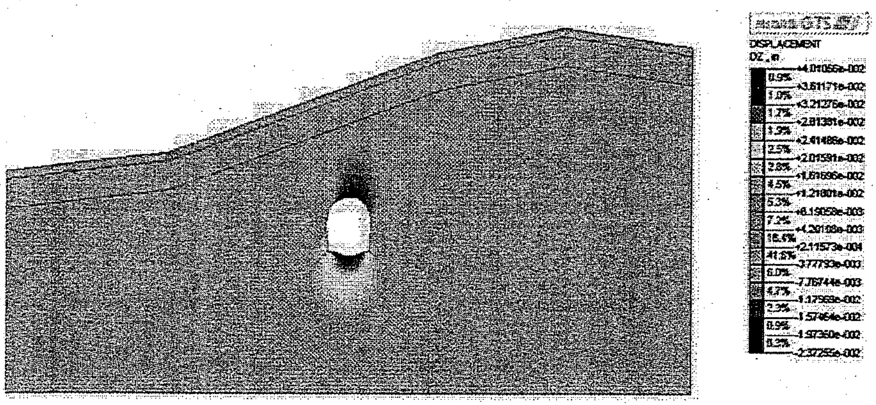
Primary Support Design...



Computational Model DK14+080

A Typical Case of NATM

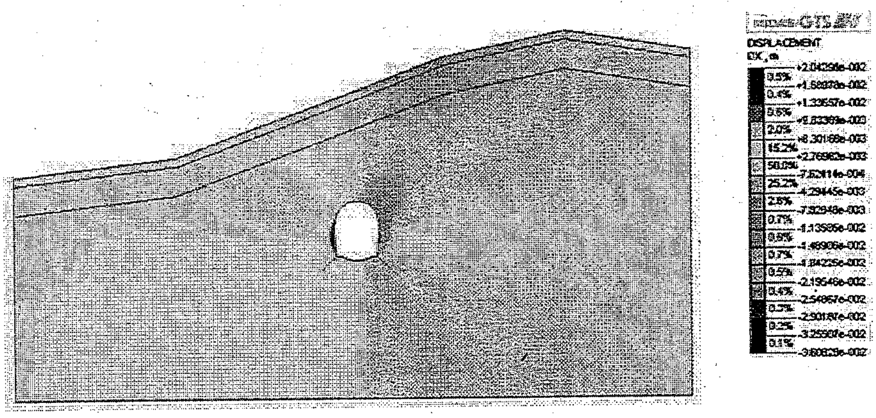
Primary Support Design...



Vertical Displacements

A Typical Case of NATM

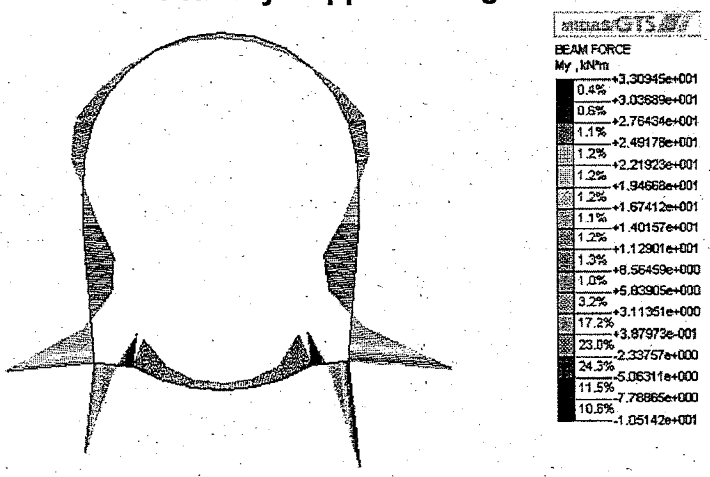
Primary Support Design...



Horizontal Displacements

A Typical Case of NATM

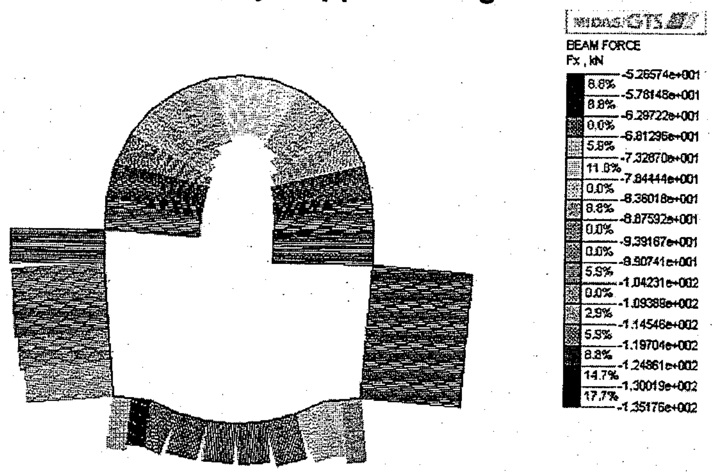
Primary Support Design...



Bending Moment

A Typical Case of NATM

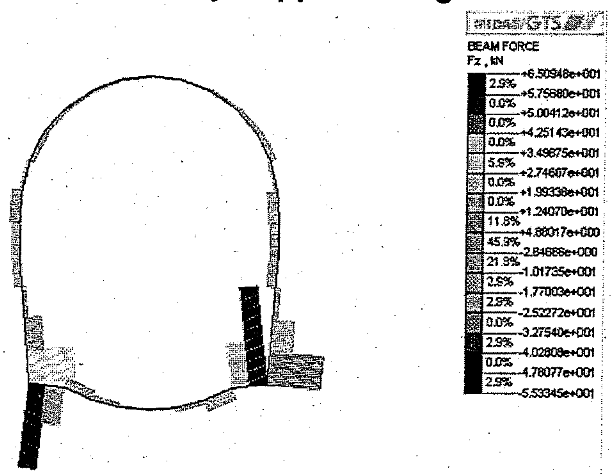
Primary Support Design...



Axial Force

A Typical Case of NATM

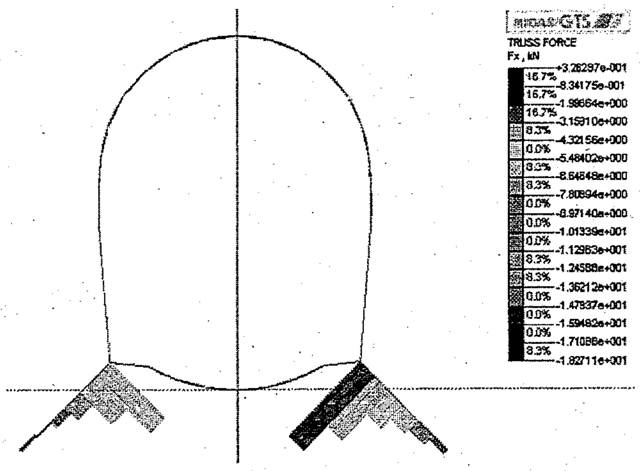
Primary Support Design...



Shear Force

A Typical Case of NATM

Primary Support Design...



Tie Back Anchor Force

A Typical Case of NATM

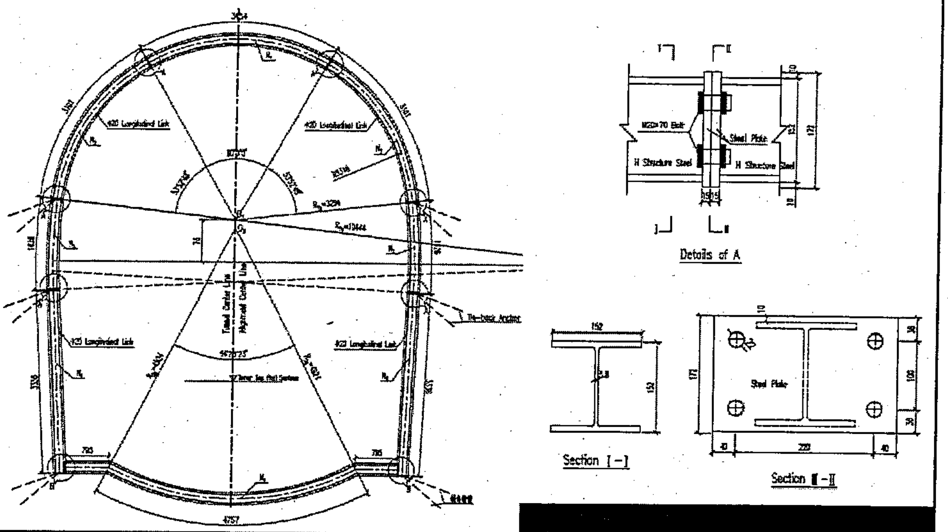
Primary Support Design...

Summary of the FEM analyses

Design Section	Max. Axial Force (kN)	Max. Bending Moment (kNm)	Max. Shear Force (kN)	Max. Displacement (steel frame) (mm)	Max. Axial Force of Anchor (kN)
DK5+680	123.8	34.0	58.0	31.0	14.7
DK14+080	135.2	33.1	65.1	40.0	18.3
DK14+180	124.7	32.9	68.7	66.0	18.4

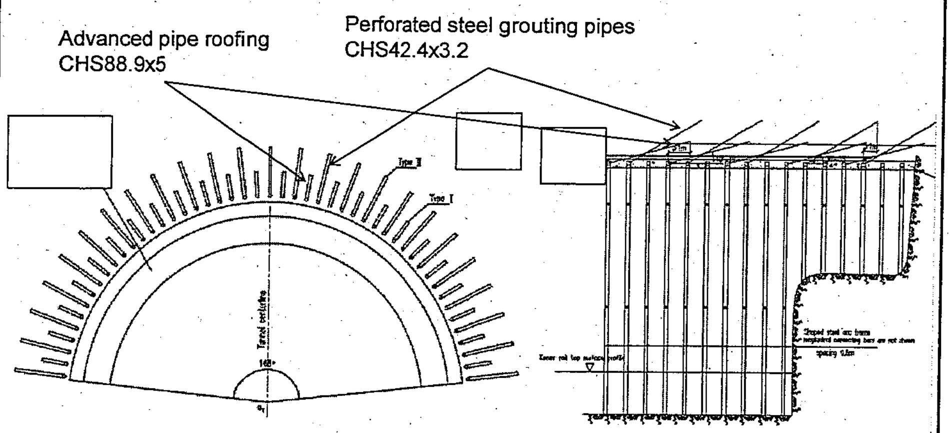
A Typical Case of NATM

Primary Support Design...



