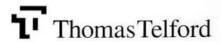
## Tunnel lining design guide



The British Tunnelling Society and The Institution of Civil Engineers







## Contents

		word nowledge	ements	X Xii	
4	Torres			1	
1		Introduction			
	1.1	Scope		1 1	
	1.2				
	1.3		structure and objectives	2 2	
		1.3.1	Chapter 2 – Project definition	2	
		1.3.2	Chapter 3 – Geotechnical characterisation	2	
		1.3.3	Chapter 4 – Design life and durability	2	
		1.3.4	Chapter 5 – Design considerations	2	
		1.3.5	Chapter 6 – Theoretical methods of analysis	3	
		1.3.6	Chapter 7 – Settlement	3	
		1.3.7	Chapter 8 – Instrumentation and monitoring	3	
		1.3.8	Chapter 9 – Quality management	3	
		1.3.9	Chapter 10 – Case histories	2 2 3 3 3 3 3 3 4	
	1.4			3	
		1.4.1	Support systems		
	1.5	Design	n process	5 7	
	1.6	Refere	References		
1920	_				
2		ject defi		8	
	2.1			8	
			Purposes	8	
			Construction	8	
			Functional requirements	8	
		2.1.4	Other factors	8	
	2.2	Opera	tional requirements	8	
		2.2.1		8	
		2.2.2	Function of the tunnel lining	9	
		2.2.3	Availability	11	
		2.2.4	Hazards	11	
	2.3	Service	eability and requirements	11	
			Durability and tunnel environment	11	
		2.3.2	Materials	11	
		2.3.3	Fire	12	
		2.3.4	Design life	12	
		2.3.5	Capital cost vs maintenance	13	
	2.4		onmental considerations	13	
			Internal environment	13	
		2.4.2	External environment	13	
	2.5		ercial framework	13	
		2.5.1	General	13	
		2.5.2	Funding and form of contract	14	
		2.5.3	Method of measurement and risk	70 E T	
			apportionment	14	
	2.6	AND AND THE PROPERTY OF THE PR			
		2.6.1	Risk Analysis and Management	14 15	
		2.6.2	1992 European Directive	16	
				-	

			UK Regulations of 1994	16
		2.6.4		
			Management of Tunnel Works in the	
		2 ( 5	United Kingdom	17
		2.6.5	Practicalities of what designers must do in	
			terms of strategy	18 19
	2.7	References		
3		Geotechnical characterisation		
	3.1	Gener:		20
	3.2		d investigation	20
		3.2.1	Ground investigation process	20
		3.2.2	Desk study and site reconnaissance	22
		3.2.3	č č	22
		3.2.4	This plant are the present the property of the best of the property of the pro	24
		3.2.5		25
	3.3	Sail as	investigation methods and scope nd rock description and classification	26
	3.3	3.3.1	Soil	26
		3.3.2	Rock	26
	3.4		dwater identification in soils and rocks	27
	3.5		d appreciation – link between investigation	21
	J.J	and de		28
		3.5.1	Interpretation process	28
		3.5.2	Soft ground, hard ground and transition	29
		3.5.3		29
		3.5.4	Foreseeing the unforeseeable	30
	3.6	Geotec	chnical parameters required for tunnel	
		lining		31
		3.6.1		
			application	31
		3.6.2	Range and certainty	31
	3.7	Groun	d improvement and groundwater control	36
		3.7.1	Changes in water table	36
		3.7.2	Effects on ground parameters	36
		3.7.3	Methods of ground improvement	36
		3.7.4	Methods of groundwater control	37
	3.8		nce ground conditions	37
	3.9	Refere	nces	38
4			and durability	40
	4.1	Definit		40
	4.2	Design		40
	4.3		lerations of durability related to tunnel use	40
	4.4		lerations of durability related to lining type	40
		4.4.1	Steel/cast-iron linings	40
	47/2	4.4.2	•	41
	4.5		and specification for durability	42
		4.5.1	Metal linings	42
		4.5.2		43
		4.5.3		47
		4.5.4		48
	16	4.5.5	Codes and standards	48
	4.6.	- China Suite Color Se	sistance	49
		4.6.1 4.6.2	[ - 10 10 10 10 10 10 10 10 10 10 10 10 10	50
		4.6.3	Types of fire	50 50
		7.0.3	Lining material behaviour in fire	30

		4.6.4	Codes and other standards	52
		4.6.5	Design for fire	53
		4.6.6	Fire protection	53
		4.6.7	(A) 1. (A	53
	4.7		proofing	54
			Membranes	54
		4.7.2	Gaskets	56
		4.7.3		57
		4.7.4	Grouting for leakage prevention	57
	4.8	Refere	ences	58
5	Des	Design considerations		
	5.1	Introd	uction	59
		5.1.1	The state of the s	59
		5.1.2	Tunnel design practice	59
		5.1.3	5 일 [ )는 10.15 4 1일 [ ] 전 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10 10.10	60
	5.2	•	eering design process	61
		5.2.1	5 5	61
	5.3		n considerations	63
		5.3.1	The state of the s	63
		5.3.2		65
		5.3.3		68
		5.3.4		68
		5.3.5	•	
			management on linings	69
		5.3.6		71
			Choice of lining systems	73
	5.4		ental linings	75
		5.4.1		75
		5.4.2	- [ - [ - [ - [ - [ - [ - [ - [ - [ - [	78
	5.5		ed concrete linings	79
			Potential weaknesses	80
			Design issues	81
			Detailing	82
		5.5.4	Performance requirements	82
	5.6		n situ linings	83
			Design requirements	83
		5.6.2		83
	5.7		al constructions	83
		5.7.1		83
			Junctions and portals	86
		5.7.3	Portals, launch chambers and reception	
			chambers	87
			Tunnels in close proximity	88
			Jacking pipes	88
		5.7.6	Pressure tunnels	88
	5.8	4 000 0000	n guidelines on performance requirements	89
			Key Performance Indicators	90
			Ground response	90
			Lining flexibility	90
			Lining distortion	92
			Critical strains in the ground	92
	5.9	Refere	ences	95
6	The	oretical	methods of analysis	98
	6.1	Introd		98
		6.1.1	Purposes	98

