## ACKNOWLEDGMENTS

The PEER reconnaissance team included the authors of this report and four representatives of the PEER Business and Industry Partnership (BIP): Mr. Atila Zekioglu of Ove Arup and Partners, Los Angeles, California; Messrs. Jay Love and Chris Smith of Degenkolb Engineers, California; and Dr. Nesrin Basoz of K2 Technologies, San Jose, California. The contributions of these expert design professionals to the reconnaissance effort are gratefully acknowledged. Mss. Janine Hannel and Claire Johnson carefully edited the report and their assistance is also acknowledged.

The PEER reconnaissance team received substantial advice and logistical support from faculty at universities in Turkey. This advice and support was most graciously provided at an exceedingly difficult and demanding time for expert engineers in Turkey. Special thanks are due to Professor Polat Gulkan of the Middle East Technical University, and the faculty at the Department of Civil Engineering at Bogaziçi University including Professors Gulay Altay, Nuray Aydinoglu, Sami Kilic, Emre Otay, and Ali Atilgan. Messrs. Husamettin Danis of Tüpras, Nuri Duzgoren of KordSA, Dursun Parlak of EnerjiSA, Tamer Unlu of ToyotaSA, Ahmet Bilgic of Petkim, Ahmet Akdag of SEKA, and Carey Terrell of DuPont, provided access, assistance, and information to the team during the reconnaissance of selected industrial facilities. The efforts of these individuals and their staffs are gratefully acknowledged.

Two representatives of the Miami-Dade County Urban Search and Rescue Team, Messrs. Robert Sullivan, P.E., and Fred Stolaski, P.E., provided much logistical support and technical advice to the reconnaissance team. Messrs. Sullivan and Stolaski were air-lifted into the epicentral region immediately after the earthquake under orders from the Office of Foreign Disaster Assistance to aid local officials in the search and recovery effort. The PEER reconnaissance team joined with Messrs. Sullivan and Stolaski to survey the epicentral region for the United States State Department. The United States Air Force (Captain Don Treanor) and the United States Marine Corps (Major Coke) provided logistical support for the mission. The helicopters were flown by pilots and crew from the Marine Corps from the USS Kersage, which was diverted from its Kosovo mission by Presidential Order. The PEER reconnaissance team sincerely thanks Messrs. Sullivan and Stolaski, Captain Treanor and Major Coke, and the Air Force and the Marine Corps for their invaluable assistance.

Finally, the senior authors (Whittaker, Mosalam, Wallace, and Stanton) owe a debt of thanks to Professor Sozen of Purdue University. In addition to providing advice and information to the PEER reconnaissance team, Professor Sozen spent significant time with Berkeley graduate students Halil Sezen and Ken Elwood when they first arrived in Turkey, in advance of the remainder of the PEER reconnaissance team. The time spent with Professor Sozen was an opportunity of a lifetime for our two graduate students and they learned much from Professor Sozen in a short period of time. Also, the graduate-student authors (Sezen and Elwood) would like to thank their thesis advisor Professor J. P. Moehle, PEER Center Director, for his patience and understanding during the preparation of this report.

The work described in this report made use of the Pacific Earthquake Engineering Research Center shared facilities supported by the Earthquake Engineering Centers Program of the National Science Foundation under Award Number EEC-9701568.