A Typical Case of NATM

Advanced Supports

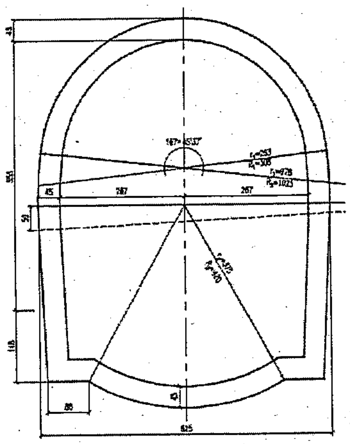


Typical Section of Advanced Support

Longitudinal Layout of Support

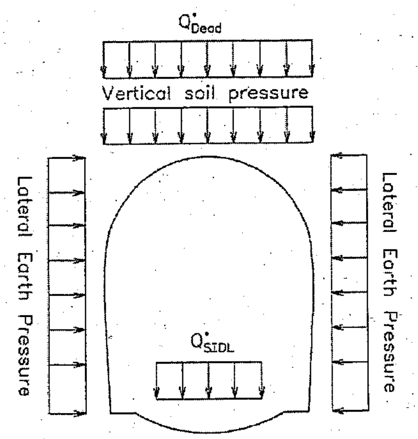
A Typical Case of NATM

Permanent Support Design



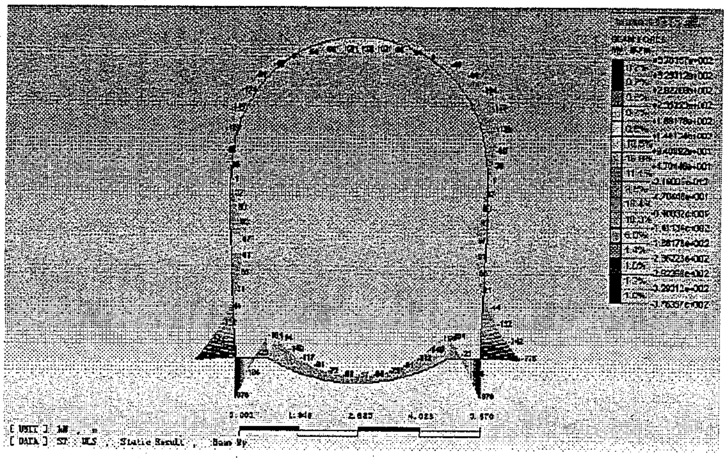
A Typical Case of NATM

Permanent Support Design



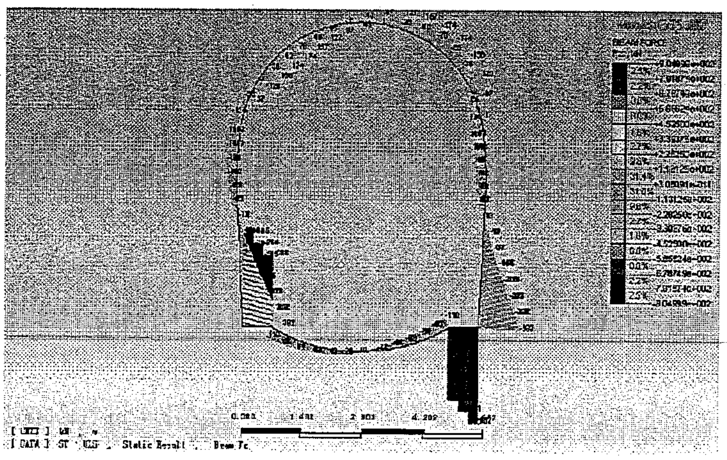
A Typical Case of NATM

Permanent Support Design



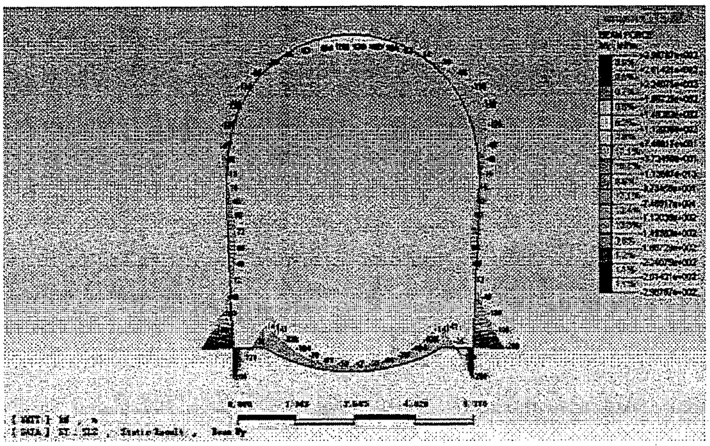
A Typical Case of NATM

Permanent Support Design



A Typical Case of NATM

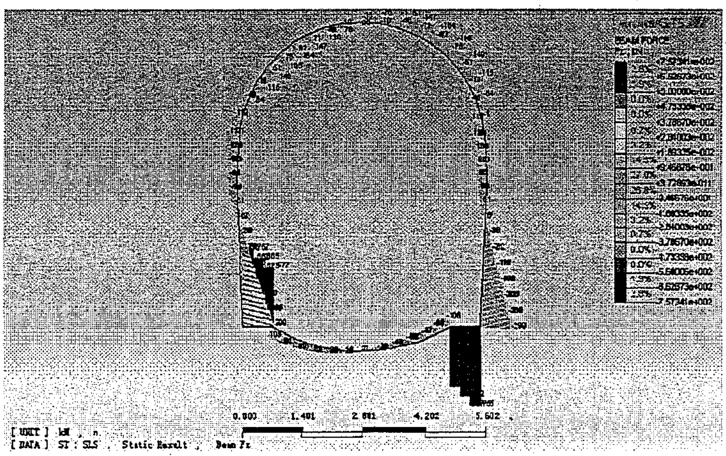
Permanent Support Design



Bending Moment-SLS

A Typical Case of NATM

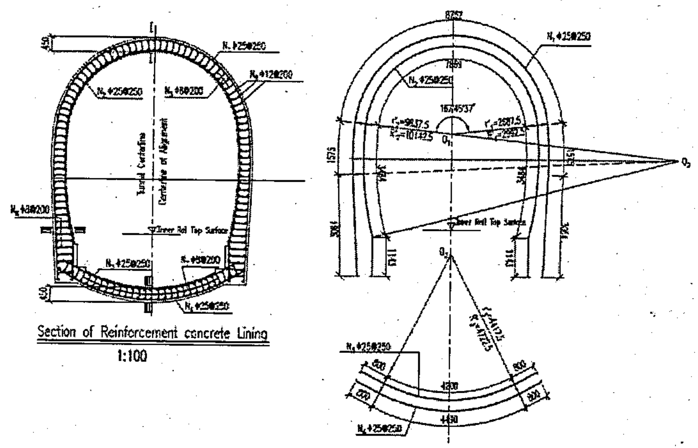
Permanent Support Design



Shear Force-SLS

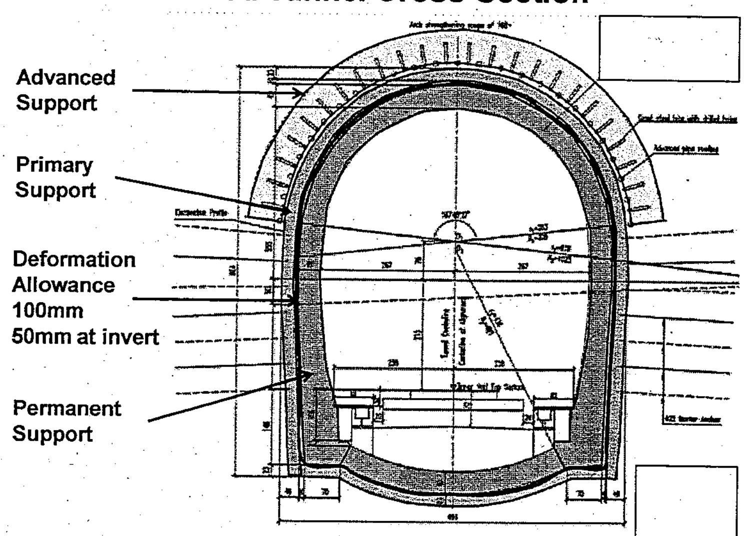
A Typical Case of NATM

Permanent Support Design



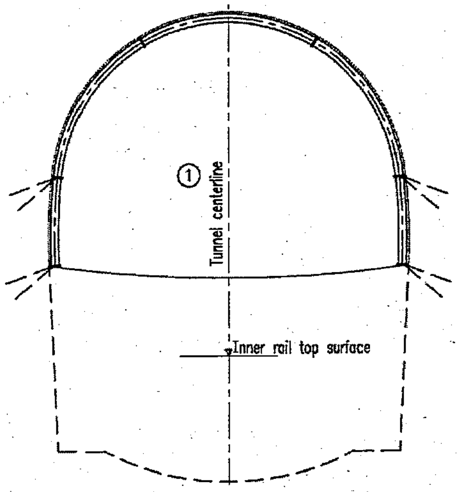
A Typical Case of NATM

Mined Tunnel Cross Section



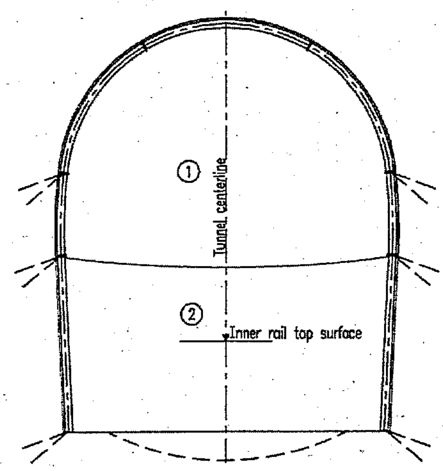
A Typical Case of NATM

Construction Sequence



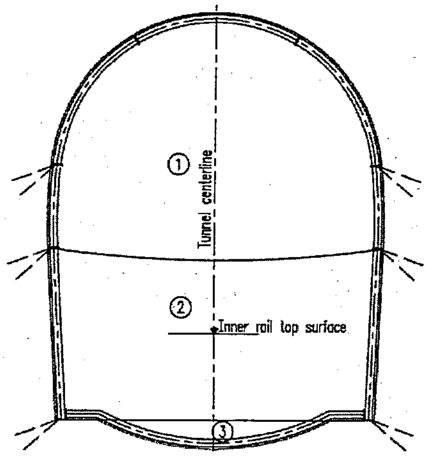
A Typical Case of NATM

Construction Sequence



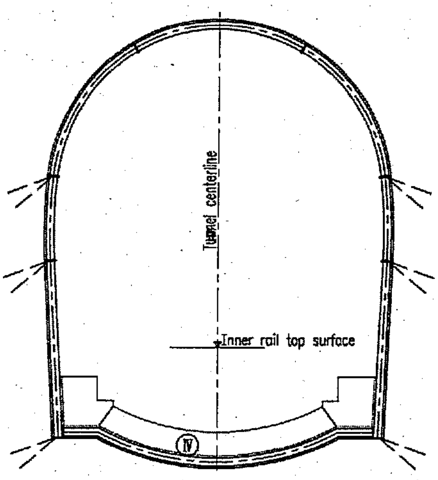
A Typical Case of NATM

Construction Sequence



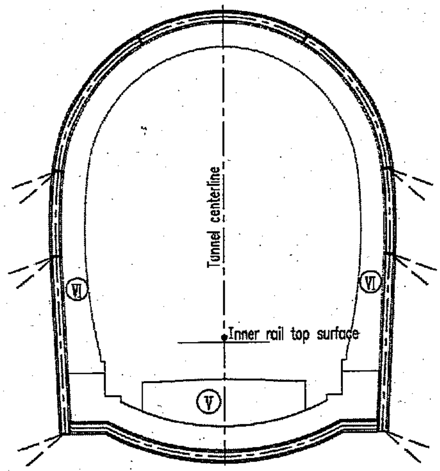
A Typical Case of NATM

Construction Sequence



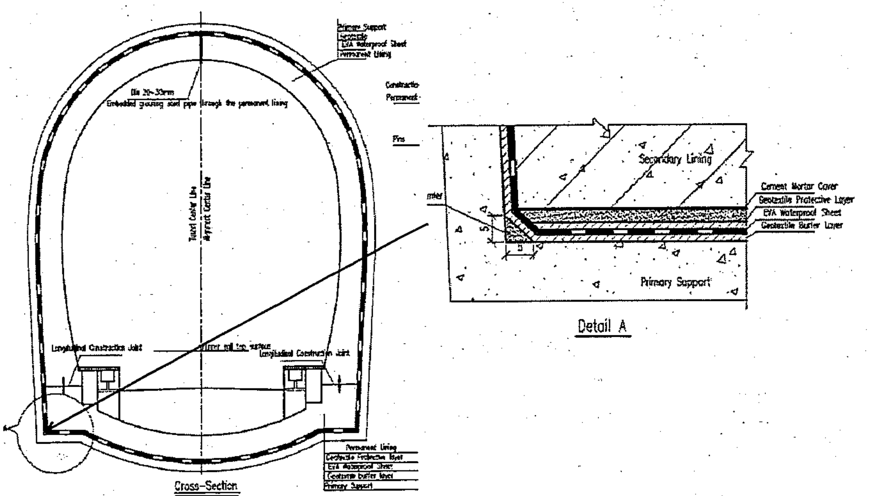
A Typical Case of NATM

Construction Sequence



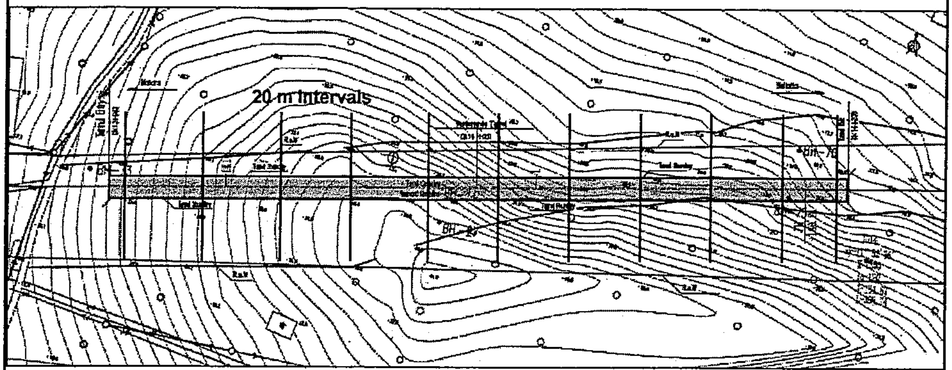
A Typical Case of NATM

Tunnel Waterproofing



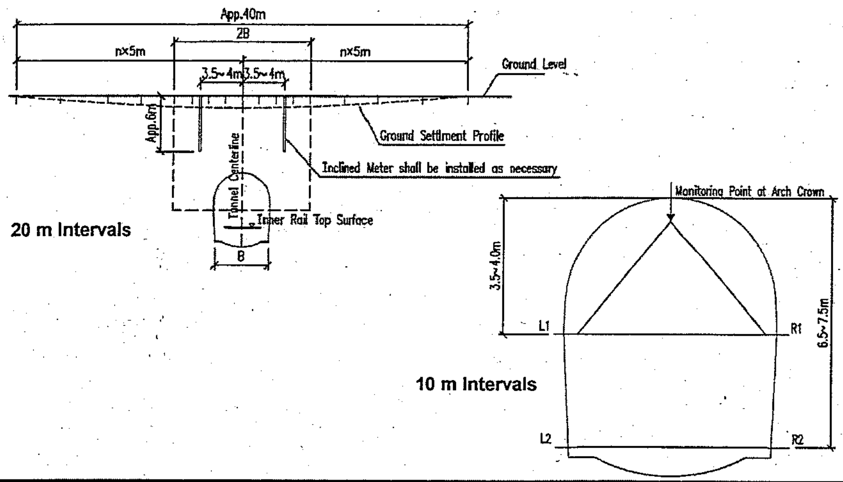
A Typical Case of NATM

Tunnel Monitoring



A Typical Case of NATM

Tunnel Monitoring



Concluding Remarks

- In land scarce, highly urbanized areas generally tunnelling is resorted as a means for infrastructure development.
- In the context of railway infrastructure development, grade requirements might lead to the adoption of tunnelling in mountainous terrains.
- A wide range of tunnelling methods although available, the choice of the tunnelling method and accordingly the tunnel design and construction depends on ground conditions, tunnel size/geometry, length, project duration etc.

