Ac	know	ledgements	IX					
No	tatio	n	XI					
Se		Unit Conversions	XIII					
		versions from American (British) to SI Units	XIII					
	Con	versions from SI Units to American (British) Units	XIII					
Ab	out t	he Authors	XXIII					
1		oduction to Rigidly Framed Earth Retaining Structures	1					
	1.1	Rigidly Framed Earth Retaining Structures (RFERS)	1					
	1.2	Initial Lateral Earth Pressure	2					
	1.3	The Effects of Thermal Movements.	3					
	1.4	Scope of Contribution to the Behavior of REFRS	4					
		1.4.1 Closed Form Expressions for Lateral Deflection of						
		RFERS	4					
		1.4.2 Experimental Study	4					
		1.4.3 Numerical Analysis	5					
2	Clad	ssical Earth Pressure Theory Related to Framed Structures	7					
_	2.1	Introduction	7					
	2.2	The Development of Earth Pressure Theory	8					
		2.2.1 Inadequacies of Classical Solutions	9					
		2.2.2 The Stiffness of the Retaining Wall	10					
	2.3	The Case of the Integral Bridge Abutment	10					
	2.4	The Case of Rigidly Framed Earth Retaining Structures	14					
3	Clos	sed-Form Expressions for Lateral Deflection of Rigid						
_		mes	15					
	3.1 Introduction							



	3.2			•	of Buildings	16		
	3.3		-		ateral Deflection of Rigidly	16		
						16		
		3.3.1		-	ions for Lateral Deflection, δ_s	18		
		3.3.2		_	alent Area, A _o	22		
		3.3.3			ic Modeling to Calibrate Derived			
						26		
		3.3.4	Calibrat	ion Factors	for Derived Equations	26		
	3.4	Confi	dence in t	he Derived l	Equations	29		
		3.4.1	Weibull	Statistical A	Analysis	32		
		3.4.2	Confide	nce in the D	erived Equations	34		
	3.5	Effect	of Input	Parameters of	on Expression Accuracy	36		
	3.6	Exam	ples			38		
		3.6.1	Symmet	ric Rigidly	Framed Structure Subject to	39		
		3.6.2			Subject to Wind Load	39		
		3.6.3			th Retaining Structure Subject to			
		3.0.3				40		
	3.7	Linko			istributions	41		
	3.8	_				42		
	3.9		Earth Pressure from a Known Deflection					
						42 44		
		0 Limitations of the Developed Equations						
	3.11	Conci	usions	***************************************		44		
4					RS in Service	45 45		
	4.1	Introduction						
		4.1.1			re	49		
		4.1.2			strumentation and Monitoring			
						49		
	4.2		mentation	١		50		
		4.2.1	Selectio	n of Instrum	ents	50		
		4.2.2	Instrume	entation Det	ails	51		
			4.2.2.1	Vibrating '	Wire Displacement Transducers			
				(VW)		51		
			4.2.2.2	Electrolyti	c Tiltmeters	54		
			4.2.2.3	Data Colle	ction and Management	56		
				4.2.2.3.1	Atomatic Data Acquisition	56		
				4.2.2.3.2	Manual Data Acquisition	57		
				4.2.2.3.3	Data Management	57		
			4.2.2.4	Instrument	ation Limitations	57		
	4.3	Monit	oring Res	ults of Instr	umented RFERS	57		
		4.3.1			sors Data	58		
			4.3.1.1		c Tilt Sensors on Level A	59		
			4.3.1.2		c Tilt Sensors on Level B	59		