AE	BSTR	ACT	iii
AC	CKNC	DWLEDGMENTS	v
TA	BLE	OF CONTENTS	vii
LIS	ST O	F FIGURES	xi
LIS	ST O	F TABLES	XV
1	INT	RODUCTION	1
	1.1	1999 Izmit Earthquake	1
	1.2	Seismological and Geotechnical Aspects	1
	1.3	Scope and Organization of Report	3
r	EVI	N LITION OF SEISMIC DUIL DING DESIGN DDACTICE IN TUDVEY	0
Ζ		JUTION OF SEISMIC BUILDING DESIGN PRACTICE IN TURKET	9
	2.1	Major Forth quality in The 20th Contains	9
	2.2	Major Earinquakes in Turkey in the 20th Century	10
	2.3	Building Code Requirements for Reinforced Concrete	11 11
	2.4	Seismic Design Codes	11
		2.4.1 Years 1940 to 1953	11
		2.4.2 Years 1954 to 1967	12
		2.4.3 Years 1968 through 1971	13
		2.4.4 Years 1972 through 1996	15
	~ -	2.4.5 Years after 1997	1/
	2.5	Comparison of United States and Turkish Codes of Practice	18
	2.6	Summary Remarks	19
3	REI	NFORCED CONCRETE FRAME AND WALL BUILDINGS	29
5	3.1	Introduction	29
	3.2	Construction Practice	29
	3.3	Moment-Resisting Frame Construction	30
	5.5	3 3 1 Typical Framing Systems for Residential Construction	30
		3.3.2 Typical Construction Details	31
	3.4	Behavior of Moment-Resisting Frame Construction	32
	2.1	3.4.1 Moment-Frame Buildings Straddling or Adjacent the Line of Rupture	32
		3.4.2 Variability of Moment-Frame Building Response	
		3.4.3 Role of Infill Walls in Response of Moment-Frame Buildings	
	3.5	Response of Moment-Frame Components	
	0.0	3.5.1 Beams	
		3.5.2 Columns	34
		3.5.3 Beam-Column Joints	35
		3 5 4 Asmolen Slab System	36
	36	Shear-Wall Construction	36
	5.0	3.6.1 Behavior of Shear-Wall Construction	36
	3.7	Performance of Selected Buildings	37
	5.1	3.7.1 Building A	37
		3.7.1.1 Building Description	

		3.7.1.2 Component Failures	
		3.7.1.3 System Response	
		3.7.2 Building B	
		3.7.2.1 Building Description	
		3.7.2.2 Component Failures	
		3.7.2.3 System Response	
		3.7.3 Building C	40
		3.7.3.1 Building Description	40
		3.7.3.2 Component Failures	41
		3.7.3.3 System Response	41
		3.7.4 Building D	42
		3.7.4.1 Building Description	42
		3.7.4.2 System Response	42
		3.7.5 Summary Remarks	42
4	IND	DUSTRIAL FACILITIES	77
	4.1	Overview of Construction and Damage	77
		4.1.1 Introduction	77
		4.1.2 In-Situ Reinforced Concrete Structures	81
		4.1.3 Prefabricated Reinforced Concrete Structures	81
		4.1.4 Steel-Frame Structures	
	4.2	Petrochemical Industry	
		4.2.1 Introduction	
		4.2.2 Tüpras Refinery	83
		4.2.2.1 Introduction	
		4.2.2.2 Loading Jetty	84
		4.2.2.3 Tank Farms and Floating Roof Tanks	
		4.2.2.4 Main Processing Facility	
		4.2.3 Petkim Petrochemical Plant	
	4.3	Automotive Industry	
		4.3.1 Introduction	
		4.3.2 Ford Assembly Plant	
		4.3.3 Hyundai Assembly Plant	
		4.3.4 Toyota Assembly Plant	
		4.3.5 Pirelli Tire Plant	
		4.3.6 Goodyear Tire Plant	
		4.3.7 BekSA	
		4.3.8 DuSA	
		4.3.9 KordSA	
	4.4	Power Generation and Transmission Systems	
		4.4.1 Introduction	
		4.4.2 Power Generation	
	4 7	4.4.3 Power Transmission	
	4.5	Other Heavy Industry	
		4.5.1 Bastas Plant	
		4.5.2 Çap Plant	

4.5.3 Habas Plant	91
4.5.4 Mannesmann Boru Plant	
4.5.5 SEKA Plant	92
4.5.6 Liquid Gas Tanks	93
5 SUMMARY AND CONCLUSIONS	139
5.1 Summary	139
5.2 Conclusions and Recommendations	140
APPENDIX PERFORMANCE OF THE ADAPAZARI CITY HALL	143
A.1 Introduction	143
A.2 Background Information	143
A.3 1967 Akyazi Earthquake, Damage and Building Retrofit	144
A.4 1999 Kocaeli Earthquake and Aftershock	145
A.5 Summary Remarks	145
•	
REFERENCES	153