Thank You

Tensar

Annual Conference of Sri Lanka Geotechnical Society

Application of Geosynthetics in Railway Projects

Presented by
Richard Ong
Area Manager - Asia

RAIL

Application of Geosynthetics in Railway Projects

Tensar

- OUTLINE:
- Introduction
- Cellular Foundation Mattress for Railway Embankment
  - Background on cellular foundation mattress
  - Case study of Senkvice embankment in Slovakia
- Reinforced Soil Structure for Railway Projects
  - Background on reinforced soil structure
  - Case study of KKRP slope repair in Malaysia
- Mechanical Stabilisation for Railway Projects
  - Background on ballast & sub-ballast stabilisation
  - Case study of Dingo-Wallaroo project in Australia
- Closing Remarks

Application of Geosynthetics in Railway Projects

Tensar

- Cellular Foundation Mattress System

Application of Geosynthetics in Railway Projects

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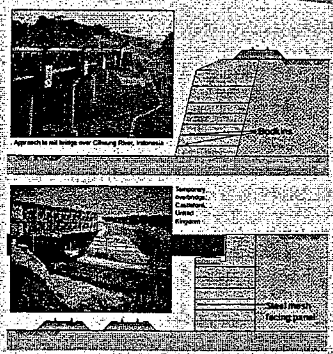
- Reinforced soil structures (RSS):
  - RS Slope
  - RS Wall



Application of Geosynthetics in Railway Projects

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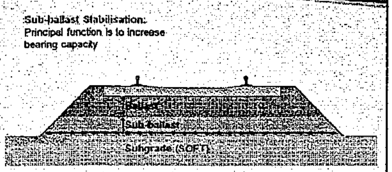
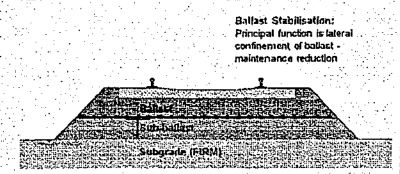
- Ground Stabilisation:
  - Sub-ballast Stabilisation
  - Ballast Stabilisation





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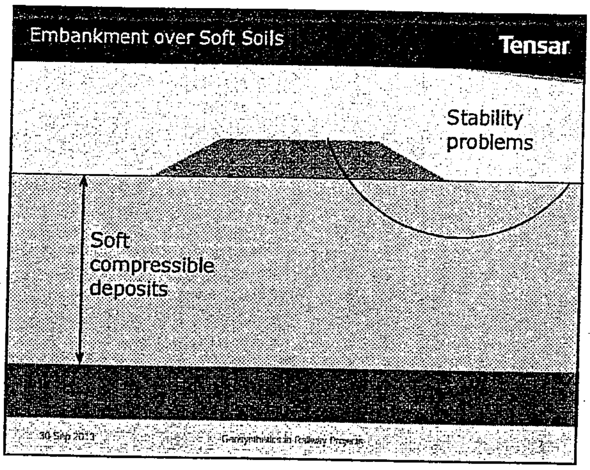
Cellular Foundation Mattress

RAIL


Embankment over Soft Soils
Tensar
Stability problems
Soft compressible deposits
30 Sep 2013
Geosynthetics in Railway Projects
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Embankment over Soft Soils
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Embankment failure
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Embankment over Soft Soils
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Embankment failure
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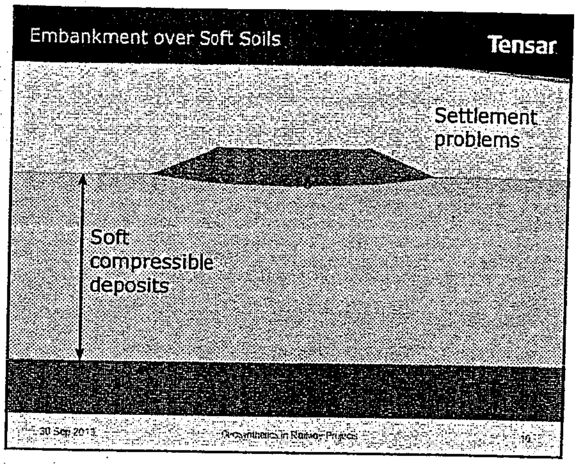
Embankment over Soft Soils
Tensar
Settlement problems
Soft compressible deposits
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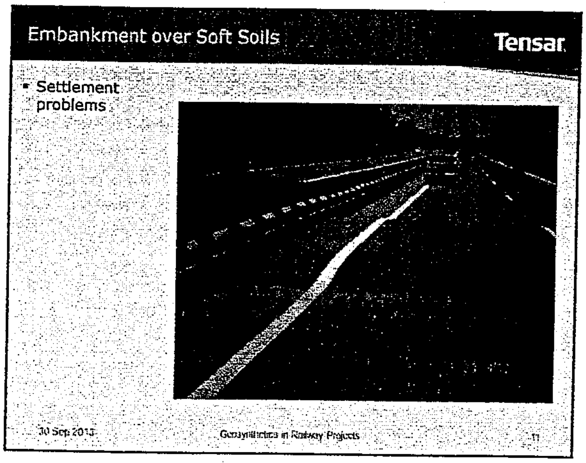
Embankment over Soft Soils
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Settlement problems
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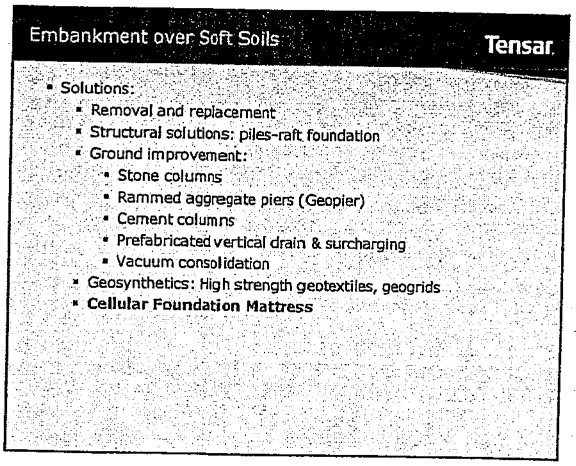
Embankment over Soft Soils
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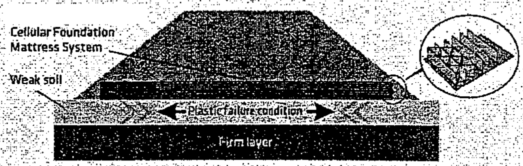
Solutions:
Removal and replacement
Structural solutions: piles-raft foundation
Ground improvement:
Stone columns
Rammed aggregate piers (Geopier)
Cement columns
Prefabricated vertical drain & surcharging
Vacuum consolidation
Geosynthetics: High strength geotextiles, geogrids
Cellular Foundation Mattress

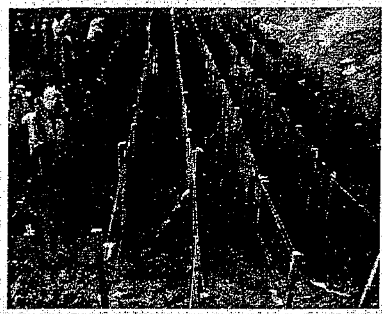
Cellular Foundation Mattress — Tensar

Cellular Foundation Mattress or Geocell Mattress is a basal mattress where a 3D honeycombed structure is formed via a series of interlocking cells.



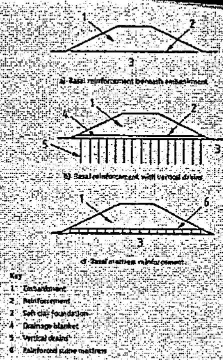
Cellular Foundation Mattress — Tensar

- Cellular foundation mattress for a road embankment in Thailand



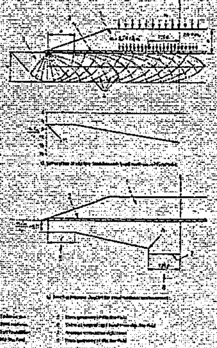
Cellular Foundation Mattress — Tensar

- BS 8006-1:2010 includes the cellular foundation mattress (basal mattress) as a technique for building embankments over soft and very soft foundation soils.
- Section 8.3.2.9 describes the cellular foundation mattress as a 3-D honeycombed structure formed from a series of interlocking cells, typically 1 m high and filled with granular fill.



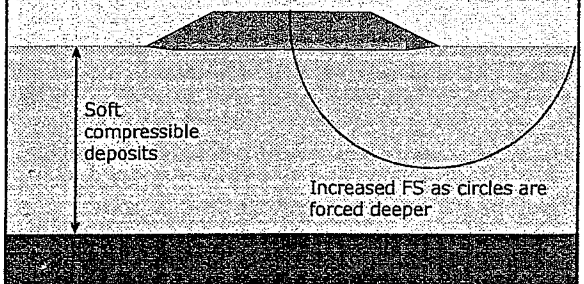
Cellular Foundation Mattress — Tensar

- Benefits of cellular foundation mattress include:
  - Creating good adhesion interface with soft soil underneath;
  - Producing a relatively stiff platform to ensure an even distribution of load and more uniform stress field within the soft foundation.
- These properties enable the cellular foundation mattress to influence the deformation of the soft foundation and hence mobilize its maximum shear strength and bearing capacity.

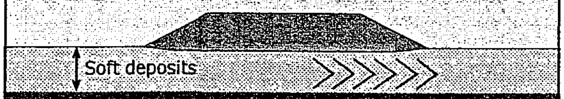


Benefits of Using Cellular Foundation Mattress — Tensar

Improved factor of safety (FS) due to cellular foundation mattress stiffness



Benefits of Using Cellular Foundation Mattress — Tensar

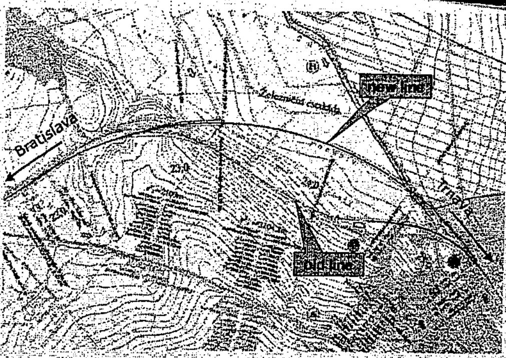


Mode of failure becomes one of lateral squeezing or extrusion, which results in significant increase in bearing capacity

Special case when soft soil deposit is relatively thin compared to width of embankment

Case Study: Senkvice Embankment, Slovakia

Tensar



Geological Conditions

Tensar

- **Quaternary (upper part)** – loam, clay, sandy clays, clay with ogranic matter , konsistency stiff to slurry, middle and high plasticity
- **Neogene** – calcareus and sandy clays, high plasticity clays with layers of sand
- Water table: 0.5 to 1.5m under terrain

Requirements of Slovak Railways

Tensar

- Minimize a total settlement and differential settlement in cross direction
- Solve transient zone between embankment and bridge
- After finishing a viaduct the transportation will start without any limitations

Foundation Systems Considered

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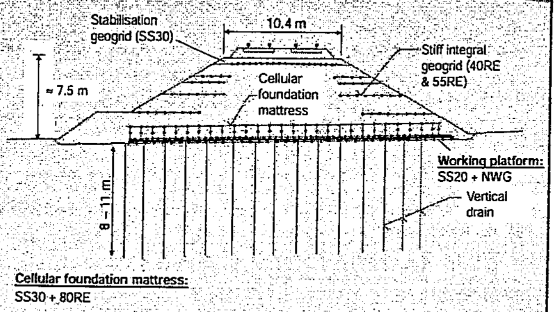
- Excavation and re-filling with suitable material
- Excavation and re-filling + horizontal reinforcement
- Vibro stone column with geosynthetic sleeve + horizontal reinforcement
- Piles + head concrete deck + horizontal reinforcement
- Deep stabilisation with lime
- Dynamic stabilisation
- **Cellular mattress foundation + vertical drain**

Typical Cross-Section of Embankment

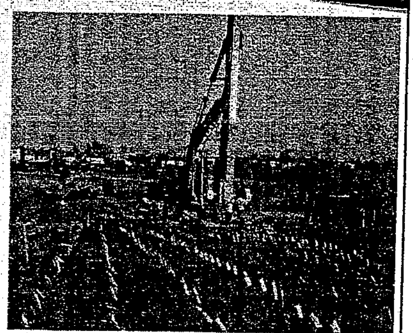
Tensar



Site Photos

Tensar

- PVD installation



Site Photos

Tensar

- Arial view of cellular foundation mattress construction

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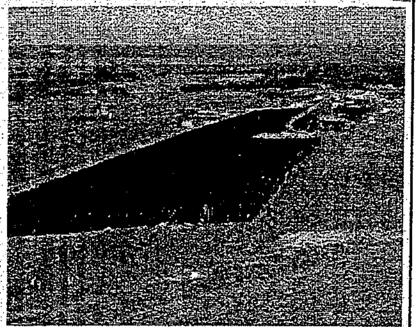
Site Photos