Contents XVII

			4.3.1.3 Electrolytic Tilt Sensors on Level C	65
			4.3.1.4 Electrolytic Tilt Sensors on Level D	69
		4.3.2	Vibrating-Wire Displacement Transducers	71
			4.3.2.1 Thermal Study of Structure: Sensors Normal	
			to Expansion Joint	72
			4.3.2.1.1 Annual Range of Movements	72
			4.3.2.1.2 Seasonal Behavior	75
			4.3.2.2 Sensors Parallel to Expansion Joint	=0
			(North-South Direction)	78
			4.3.2.2.1 Roof Level Sensors	78
	4 4	Conclu	4.3.2.2.2 Level B Sensors	81 83
	4.4	Conciu	ISIOHS	0.5
5	Rela	tionshi	ip between Temperature and Earth Pressure	
	for F			85
	5.1		uction	85
	5.2		ng Description	86
	5.3	Geote	chnical Properties of the Retained Soil	86
	5.4		mentation Program	89
	5.5	Appar	rent Thermal Coefficient of Expansion of PG-1	90
	5.6	Latera	al Displacement of Building Parallel to Earth Pressure	91
		5.6.1	Measured Lateral Displacement	91
		5.6.2	Baseline Correction Due to Thermal Movement of PG-2	96
		5.6.3	Correction of Lateral Displacement Due to Thermal	
		2.0.2	Movement of PG-1	96
		5.6.4	Accuracy of Computed PG-1 Movements	97
	5.7		onship between Lateral Deflection and Earth Pressure	99
	5.8		Pressure Causing Lateral Deformation	102
	5.9		ations of This Study	104
			usions	105
_	•			105
í	Num 6.1		Analysis of Instrumented RFERSuction	107 107
	6.2		inite Element Model	107
	0.2	6.2.1	The Structural Frame	108
		6.2.2	The Backfill Soil	108
		6.2.3	The Analysis Procedure	1109
	6.3			
	0.3	6.3.1	rical Analysis Thermal Analysis of Rigid Frame (Part 1)	110
		0.3.1	6.3.1.1 Description of Analysis Procedure	110 110
			6.3.1.2 Numerical Analysis Results (Part 1)	
		6.3.2	Thermal Analysis of Rigid Frame with Mohr-Coulomb	111
		0.3.4	Backfill (Part 2)	113

XVIII Contents

			6.3.2.1		11
			6.3.2.2	Numerical Analysis Results (Part 2)	11
		6.3.3		Analysis of Rigid Frame with Hardening-Soil (Part 3)	11
			6.3.3.1	Description of Analysis Procedure	11
			6.3.3.2	Numerical Analysis Results (Part 3)	11
		6.3.4		ison of Numerical Analysis Results	12
1	6.4		-		12
	···	001101			
7	Para	ametric	Study of	f Earth Pressure behind RFERS at Backfill	
	-				12
	7.1				12
•	7.2			nerical Analysis	12
		7.2.1		lement Analysis Model Details	12
		7.2.2	_	Story Rigidly Framed Earth Retaining	
				es	13
			7.2.2.1	Backfill Soil with 30° Internal Friction Angle	13
			7.2.2.2	Effect of Lateral Frame Stiffness on the	
				Mobilizations of Active Earth Pressure	13
			7.2.2.3	Effect of Staged Construction Calculation on the	
				Mobilizations of Active Earth Pressure	13
			7.2.2.4	Backfill Soil with 40° Internal Friction Angle	13
		7.2.3		ory Rigidly Framed Earth Retaining Structures	13
			7.2.3.1	Backfill Soil with 30° Internal Friction Angle	13
			7.2.3.2	Backfill Soil with 40° Internal Friction Angle	13
		7.2.4		tory Rigidly Framed Earth Retaining Structures	14
			7.2.4.1	Backfill Soil with 30° Internal Friction Angle	14
			7.2.4.2	Backfill Soil with 40° Internal Friction Angle	14
		7.2.5	Four-St	ory Rigidly Framed Earth Retaining Structures	14
			7.2.5.1	Backfill Soil with 30° Internal Friction Angle	14
			7.2.5.2	Backfill Soil with 40° Internal Friction Angle	14
		7.2.6	Five-Sto	ory Rigidly Framed Earth Retaining Structures	14
			7.2.6.1	Backfill Soil with 30° Internal Friction Angle	14
			7.2.6.2	Backfill Soil with 40° Internal Friction Angle	14
		7.2.7		se of Frames Braced against Lateral Sway	15
		7.2.8	Analysi	s of a Single Story 6-Bay Shear Wall Structure	15
		7.2.9	Analysi	s of a Two Story 15-Bay Shear Wall Structure	15
•	7.3	Concl	usions		15
8 .	Ana	lysis of	Single S	tory RFERS Subject to Temperature	
					15
	8.1				15
	8.2			metric Analysis	15