## LIST OF FIGURES

Figure 1-1	Map of affected region showing horizontal and vertical offsets	4
Figure 1-2	Vertical offset measured near Ford plant in Gölcük	4
Figure 1-3	Acceleration time histories from the YPT station	5
Figure 1-4	Acceleration response spectra for 5% damping	6
Figure 1-5	Failure of a bridge over the Trans-European Motorway	7
Figure 1-6	Unseating of the simply supported span from the abutment-mounted bearings	7
Figure 1-7	Collapsed and submerged bridge near Akyazi	8
Figure 2-1	Distribution of coefficient $C_0$ with height above grade in 1961 seismic code	21
Figure 2-2	1963 earthquake zonation map (IAEE 1966)	21
Figure 2-3	Spectral coefficients, S, from 1975 seismic code	22
Figure 2-4	Detailing requirements for beams and shear walls from 1975 seismic code	23
Figure 2-5	Detailing requirements for columns from 1975 code	24
Figure 2-6	Earthquake zonation map of Turkey (1997 Turkish Seismic Code)	25
Figure 2-7	Transverse reinforcement requirements for beams (1997 Seismic Code)	25
Figure 2-8	Column confinement zones and detailing requirements (1997 Seismic Code)	26
Figure 2-9	Comparison of elastic response spectra from 1997 UBC and Turkish	
-	seismic codes	27
Figure 2-10	Comparison of lateral force coefficient, C, in the 1997 UBC, and 1975 and	
-	1997 Turkish seismic codes	28
Figure 3-1	High-quality apartment building construction in Yalova	44
Figure 3-2	Poor-quality construction of a shear wall in an apartment building in Yalova	44
Figure 3-3	Homeowner apartment building construction	45
Figure 3-4	Construction details for apartment building of Figure 3-3	45
Figure 3-5	Typical framing systems in the epicentral region	46
Figure 3-6	Three-story moment-resisting frame east of Gölcük	46
Figure 3-7	Floor plan for three-story building of Figure 3-6	47
Figure 3-8	Plan of roof framing for a five-story apartment	47
Figure 3-9	Typical modern beam and column rebar details	48
Figure 3-10	Hollow clay tile block used for infill walls	48
Figure 3-11	Asmolen floor system in a four-story building	49
Figure 3-12	Collapse of moment-frame buildings in Gölcük	49
Figure 3-13	Collapsed moment-frame and wall buildings in Adapazari	50
Figure 3-14	Collapsed school building that straddled the line of rupture	50
Figure 3-15	Collapsed and damaged moment-frame buildings on the Gölcük naval base	51
Figure 3-16	Collapsed building that straddled the line of rupture	51
Figure 3-17	Undamaged building located within 2 m of the line of rupture	52
Figure 3-18	Variability of building response	52
Figure 3-19	Varying degrees of damage to infill masonry walls	53
Figure 3-20	Damage to infill masonry walls	54
Figure 3-21	Collapsed apartment building in Gölcük	54
Figure 3-22	Failure of two stories of a moment-frame building with infill masonry walls	55
Figure 3-23	Formation of a soft and weak story	55
Figure 3-24	Damage to a nonductile reinforced concrete beam	56
Figure 3-25	Failure of lap splices in a moment-frame column	56