Tensar

- Arial view of cellular foundation mattress construction



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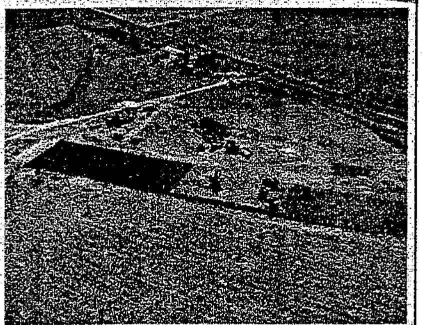
Site Photos

Tensar

- Arial view of cellular foundation mattress construction



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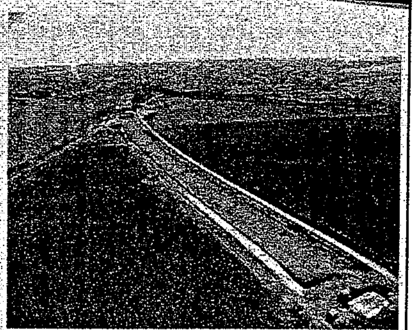
Site Photos

Tensar

- Arial view of cellular foundation mattress construction



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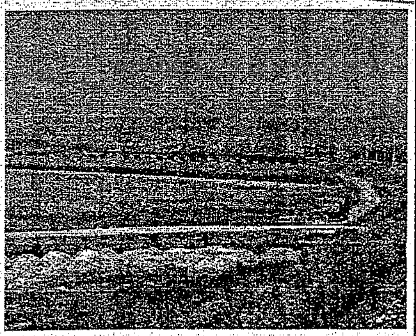
Site Photos

Tensar

- Completed embankment



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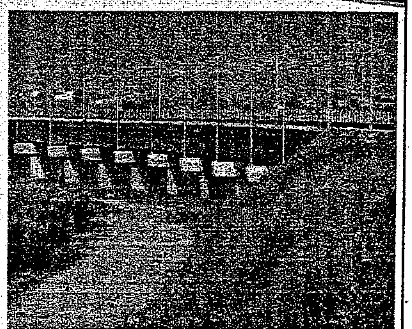
Site Photos

Tensar

- Completed embankment



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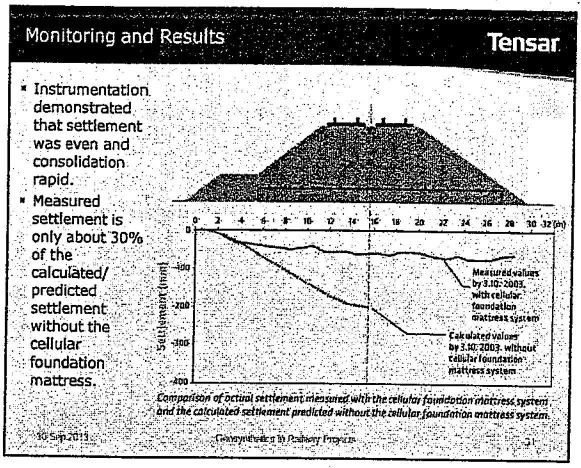
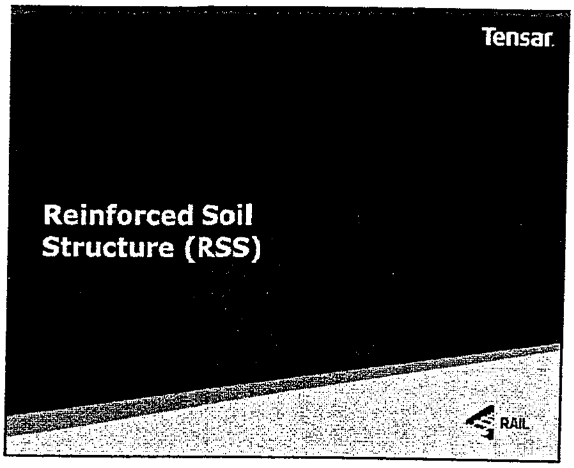
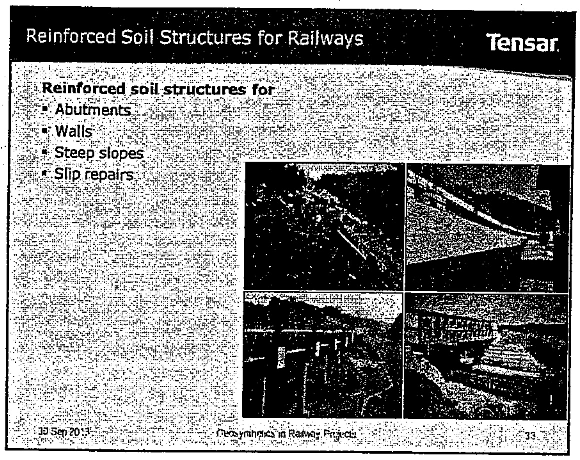
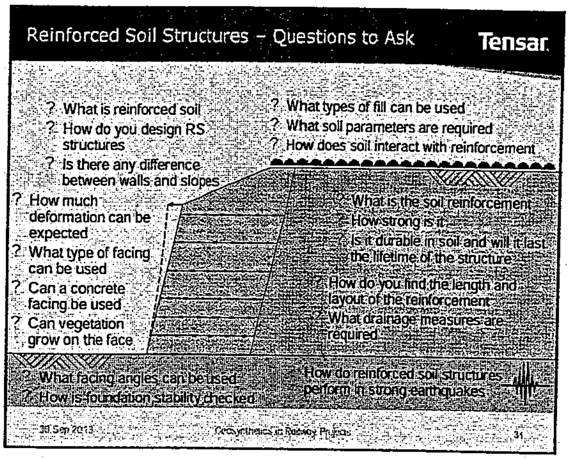

Monitoring and Results
Tensar
Instrumentation demonstrated that settlement was even and consolidation rapid.
Measured settlement is only about 30% of the calculated/ predicted settlement without the cellular foundation mattress.
Settlement (mm)
Measured values by 3.10.2003, with cellular foundation mattress system
Calculated values by 3.10.2003, without cellular foundation mattress system
Comparison of actual settlement measured with the cellular foundation mattress system and the calculated settlement predicted without the cellular foundation mattress system.


Tensar
Reinforced Soil Structure (RSS)
RAIL


Reinforced Soil Structures for Railways
Tensar
Reinforced soil structures for
Abutments
Walls
Steep slopes
Slip repairs


Reinforced Soil Structures – Questions to Ask
Tensar
? What is reinforced soil
? How do you design RS structures
? Is there any difference between walls and slopes
? What types of fill can be used
? What soil parameters are required
? How does soil interact with reinforcement
? How much deformation can be expected
? What type of facing can be used
? Can a concrete facing be used
? Can vegetation grow on the face
? What is the soil reinforcement
? How strong is it
? Is it durable in soil and will it last the lifetime of the structure
? How do you find the length and layout of the reinforcement
? What drainage measures are required
? What facing angles can be used
? How is foundation stability checked
? How do reinforced soil structures perform in strong earthquakes
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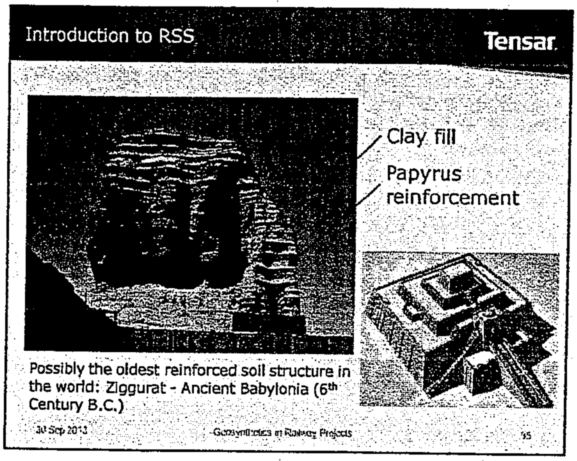
31


Introduction to RSS
Tensar
Clay fill
Papyrus reinforcement
Possibly the oldest reinforced soil structure in the world: Ziggurat - Ancient Babylonia (6th Century B.C.)
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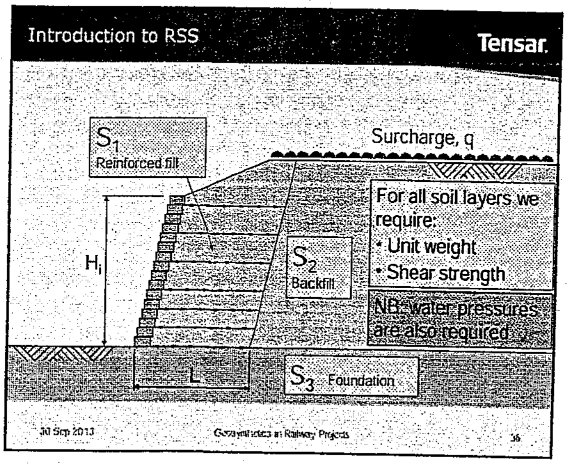
35


Introduction to RSS
Tensar
S1
Reinforced fill
Surcharge, q
For all soil layers we require:
• Unit weight
• Shear strength
NB: water pressures are also required
H
S2
Backfill
L
S3 Foundation
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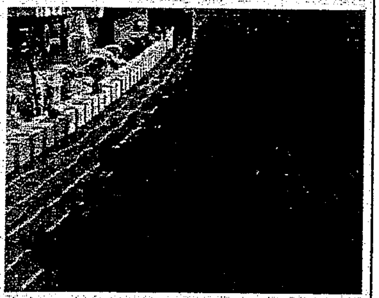
Design Parameters for Soil

Tensar

A wide variety fills types may be used

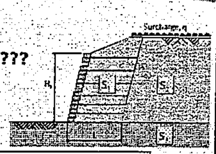
- Reinforced soil structures are 99.9% soil
- A wide variety of fill soil types may be used with HDPE uniaxial geogrids
- but, it is important that properties of soil are well understood



Design Parameters for Soil

Tensar

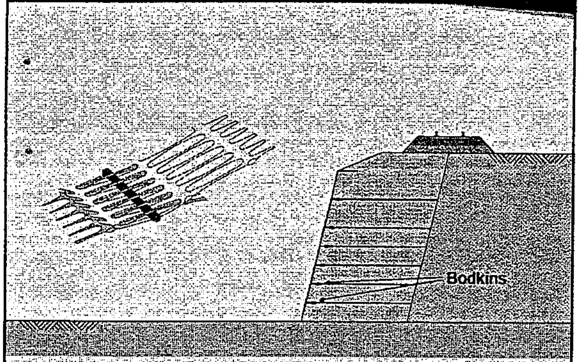
Soil properties for design: drained or undrained shear strength???



Soil zone	Source	Soil strength parameters	
		Drained	Undrained
S_1	Fill	All soil types	Never
S_2	Fill (but can be natural)	All soil types	Never
S_3	Natural (but can be fill)	Granular (sands, gravels)	Cohesive (clays)

RSS – Steep Slope

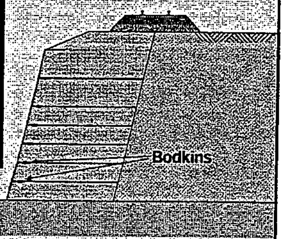
Tensar



RSS – Steep Slope

Tensar

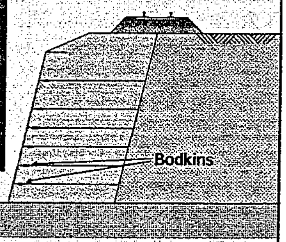
Approach to rail bridge over Ciliwung River, Indonesia