Contents XIX

	8.3	Analy	sis of Sing	gle Story Rigidly Framed Earth Retaining
		Struct	ures	
		8.3.1	Backfill	Soil with 30° Internal Friction Angle
			8.3.1.1	Single Bay Frame (Bay Length, Lb, 10 Feet,
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)
			8.3.1.2	Single Bay Frame (Bay Length, Lb, 10 Feet,
				Column to Beam Stiffness Ratio, Sc/Sb, of 4)
			8.3.1.3	Single Bay Frame (Bay Length, Lb, 20 Feet,
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)
			8.3.1.4	Single Bay Frame (Bay Length, Lb, 20 Feet,
				Column to Beam Stiffness Ratio, Sc/Sb, of 4)
			8.3.1.5	10-Bay Frame (Bay Length, Lb, 10 Feet,
			0.0	Column to Beam Stiffness Ratio, Sc/Sb, of 1)
			8.3.1.6	10-Bay Frame (Bay Length, Lb, 10 Feet,
			0.01.110	Column to Beam Stiffness Ratio, Sc/Sb, of 4)
			8.3.1.7	10-Bay Frame (Bay Length, Lb, 20 Feet,
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)
			8.3.1.8	10-Bay Frame (Bay Length, Lb, 20 Feet,
			0.5.1.0	Column to Beam Stiffness Ratio, Sc/Sb, of 4)
			8.3.1.9	20-Bay Frame (Bay Length, Lb, 10 Feet,
			0.5.11.5	Column to Beam Stiffness Ratio, Sc/Sb, of 1)
			83110	20-Bay Frame (Bay Length, Lb, 10 Feet,
			0.511110	Column to Beam Stiffness Ratio, Sc/Sb, of 4)
	8.4	Concl	usions	Column to Domin Guinness Traile, 50 50, 61 17
)	Mul	ti_ctory	DEEDC	Subject to Temperature Variation
	9.1			Subject to Temperature variation
	9.2			metric Analysis
	٠. ـ ـ	9.2.1		ory Rigidly Framed Earth Retaining
		J.2.1		es
			9.2.1.1	Frames with Bay Length, Lb, 10 Feet, and
			J.2.1.1	Column to Beam Stiffness Ratio, Sc/Sb, of 1
			9.2.1.2	Frames with Bay Length, Lb, 10 Feet, and
			7.2.1.2	Column to Beam Stiffness Ratio, Sc/Sb, of 4
			9.2.1.3	Frames with Bay Length, Lb, 20 Feet, and
			7.4.1.3	Column to Beam Stiffness Ratio, Sc/Sb, of 1
			9.2.1.4	Frames with Bay Length, Lb, 20 Feet, and
			7.2.1.7	Column to Beam Stiffness Ratio, Sc/Sb, of 4
		000		
			Five Sto	
		9.2.2		ry Rigidly Framed Earth Retaining Structures
		9.2.2	Five Stor 9.2.2.1	ry Rigidly Framed Earth Retaining Structures Frames with Bay Length, Lb, 10 Feet, and
		9.2.2	9.2.2.1	ry Rigidly Framed Earth Retaining Structures Frames with Bay Length, Lb, 10 Feet, and Column to Beam Stiffness Ratio, Sc/Sb, of 1
		9.2.2		Frames with Bay Length, Lb, 10 Feet, and Column to Beam Stiffness Ratio, Sc/Sb, of 1 Frames with Bay Length, Lb, 10 Feet, and
	9.3		9.2.2.1 9.2.2.2	ry Rigidly Framed Earth Retaining Structures Frames with Bay Length, Lb, 10 Feet, and Column to Beam Stiffness Ratio, Sc/Sb, of 1