6.2		
	6.2.1 Geometry	99
	6.2.2 Construction method	99
	6.2.3 Constitutive modelling	99
	6.2.4 Theoretical basis	100
	6.2.5 Interpretation	100
	6.2.6 Human error	100
6.3	Design methods	100
	6.3.1 Empirical methods	102
	6.3.2 'Closed-form' analytical methods	104
	6.3.3 Numerical modelling	106
	6.3.4 Modelling geometry	108
	6.3.5 Discretisation	108
	6.3.6 Modelling construction processes	109
	6.3.7 Constitutive modelling	110
	6.3.8 Validation	111
	6.3.9 Advances in numerical analyses	111
	6.3.10 Physical modelling	112
6.4	Recommendations on design methods	113
6.5	References	113
Sett	lement	115
7.1	Prediction of ground movements	115
	7.1.1 Characterisation	115
	7.1.2 Models and methods	115
7.2	Effects of ground movements	117
		117
	7.2.2 Pipelines	118
	7.2.3 Piled structures	118
7.3		118
		118
		119
7.4	References	120
Insti	umentation and monitoring	122
8.1	Introduction	122
8.4		123 123
	8.4.1 General	123
	8.4.2 Observational Method	128
		129
8.5	그렇게 있다면 하다	131
8.6		132
	8.6.1 General	132
	8.6.2 Trigger values	133
8.7	Case histories	134
8.8	References	135
Qua	lity management	137
9.1	Introduction	137
9.2	Design stage	137
	9.2.1 Quality Plan	137
	J Quality I luli	1 . 1
		139 139
9.3	9.2.2 Design development statements	139
	6.4 6.5 Settl 7.1 7.2 7.3 7.4 Instr 8.1 8.2 8.3 8.4 8.5 8.6 Qua 9.1	6.2.1 Geometry 6.2.2 Construction method 6.2.3 Constitutive modelling 6.2.4 Theoretical basis 6.2.5 Interpretation 6.2.6 Human error 6.3 Design methods 6.3.1 Empirical methods 6.3.2 'Closed-form' analytical methods 6.3.3 Numerical modelling 6.3.4 Modelling geometry 6.3.5 Discretisation 6.3.6 Modelling construction processes 6.3.7 Constitutive modelling 6.3.8 Validation 6.3.9 Advances in numerical analyses 6.3.10 Physical modelling 6.4 Recommendations on design methods 6.5 References  Settlement 7.1 Prediction of ground movements 7.1.1 Characterisation 7.1.2 Models and methods 7.2 Effects of ground movements 7.2.1 Buildings 7.2.2 Pipelines 7.2.3 Piled structures 7.3 Compensation grouting 7.3.1 Effects on linings 7.3.2 Controlling factors 7.4 References  Instrumentation and monitoring 8.1 Introduction 8.2 Value of instrumentation and monitoring 8.3 Existing guidance 8.4 Instrumentation and monitoring and lining design 8.4.1 General 8.4.2 Observational Method 8.4.3 Design checklist 8.5 Management of third-party issues 9.6 Data acquisition and management 8.6.1 General 8.6.2 Trigger values 8.7 Case histories 8.8 References  Quality management 9.1 Introduction

	9.3.2	Quality control	140
	9.3.3	Manufacture outputs	140
9.4	Cast in	situ and sprayed concrete linings	140
	9.4.1	Site quality plan	140
	9.4.2	Site quality control	141
9.5	Monito		141
	9.5.1	1 (2) A 3 (4) (3) ← (4) A 1 (	141
	9.5.2	Surface settlement	142
10 Case	histori	es	144
10.1		ow Express - design and performance of	
		m tunnels at Terminal 4	144
	10.1.1	Project background	144
		Geotechnical	144
		Design	144
		Lining details	147
		Instrumentation and monitoring	147
10.2		of Channel Tunnel lining	149
		Project history	149
		Design background	149
		Geotechnical	150
		Summary of parameters	150
	10.2.5		153
		Precast segmental lining design	155
462742		SGI lining design	156
10.3		Belt railway tunnels	159
	10.3.1		545000000
	W0 2 2	cross-section	159
		Geology	159
	10.3.3		10 V V V V V V V V V V V V V V V V V V V
		properties	160
40.4		Design of tunnel linings	161
10.4		nentation of the CTRL North Downs Tunnel	164
10.5	Referen	nces	165
Appendix	(1 Al	obreviations and symbols	166
Appendix	c 2 Ri	sk management	168
A2.1	Introdu	ection	168
	Scope		168
A2.3	Risk re	gister	169
		When to use the risk register	169
		What is it?	169
		Assessment process	169
		Key steps	169
	A2.3.5	Risk assessment, qualitative or	
	Village to the con-	quantitative?	171
		Managing risk	175
A2.4	Referen	nces	175
Bibliogra	phy		177
Index			179