RSS – Steep Slope

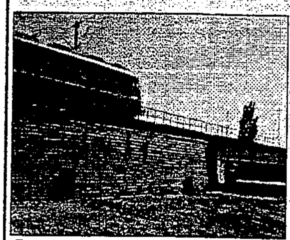
Tensar

Approach to rail bridge over Ciliwung River, Indonesia

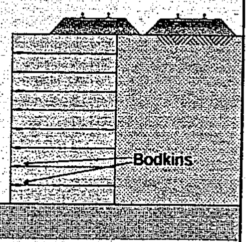


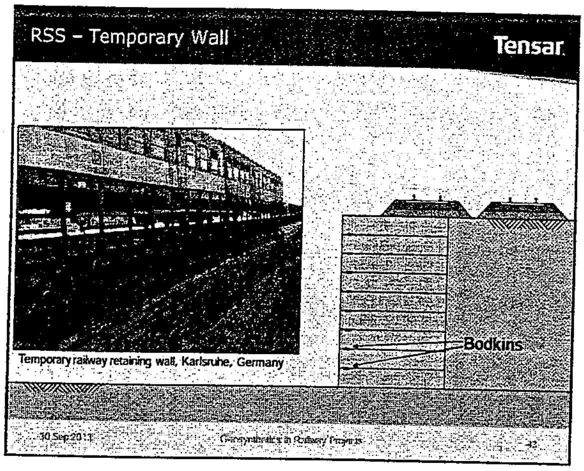
RSS – Temporary Wall

Tensar



Temporary railway retaining wall, Karlsruhe, Germany




RSS – Temporary Wall
Tensar
Temporary railway retaining wall, Karlsruhe, Germany
Bodkins
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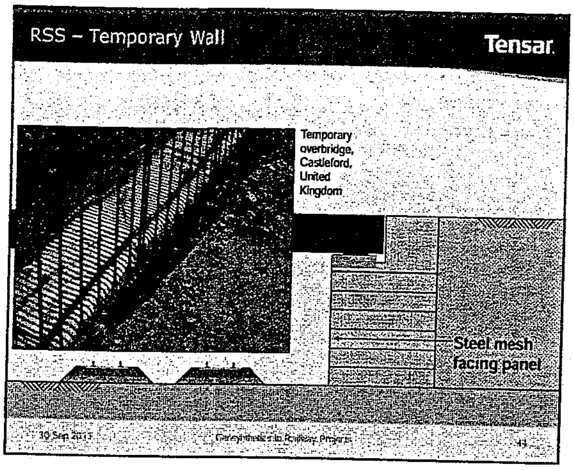
RSS – Temporary Wall
Tensar
Temporary overbridge, Castleford, United Kingdom
Steel mesh facing panel
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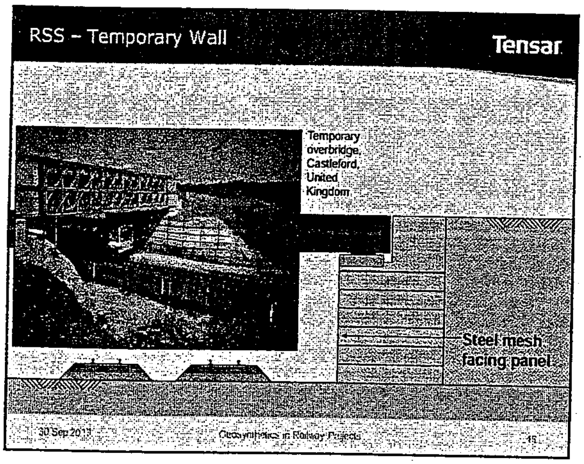
RSS – Temporary Wall
Tensar
Temporary overbridge, Castleford, United Kingdom
Steel mesh facing panel
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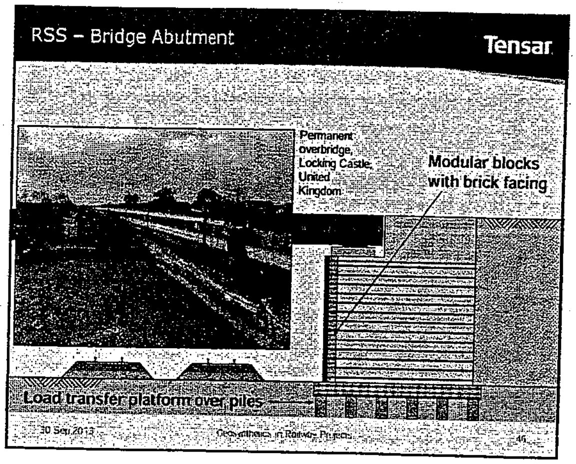
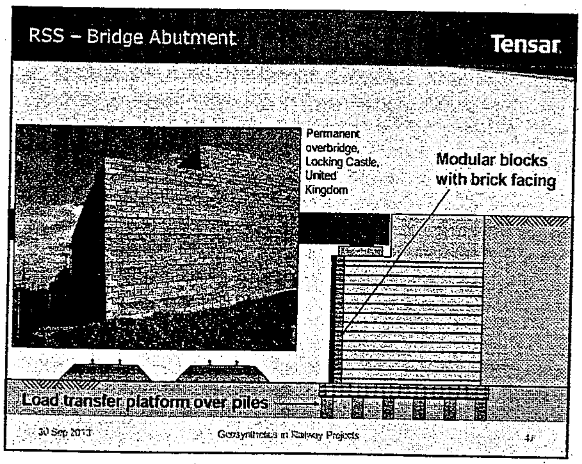
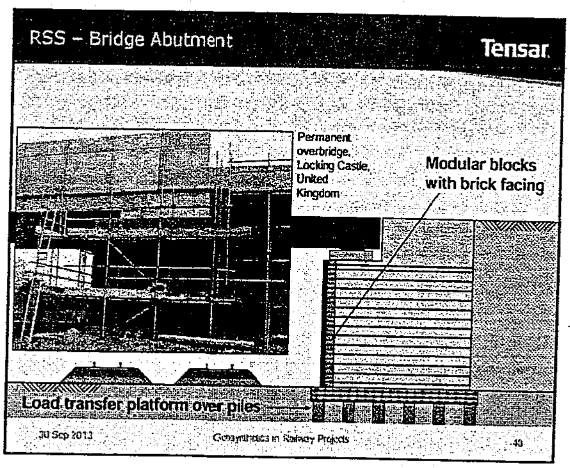
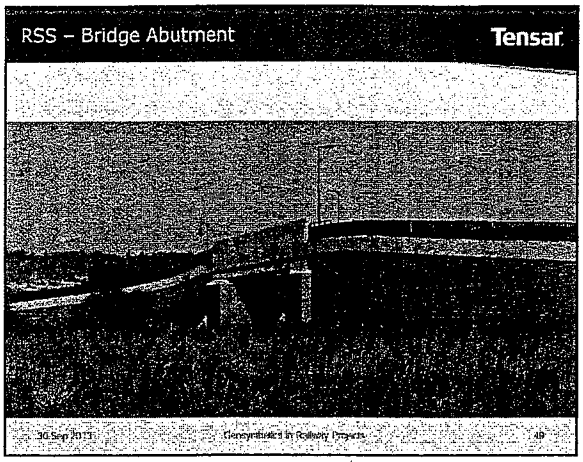
Geosynthetics in Railway Projects


RSS – Bridge Abutment
Tensar
Permanent overbridge, Locking Castle, United Kingdom
Modular blocks with brick facing
Load transfer platform over piles
30 Sep 2013
Geosynthetics in Railway Projects


RSS – Bridge Abutment
Tensar
Permanent overbridge, Locking Castle, United Kingdom
Modular blocks with brick facing
Load transfer platform over piles
30 Sep 2013
Geosynthetics in Railway Projects


RSS – Bridge Abutment
Tensar
Permanent overbridge, Locking Castle, United Kingdom
Modular blocks with brick facing
Load transfer platform over piles
30 Sep 2013
Geosynthetics in Railway Projects


RSS – Bridge Abutment
Tensar
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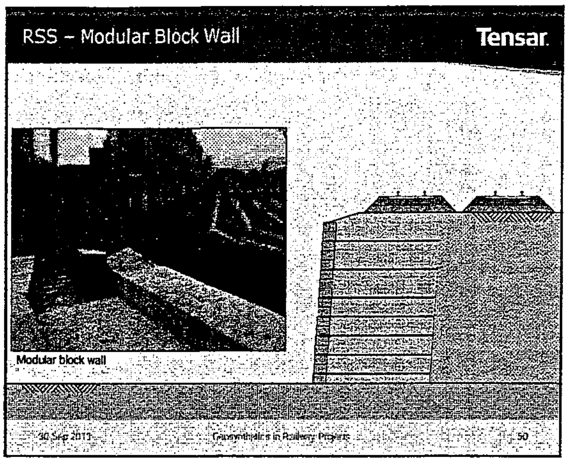
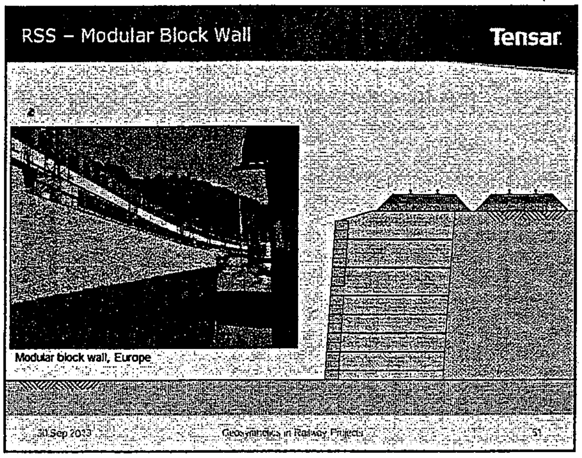
Geosynthetics in Railway Projects
49


RSS – Modular Block Wall
Tensar
Modular block wall
30 Sep 2013
Geosynthetics in Railway Projects
50


RSS – Modular Block Wall
Tensar
Modular block wall, Europe
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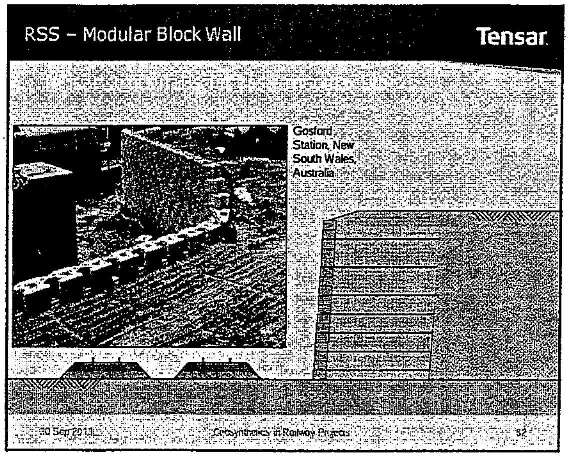
51


RSS – Modular Block Wall
Tensar
Gosford Station, New South Wales, Australia
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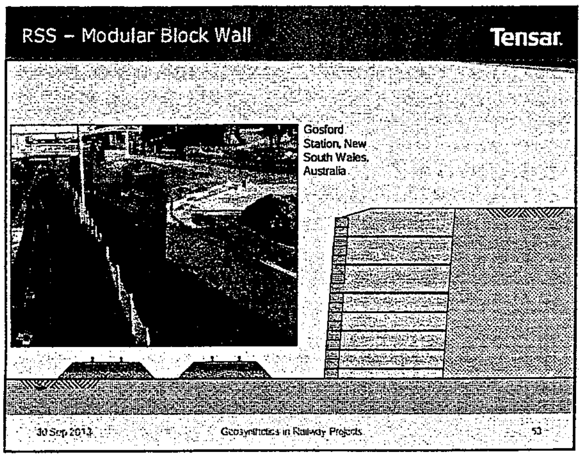
52


RSS – Modular Block Wall
Tensar
Gosford Station, New South Wales, Australia
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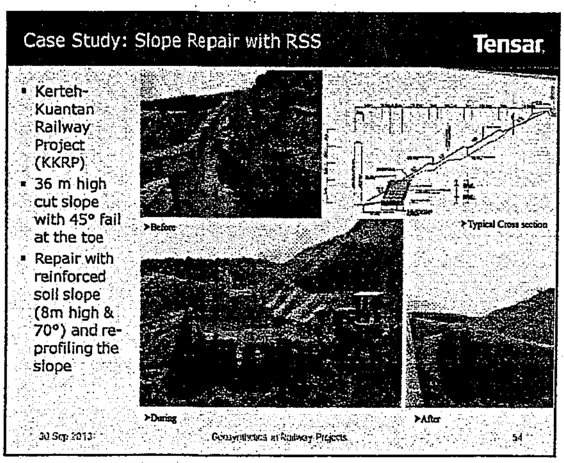
Geosynthetics in Railway Projects
53


Case Study: Slope Repair with RSS
Tensar
▪ Kerteh-Kuantan Railway Project (KKRP)
▪ 36 m high cut slope with 45° fail at the toe
▪ Repair with reinforced soil slope (8m high & 70°) and re-profiling the slope
➢Before
➢Typical Cross section
➢During
➢After
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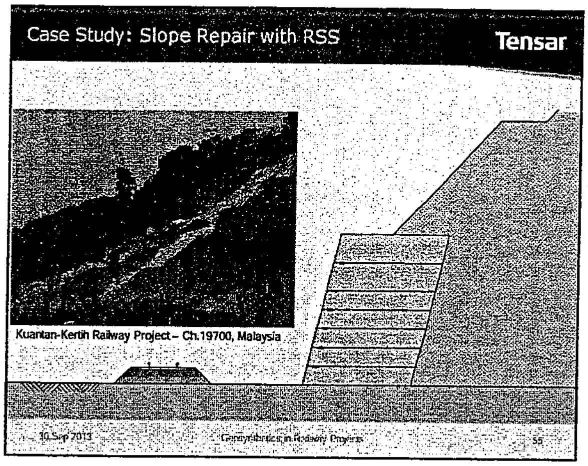
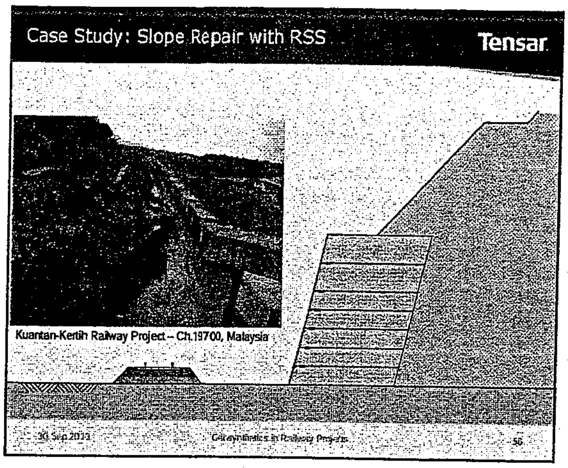
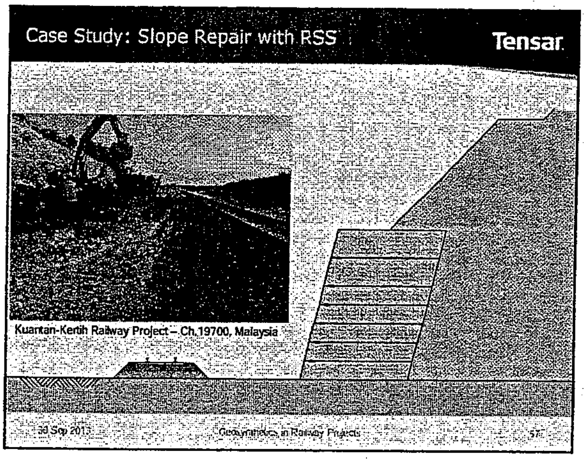
Geosynthetics in Railway Projects
54