XX Contents

10				commendations	221
	10.1	Summ	ary and C	Conclusions	221
				entation and Monitoring of in Service	
			RFERS		221
		10.1.2	Numerio	cal Analysis of In-Service Structure	223
		10.1.3	Approxi	mate Expressions for Lateral Deflection of	
			Frames.		225
		10.1.4	Relation	ship between Temperature and Earth	
			Pressure	· · · · · · · · · · · · · · · · · · ·	225
		10.1.5	Numerio	cal Analysis of Earth Pressure at Backfill	
			Stage		226
		10.1.6	Thermal	Parametric Analysis of Single Story RFERS	226
		10.1.7	Thermal	Parametric Analysis of Multi-story RFERS	229
	10.2	Recom	nmendatio	ons	231
		10.2.1	Analysis	s of RFERS at the Initial Backfill Stage	231
			10.2.1.1	Recommended Procedure for Single Story	
				RFERS	232
			10.2.1.2	Recommended Procedure for Multi-story	
				RFERS	232
		10.2.2	Analysis	s of RFERS Subject to Temperature Variations	233
Аp	pendi A. l	Therm	al Soil St	ructure Interaction of Single Story	235
					235
		A.1.1		Soil with 30° Internal Friction Angle	235
			A .1.1.1	Three-Bay Frame (Bay Length, Lb, 10 Feet,	
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)	235
			A.1.1.2	Three-Bay Frame (Bay Length, Lb, 10 Feet,	
				Column to Beam Stiffness Ratio, SJSb, of 4)	238
			A.1.1.3		
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)	242
			A.1.1.4	Three-Bay Frame (Bay Length, Lb, 20 Feet,	
				Column to Beam Stiffness Ratio, SJSb, of 4)	245
			A.1.1.5	Six-Bay Frame (Bay Length, Lb, 10 Feet,	
				Column to Beam Stiffness Ratio, Sc/Sb, of 1)	249
			A.1.1.6	Six-Bay Frame (Bay Length, Lb, 10 Feet,	
				Column to Beam Stiffness Ratio, SdSb, of 4)	252
			A.1.1.7		
				Column to Beam Stiffness Ratio, SdSb, of 1)	255
			A.1.1.8	15-Bay Frame (Bay Length, Lb, 10 Feet,	
				Column to Beam Stiffness Ratio, Sc/Sb, of 4)	257

Contents	XXI
Contents	XXI

	A.1.2	Backfill	Soil with 40° Internal Friction Angle	260
		A.1.2.1	Frames with Bay Length, Lb, 10 Feet, and	
			Column to Beam Stiffness Ratio, Sc/Sb, of 1	261
		A.1.2.2	Frames with Bay Length, Lb, 10 Feet, and	
			Column to Beam Stiffness Ratio, Sc/Sb, of 4	265
		A.1.2.3	Frames with Bay Length, Lb, 20 Feet, and	
			Column to Beam Stiffness Ratio, Sc/Sb, of 1	269
		A.1.2.4	Frames with Bay Length, Lb, 20 Feet, and	
			Column to Beam Stiffness Ratio, Sc/Sb, of 4	273
Append	ix R			279
Тррсііс В.1			ructure Interaction of Multi-story RFERS	279
2	B.1.1		ory Rigidly Framed Earth Retaining	
	2		es	279
		B.1.1.1		
			Column to Beam Stiffness Ratio, Sc/Sb, of 1	279
		B.1.1.2		
		D	Column to Beam Stiffness Ratio, Sc/Sb, of 4	284
		B.1.1.3	Frames with Bay Length, Lb, 20 Feet, and	
			Column to Beam Stiffness Ratio, Sc/Sb, of 1	288
		B.1.1.4	Frames with Bay Length, Lb, 20 Feet, and	
		D	Column to Beam Stiffness Ratio, Sc/Sb, of 4	293
	B.1.2	Four Sto	ory Rigidly Framed Earth Retaining	
			es	297
		B.1.2.1	Frames with Bay Length, Lb, 10 Feet, and	
		2111211	Column to Beam Stiffness Ratio, Sc/Sb, of 1	297
		B.1.2.2	Frames with Bay Length, Lb, 10 Feet, and	
		511.2.2	Column to Beam Stiffness Ratio, Sc/Sb, of 4	302
			Column to Beam Stations Natio, 53 55, 62 11111111	502
Referen	ces	*************		307
Subject	Indo-			313
21112164,1	HIMPX			-71-7