Figure 3-26	Typical transverse reinforcement details in columns	57
Figure 3-27	Shear failure of a moment-frame blade column	57
Figure 3-28	Lack of transverse reinforcement in moment-frame column	58
Figure 3-29	Shear cracking in short columns	58
Figure 3-30	Damage resulting from column-infill masonry wall interaction	59
Figure 3-31	Concentrated damage at ends of moment-frame columns due to drift	59
Figure 3-32	Damage and failures at ends of moment-frame columns	60
Figure 3-33	Damage to moment-frame columns	60
Figure 3-34	Damage to moment-frame beam-column joints	61
Figure 3-35	Building collapse due to failure of beam-column joints	61
Figure 3-36	Damage to new moment-frame beam-column joints	62
Figure 3-37	Typical damage to asmolen floor systems	62
Figure 3-38	Shear wall building under construction at the time of the earthquake	63
Figure 3-39	Undamaged apartment building in Gölcük	63
Figure 3-40	Shear wall building damaged due to fault rupture	64
Figure 3-41	Collapsed dual wall-frame building in Adapazari	64
Figure 3-42	Damaged wall-frame building due to ground failure and wall rotation	65
Figure 3-43	Damage to short walls or blade columns	66
Figure 3-44	Front elevation of Building A	67
Figure 3-45	Rear elevation of Building A showing intact infill masonry walls	67
Figure 3-46	Building A first-floor plan	68
Figure 3-47	Damage to first-story columns	68
Figure 3-48	Damage at the rear stairwell	69
Figure 3-49	Shear failure of Column A (see Figure 3-46)	69
Figure 3-50	Axial failure of Column B (see Figure 3-46)	70
Figure 3-51	Axial failure at the lap splice in Column C (see Figure 3-46)	70
Figure 3-52	Elevation of Building B	71
Figure 3-53	Details of damage to the third-story column	71
Figure 3-54	Elevation of Building C	72
Figure 3-55	View of retail space in first story of building	72
Figure 3-56	Shear crack in first-story column in rear of building	73
Figure 3-57	Damaged beam-column joints at top of first-story columns	73
Figure 3-58	Damaged beam-column joint at top of first-story corner column	74
Figure 3-59	Elevation of Building D	74
Figure 3-60	Settlement of Building D due to liquefaction and soil-bearing failure	75
Figure 4-1	Map of the eastern end of Izmit Bay	94
Figure 4-2	Aerial photograph of industrial facilities in Körfez looking west	94
Figure 4-3	Prefabricated reinforced concrete construction	95
Figure 4-4	Typical plank roof construction and damaged doweled connections	96
Figure 4-5	Foundation connection for prefabricated reinforced concrete facilities	97
Figure 4-6	Damaged precast reinforced concrete framed building	98
Figure 4-7	Five-story steel-framed industrial facility under construction	99
Figure 4-8	Tank farm fires at the Tüpras refinery	100
Figure 4-9	Aerial photograph of Tüpras refinery showing part of tank farm	101
Figure 4-10	Aerial photograph of Tüpras refinery	101
Figure 4-11	Aerial photograph of loading and unloading jetty at Tüpras refinery	102