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
Geosynthetics in Railway Projects


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
30 Sep 2013
Geosynthetics in Railway Projects


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
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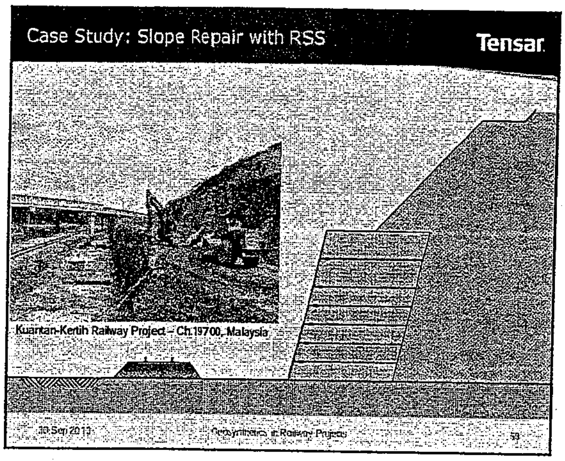
Geosynthetics in Railway Projects


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
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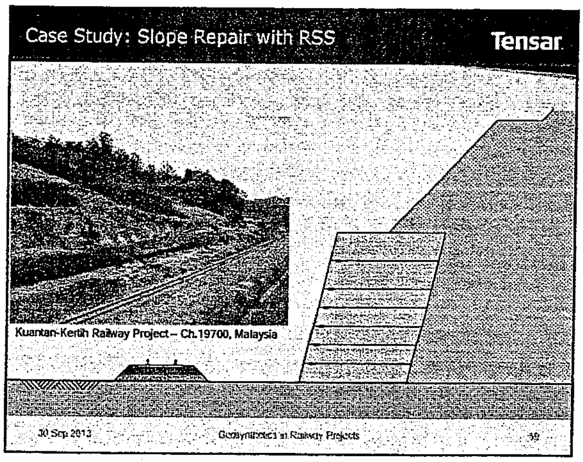
Geosynthetics in Railway Projects


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
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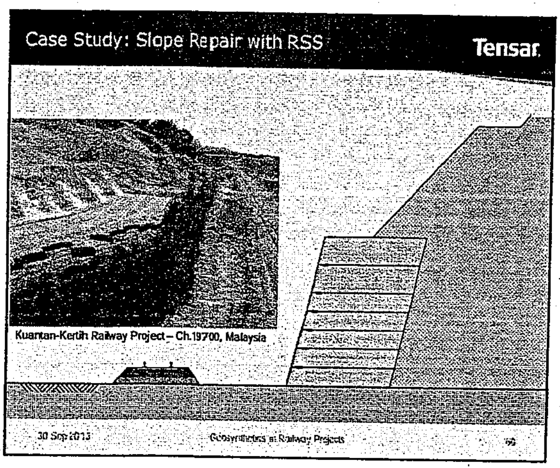
Geosynthetics in Railway Projects


Case Study: Slope Repair with RSS
Tensar
Kuantan-Kertih Railway Project – Ch.19700, Malaysia
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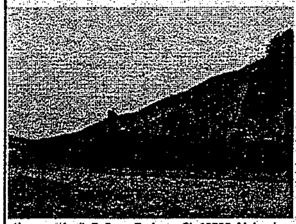
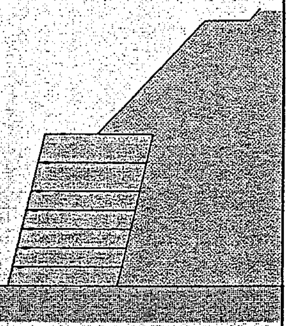
Case Study: Slope Repair with RSS

Tensar



Kuantan-Kertih Railway Project – Ch.19700, Malaysia



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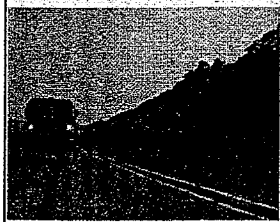
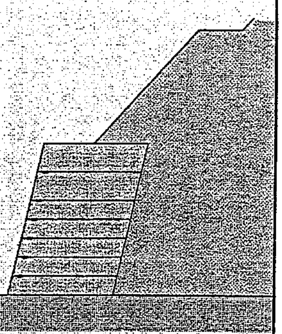
Case Study: Slope Repair with RSS

Tensar



Kuantan-Kertih Railway Project – Ch.19700, Malaysia



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Tensar

Mechanical Stabilisation of Track Ballast & Sub-ballast

RAIL

Key Problems for Railways over Weak Soils

Tensar

- Construction of new railway on weak soil
- Upgrading existing line on weak soil
- Frequent maintenance of ballast layers

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Other Potential Problems

Tensar

- Difficult access to the site
- Difficulty in compaction of construction layers
- Large volume of soil materials to be excavated and exported and/or imported while using standard solutions
- Time pressure
- Cost

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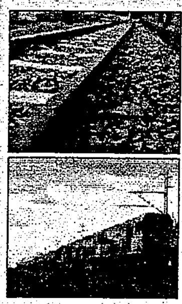
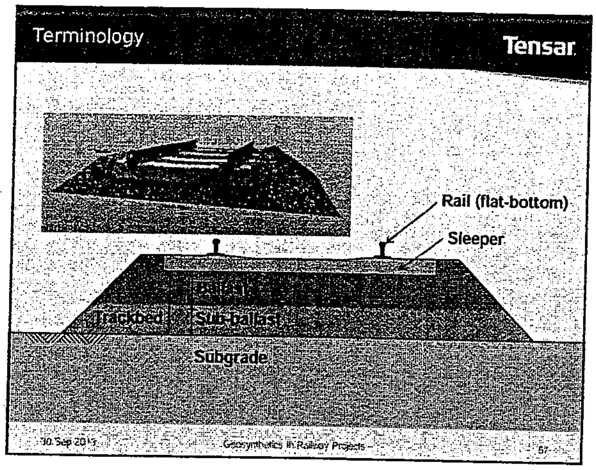
Mechanical Stabilisation Solutions

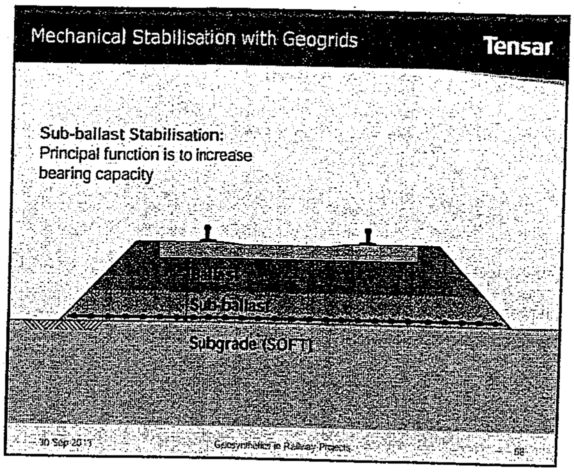
Tensar

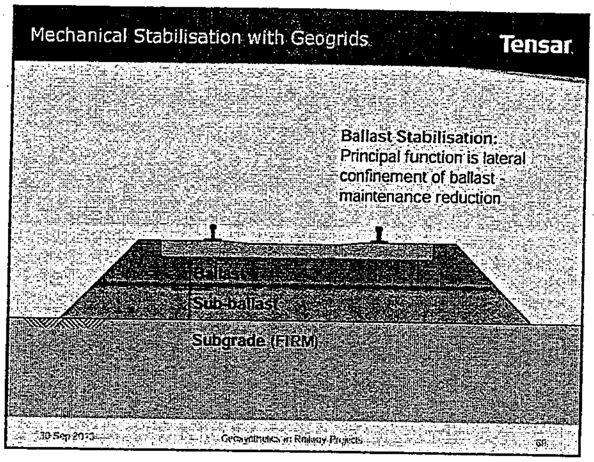
Stiff geogrids can be used to stabilise track ballast & sub-ballast to achieve:

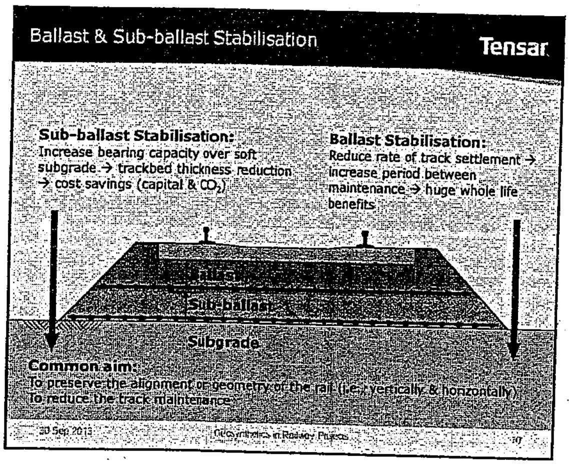
- Interlocking mechanism
- Improved performance – reduce rate of ballast settlement & maintain track geometry for longer
- Reduced trackbed thickness
- Longer interval between reballasting – extend maintenance cycle by a factor of about 3 & reduce traffic-induced ballast degradation

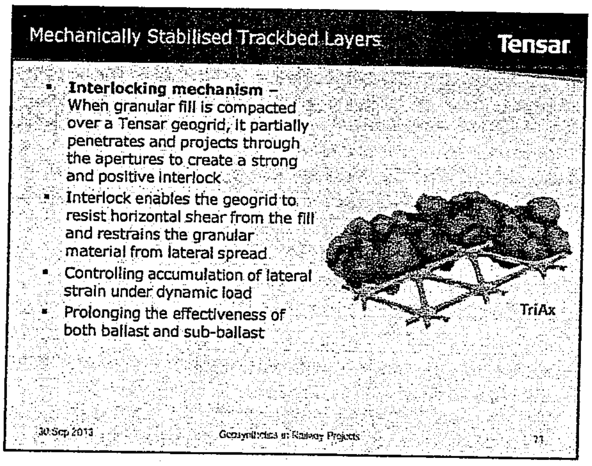


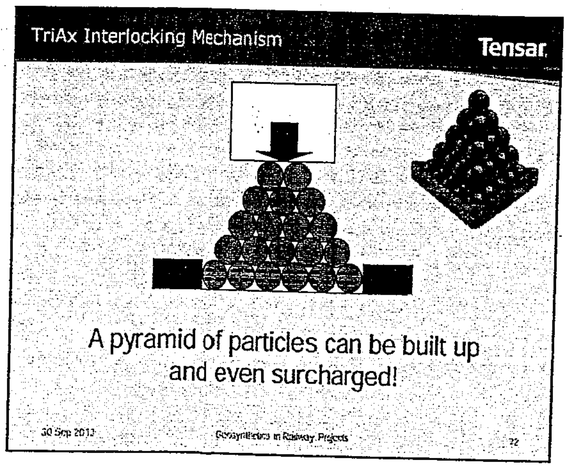

Terminology
Tensar
Rail (flat-bottom)
Sleeper
Ballast
Trackbed
Sub-ballast
Subgrade

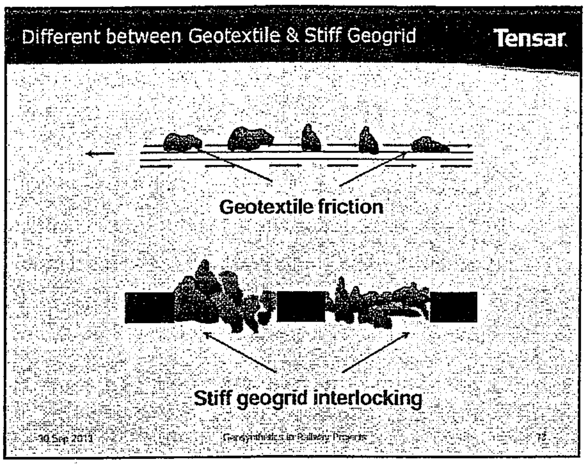

Mechanical Stabilisation with Geogrids
Tensar
Sub-ballast Stabilisation:
Principal function is to increase bearing capacity
Ballast
Sub-ballast
Subgrade (SOFT)


Mechanical Stabilisation with Geogrids
Tensar
Ballast Stabilisation:
Principal function is lateral confinement of ballast - maintenance reduction
Ballast
Sub-ballast
Subgrade (FIRM)


Ballast & Sub-ballast Stabilisation
Tensar
Sub-ballast Stabilisation:
Increase bearing capacity over soft subgrade → trackbed thickness reduction → cost savings (capital & CO_2)
Ballast Stabilisation:
Reduce rate of track settlement → increase period between maintenance → huge whole life benefits
Ballast
Sub-ballast
Subgrade
Common aim:
To preserve the alignment or geometry of the rail (i.e. vertically & horizontally)
To reduce the track maintenance


Mechanically Stabilised Trackbed Layers
Tensar
Interlocking mechanism – When granular fill is compacted over a Tensar geogrid, it partially penetrates and projects through the apertures to create a strong and positive interlock
Interlock enables the geogrid to resist horizontal shear from the fill and restrains the granular material from lateral spread
Controlling accumulation of lateral strain under dynamic load
Prolonging the effectiveness of both ballast and sub-ballast
TriAx


TriAx Interlocking Mechanism
Tensar
A pyramid of particles can be built up and even surcharged!