Figure 4-12	Failed crude-oil pipeline along the sea wall at the Tüpras refinery	102
Figure 4-13	Photograph from the sea wall of damaged loading and unloading jetty	103
Figure 4-14	Damage to jetty and elevated pipeway at Tüpras refinery	104
Figure 4-15	Tank 211 in Tüpras refinery tank farm	104
Figure 4-16	Floating roof of Tank 211 and spilled oil due to fluid sloshing	105
Figure 4-17	Perimeter seal of floating roof in Tank 211	105
Figure 4-18	Part view of Tüpras tank farm showing Tank 211 and two tank burn zones	106
Figure 4-19	Overtopping of tank wall due to fluid sloshing and failure of perimeter seals	106
Figure 4-20	View of tank wall damage	107
Figure 4-21	Photograph from top of Tank 211 looking approximately south (1 of 2)	107
Figure 4-22	Photograph from top of Tank 211 looking approximately south (2 of 2)	108
Figure 4-23	Photograph of tank destroyed by fire in tank burn zone 1	108
Figure 4-24	Photograph of tank destroyed by fire in tank burn zone 2	109
Figure 4-25	Destroyed walls, walkways, and floating roof of tank of Figure 4-24	109
Figure 4-26	Gross expansion of fixed roof tank adjacent to tank of Figure 4-24	110
Figure 4-27	Photograph of failed 300-ft-tall heater stack	110
Figure 4-28	Damage to heater unit caused by collapse of heater stack	111
Figure 4-29	Damage to pipework caused by collapse of heater stack	111
Figure 4-30	Typical framing in the main processing facility of the Tüpras refinery	112
Figure 4-31	Collapsed wooden cooling tower at the Petkim petrochemical facility	113
Figure 4-32	Damage to nonductile reinforced concrete columns in Petkim cooling tower	113
Figure 4-33	Rebar details and damage in reinforced concrete cooling tower at Petkim	114
Figure 4-34	Loading and unloading port facility at the Petkim petrochemical plant	114
Figure 4-35	Failure of battered reinforced concrete piles beneath jetty at Petkim facility	115
Figure 4-36	Framing of new body shop in Ford plant near Gölcük	115
Figure 4-37	Ground movement near the Ford plant in Gölcük	116
Figure 4-38	Exterior view of the damaged Ford body shop	116
Figure 4-39	Photograph of the BekSA plant	117
Figure 4-40	Damage to the DuSA main plant building	117
Figure 4-41	Photograph of KordSA main building showing steel brace framed tower	118
Figure 4-42	Perimeter of precast reinforced concrete framed DuSA main plant building	118
Figure 4-43	Roof collapse in storage area at KordSA plant	119
Figure 4-44	Rail-mounted transformers in the EnerjiSA transformer yard	119
Figure 4-45	Toppled transformer in EnerjiSA transformer yard	120
Figure 4-46	Heat-recovery steam boiler in the EnergiSA plant	121
Figure 4-47	Damage to steel framing of the in-service EnergiSA steam generator	122
Figure 4-48	Damage to steel framing of the new EnergiSA steam generator	123
Figure 4-49	Aerial photograph of the Adapazari substation	124
Figure 4-50	Fractured porcelain components	125
Figure 4-51	Pre- and post-earthquake circuit breakers and rigid bus connectors	126
Figure 4-52	Braced Hitachi gas circuit breaker	127
Figure 4-53	Power transformers at the Adapazari substation	128
Figure 4-54	Precast reinforced concrete buildings at the Çap textile plant	129
Figure 4-55	Liquid gas tanks at the Habas plant	130
Figure 4-56	Liquid nitrogen tank at the Habas facility	131
Figure 4-57	Collapse of the liquid oxygen tanks	132

Figure 4-58	Buckling of the outer stainless steel shell in a liquid oxygen tank	.132
Figure 4-59	Photographs of failed columns beneath a liquid oxgen tank at the	
	Habas facility	.133
Figure 4-60	Cranes in Mannesmann Boru large-pipe storage area	.134
Figure 4-61	Damaged port facilities at the SEKA paper mill	.135
Figure 4-62	Silos at the SEKA paper mill	.136
Figure 4-63	Cylindrical liquid gas tanks	.137
Figure A-1	Typical plan and elevation of the original building	.147
Figure A-2	Building damage after the 1967 Akyazi earthquake	.148
Figure A-3	Damage in the original building columns in the 1967 Akyazi earthquake	.148
Figure A-4	Typical floor plan after retrofit showing the location of new shear walls	.149
Figure A-5	Front elevation after the retrofit in 1968 (rigid beams and shear walls added)	.149
Figure A-6	City Hall after the November 12, 1999, Duzce earthquake	.150
Figure A-7	Acceleration spectra for the August 17, 1999, main shock, the	
-	November 11, 1999, aftershock, and the November 12, 1999, main shock	.151

## LIST OF TABLES

Table 1-1	Recorded peak ground accelerations	2
Table 2-1	Key events in the evolution of seismic design codes in Turkey	10
Table 2-2	Values of <i>n</i> <sub>1</sub>	13
Table 2-3	Values of $n_2$	13
Table 2-4	Structural type coefficient, K, from 1975 code	16
Table 2-5	Response modification factors in current seismic codes	19
Table 4-1	Industrial facilities visited by the PEER reconnaissance team	78
Table 4-2	Structural damage classification	79
Table 4-3	Nonstructural damage classification	79
Table 4-4	Damage to industrial facilities visited by the PEER reconnaissance team	80
Table A-1	Characteristics of the Adapazari City Hall (Anadol 1972)	144