Different between Geotextile & Stiff Geogrid
Tensar
Geotextile friction
Stiff geogrid interlocking
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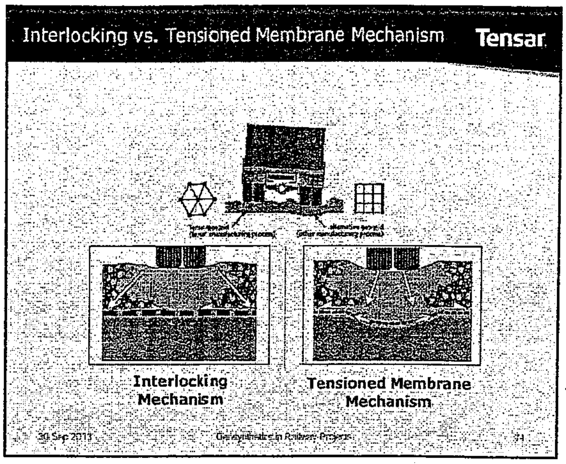
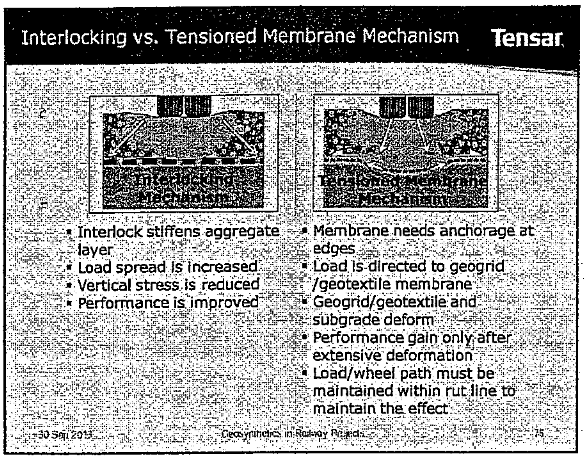

Interlocking vs. Tensioned Membrane Mechanism
Tensar
Interlocking Mechanism
Tensioned Membrane Mechanism
30 Sep 2013
Geosynthetics in Railway Projects


Interlocking vs. Tensioned Membrane Mechanism
Tensar
Interlocking Mechanism
Tensioned Membrane Mechanism
Interlock stiffens aggregate layer
Load spread is increased
Vertical stress is reduced
Performance is improved
Membrane needs anchorage at edges
Load is directed to geogrid /geotextile membrane
Geogrid/geotextile and subgrade deform
Performance gain only after extensive deformation
Load/wheel path must be maintained within rut line to maintain the effect
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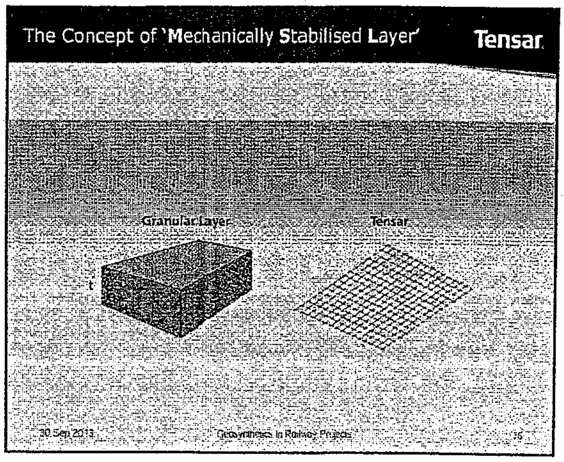
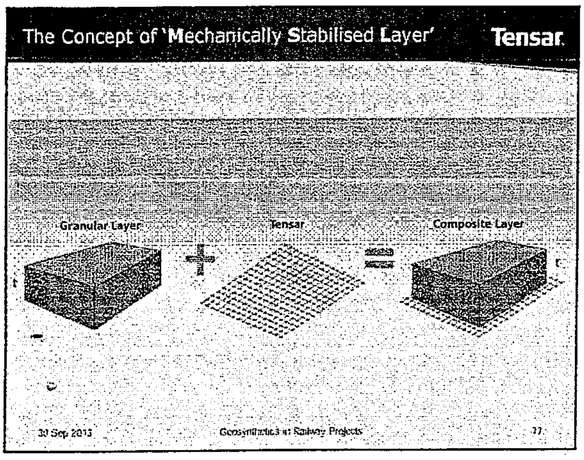
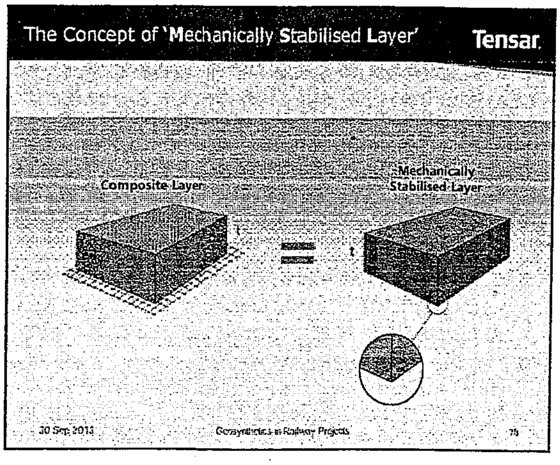

The Concept of 'Mechanically Stabilised Layer'
Tensar
Granular Layer
Tensar
t
30 Sep 2013
Geosynthetics in Railway Projects


The Concept of 'Mechanically Stabilised Layer'
Tensar
Granular Layer
Tensar
Composite Layer
t
30 Sep 2013
Geosynthetics in Railway Projects


The Concept of 'Mechanically Stabilised Layer'
Tensar
Composite Layer
Mechanically Stabilised Layer
t
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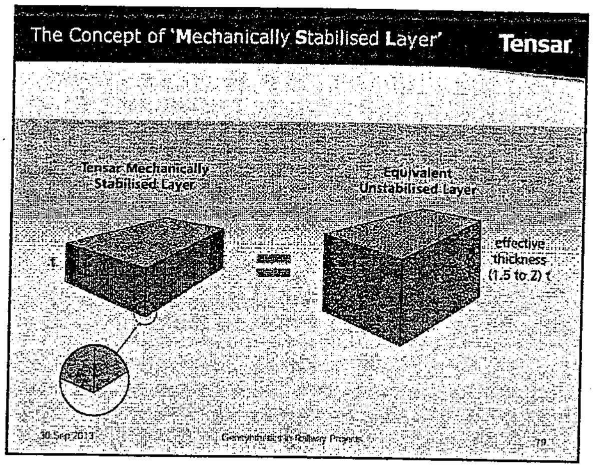

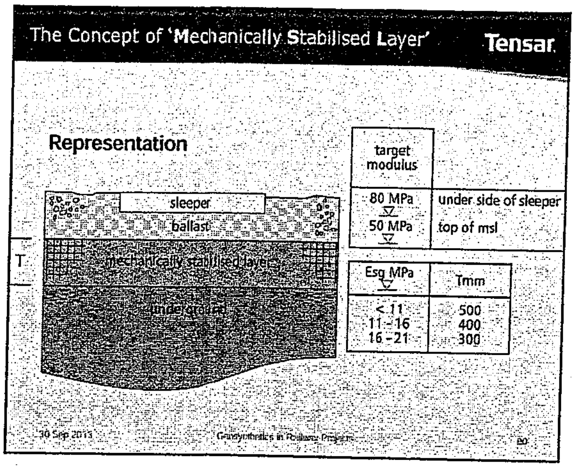

Mechanically Stabilised Trackbed Layers

Tensar

The performance of geogrids in granular layers has been researched extensively for more than 30 years.

- Substantially for use in highway pavements, but also railway trackbed – ballast and sub-ballast
- Testing includes
  - Static load tests
  - Cyclic load tests
  - Trafficking trials
  - Site demonstrations

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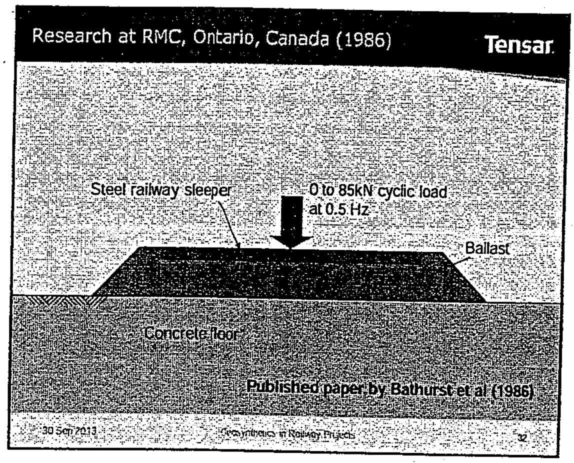

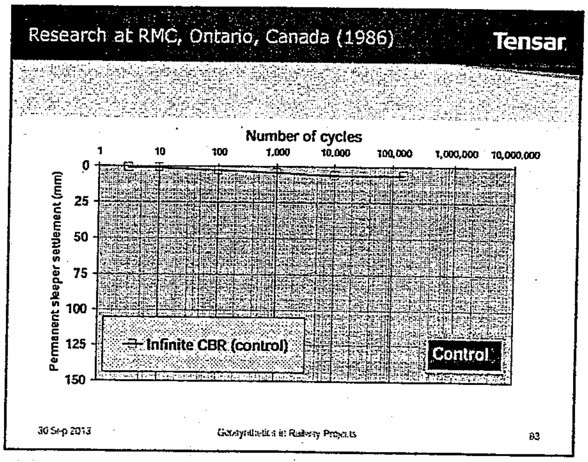

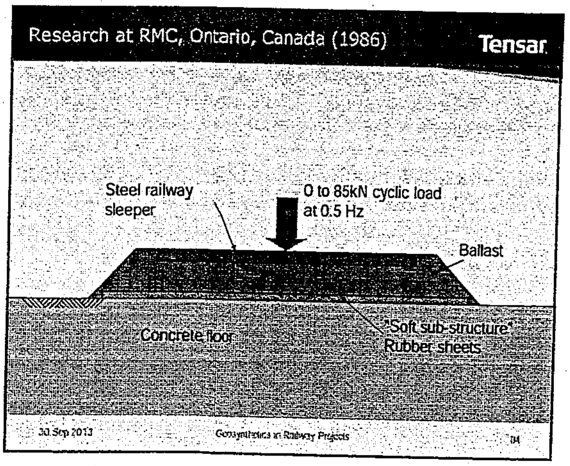

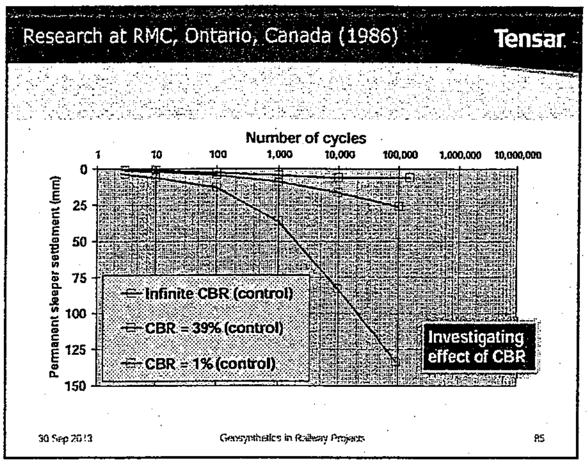
Research at RMC, Ontario, Canada (1986)
Tensar
Number of cycles
Permanent sleeper settlement (mm)
Infinite CBR (control)
CBR = 39% (control)
CBR = 1% (control)
Investigating effect of CBR
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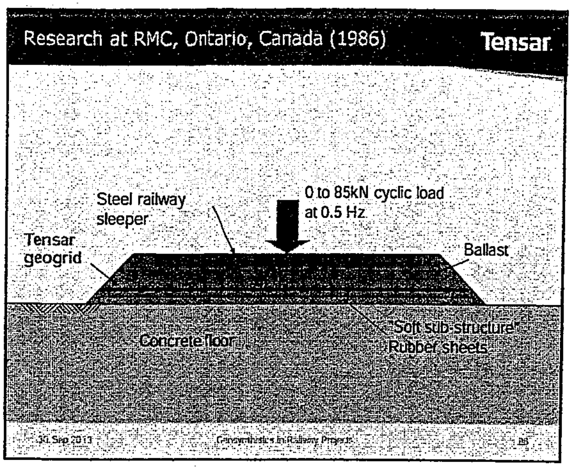
Research at RMC, Ontario, Canada (1986)
Tensar
Steel railway sleeper
0 to 85kN cyclic load at 0.5 Hz
Tensar geogrid
Ballast
Concrete floor
Soft sub-structure Rubber sheets
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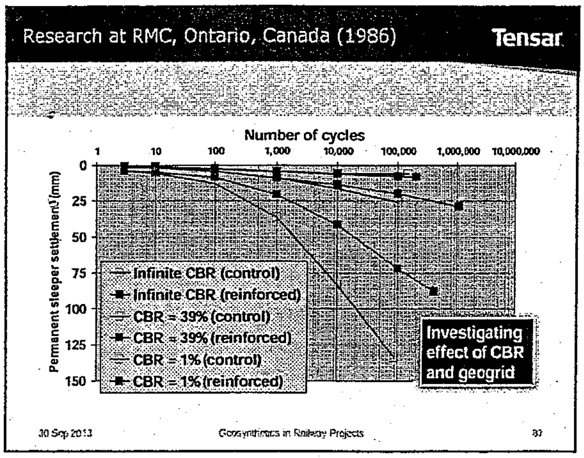
Research at RMC, Ontario, Canada (1986)
Tensar
Number of cycles
Permanent sleeper settlement (mm)
Infinite CBR (control)
Infinite CBR (reinforced)
CBR = 39% (control)
CBR = 39% (reinforced)
CBR = 1% (control)
CBR = 1% (reinforced)
Investigating effect of CBR and geogrid
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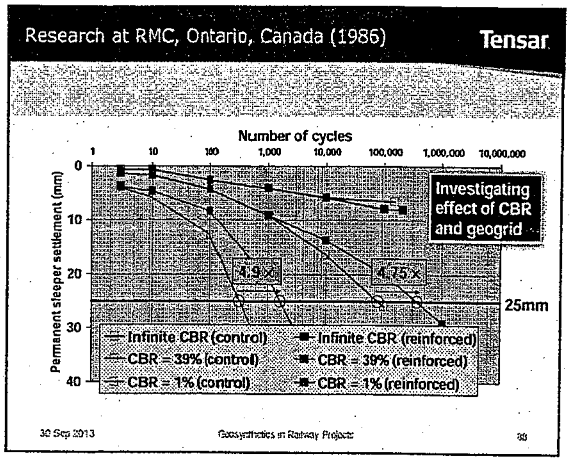
Research at RMC, Ontario, Canada (1986)
Tensar
Number of cycles
Permanent sleeper settlement (mm)
Investigating effect of CBR and geogrid
4.9 X
4.75 X
25mm
Infinite CBR (control)
Infinite CBR (reinforced)
CBR = 39% (control)
CBR = 39% (reinforced)
CBR = 1% (control)
CBR = 1% (reinforced)
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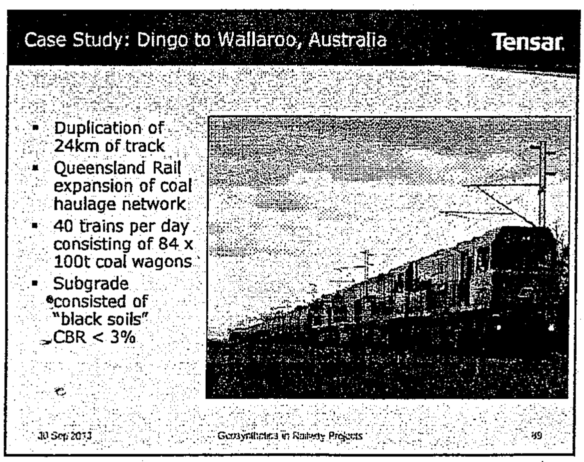
Case Study: Dingo to Wallaroo, Australia
Tensar
Duplication of 24km of track
Queensland Rail expansion of coal haulage network
40 trains per day consisting of 84 x 100t coal wagons
Subgrade consisted of "black soils" CBR < 3%
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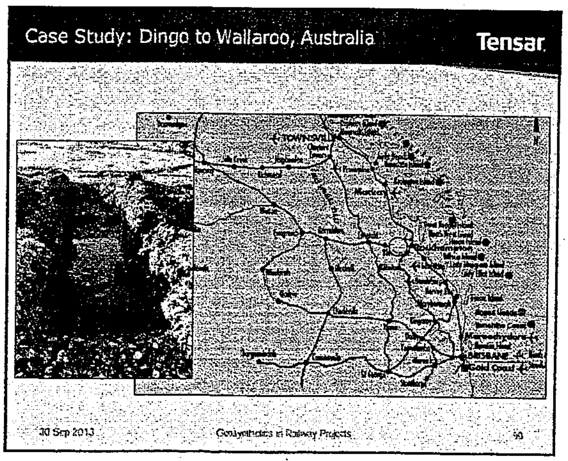
Case Study: Dingo to Wallaroo, Australia
Tensar
TOWNSVILLE
BRISBANE
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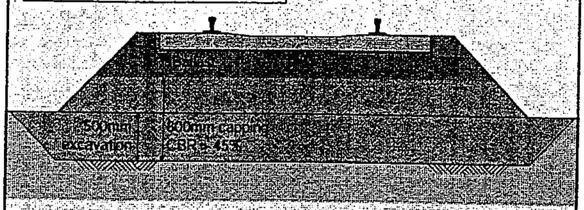
Case Study: Dingo to Wallaroo, Australia

Tensar

Original design:
500mm excavation with
800mm capping material

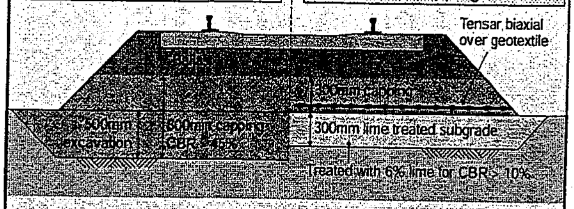


Case Study: Dingo to Wallaroo, Australia

Tensar

Original design:
500mm excavation with
800mm capping material

Final design:
300mm lime treated subgrade
with 300mm capping material



Case Study: Dingo to Wallaroo, Australia

Tensar

Benefits confirmed by the client

- Reduced the capping layer thickness by 500mm
- Avoided excavation and disposal of contaminated subgrade soils
- Reduced excavation avoided exposure of perched water lenses
- Avoided the risk of instability of the adjacent live track due to the 500mm excavation required by the original design

Above all, a cost saving of A$1.8m

Case Study: Dingo to Wallaroo, Australia

Tensar

- Lime treatment

Case Study: Dingo to Wallaroo, Australia

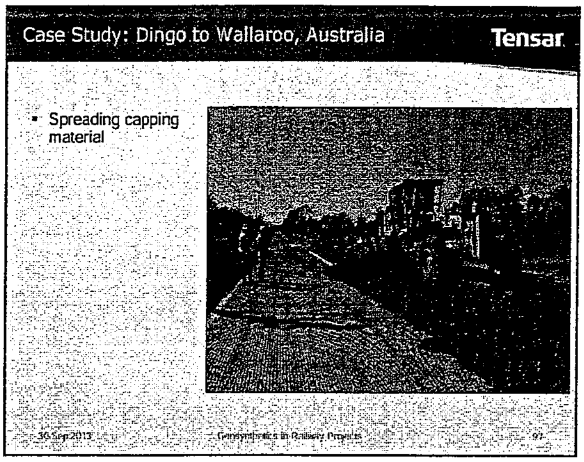
Tensar

- Unrolling geogrid over geotextile

Case Study: Dingo to Wallaroo, Australia

Tensar

- Capping material
- CBR > 45%


Case Study: Dingo to Wallaroo, Australia
Tensar
▪ Spreading capping material
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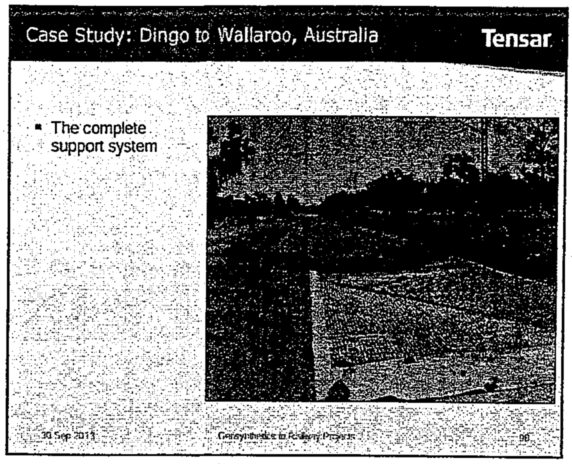
Case Study: Dingo to Wallaroo, Australia
Tensar
▪ The complete support system
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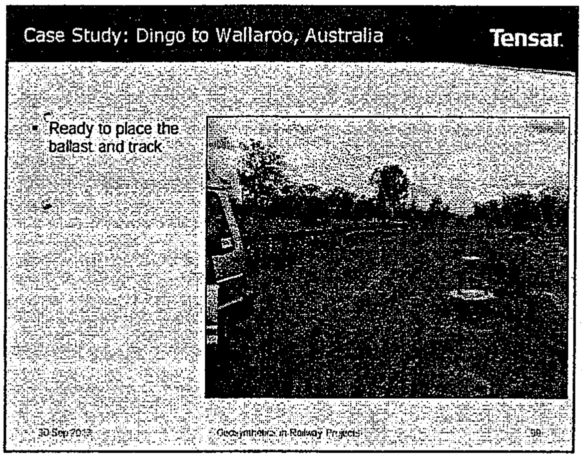
Case Study: Dingo to Wallaroo, Australia
Tensar
▪ Ready to place the ballast and track
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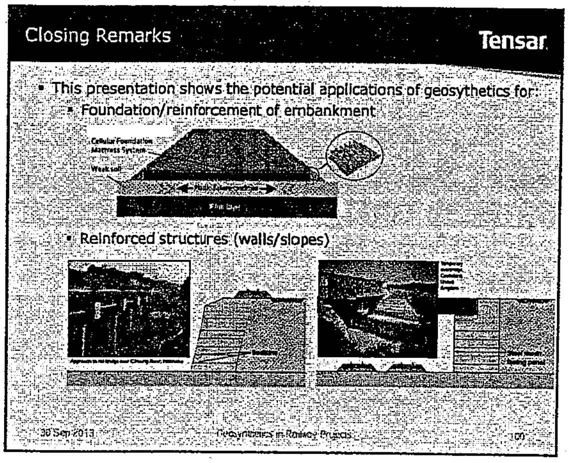
Closing Remarks
Tensar
▪ This presentation shows the potential applications of geosythetics for:
▪ Foundation/reinforcement of embankment
▪ Reinforced structures (walls/slopes)
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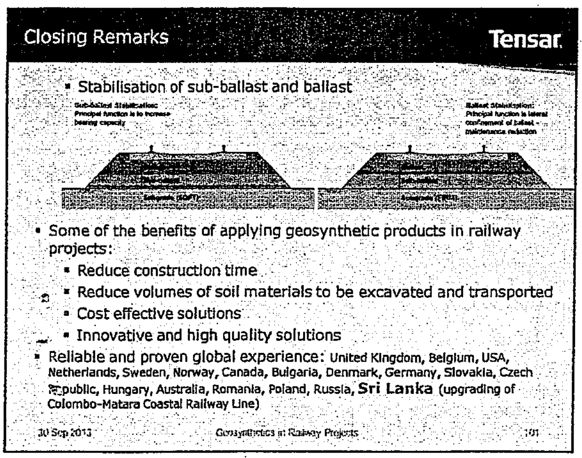
Closing Remarks
Tensar
▪ Stabilisation of sub-ballast and ballast
▪ Some of the benefits of applying geosynthetic products in railway projects:
▪ Reduce construction time
▪ Reduce volumes of soil materials to be excavated and transported
▪ Cost effective solutions
▪ Innovative and high quality solutions
▪ Reliable and proven global experience: United Kingdom, Belgium, USA, Netherlands, Sweden, Norway, Canada, Bulgaria, Denmark, Germany, Slovakia, Czech Republic, Hungary, Australia, Romania, Poland, Russia, Sri Lanka (upgrading of Colombo-Matara Coastal Railway Line)
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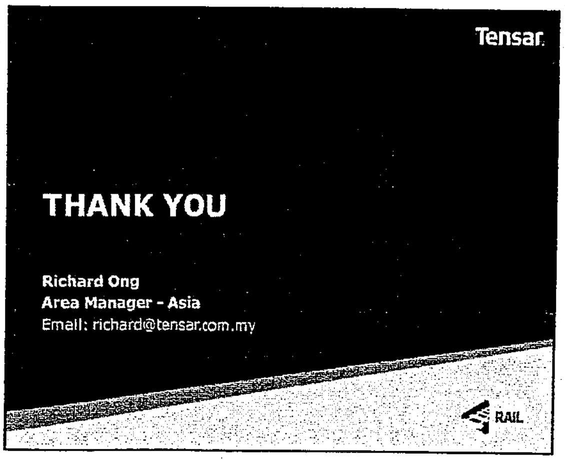
Tensar
THANK YOU
Richard Ong
Area Manager - Asia
Email: richard@tensar.com.my
RAIL