

LIST OF FIGURES

		Page No.
Figure 1.1	Collapsed Reinforced Concrete Structures during Kocaeli Earthquake	2
Figure 1.2	Typical View of Beam-Column Joint Failure	2
Figure 1.3	Details of the Parameters Investigated	6
Figure 3.1	Reinforcement Details for M20 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Static Load	22
Figure 3.2	Reinforcement Details for M20 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Reversal Load	22
Figure 3.3	Reinforcement Details for M25 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Static Load	29
Figure 3.4	Reinforcement Details for M25 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Reversal Load	29
Figure 3.5	Reinforcement Details for M30 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Static Load	36
Figure 3.6	Reinforcement Details for M30 Concrete Beam-Column Joint Specimen as per Code IS 456:2000 subjected to Reversal Load	36
Figure 3.7	Stirrups in Beam as per IS 13920:1993	37
Figure 3.8	Hoop Rod as per IS13920:1993	37
Figure 3.9	Beam Reinforcement as per IS 13920:1993	38
Figure 3.10	Anchorage of Beam Bars in an External Joint	39
Figure 3.11	Column and Joint Detailing as per IS13920:1993	41
Figure 3.12	Hoops used for Special Confinement	42
Figure 3.13	Reinforcement Details for M20 Concrete Beam-Column Joint Specimen as per Code IS 13920 : 1993	43
Figure 3.14	Reinforcement Details for M25 Concrete Beam-Column Joint Specimen as per Code IS 13920 : 1993	44
Figure 3.15	Reinforcement Details for M30 Concrete Beam-Column Joint Specimen as per Code IS 13920 : 1993	44
Figure 3.16	Typical View of Fabrication of Reinforcement	48
Figure 3.17	Typical View of Placing of Reinforcement in the Mould	48
Figure 3.18	Typical View of Casting of Beam-Column Joint Specimen	49
Figure 3.19	Typical View of Curing of Specimen	49
Figure 3.20	Typical View of Beam-Column Joint Specimen	50
Figure 3.21	Typical View of Beam-Column Joint Specimen Retrofitted with GFRP Sheets	50
Figure 3.22	Typical View of Beam-Column Joint Specimen Retrofitted with CFRP Sheets	51
Figure 3.23	Typical View of Beam-Column Joint Specimen Retrofitted with AFRP Sheets	51
Figure 3.24	Typical View of Beam-Column Joint Specimen Retrofitted with Sisal Fiber Sheets	52

Figure 4.1	Typical View of Test Setup	53
Figure 4.2	Typical View of Failed Beam-Column Joint Specimen	62
Figure 4.3	Typical View of Failed Beam-Column Joint Specimen Retrofitted with GFRP Sheets	62
Figure 4.4	Typical View of Failed Beam-Column Joint Specimen Retrofitted with CFRP Sheets	63
Figure 4.5	Typical View of Failed Beam-Column Joint Specimen Retrofitted with AFRP Sheets	63
Figure 4.6	Typical View of Failed Beam-Column Joint Specimen Retrofitted with Sisal Fiber Sheets	64
Figure 4.7	Load-Deflection Curve of Specimens BCJ1,BCJ2 & BCJ3	65
Figure 4.8	Load-Deflection Curve of Specimens BCJ4,BCJ5 & BCJ6	67
Figure 4.9	Load-Deflection Curve of Specimens BCJ7,BCJ8 & BCJ9	68
Figure 4.10	Load-Deflection Curve of Specimens BCJ10, BCJ11 & BCJ12	70
Figure 4.11	Load-Deflection Curve of Specimens BCJ13, BCJ14 & BCJ15	71
Figure 4.12	Load-Deflection Curve of Specimens BCJ16, BCJ17 & BCJ18	73
Figure 4.13	Load-Deflection Curve of Specimens BCJ19 , BCJ20 & BCJ21	74
Figure 4.14	Load-Deflection Curve of Specimens BCJ22 , BCJ23 & BCJ24	76
Figure 4.15	Load-Deflection Curve of Specimens BCJ25, BCJ26 & BCJ27	77
Figure 4.16	Load-Deflection Curve of Specimens BCJ28, BCJ29 & BCJ30	79
Figure 4.17	Load-Deflection Curve of Specimens BCJ31, BCJ32 & BCJ33	80
Figure 4.18	Load-Deflection Curve of Specimens BCJ34, BCJ35 & BCJ36	82
Figure 4.19	Load-Deflection Curve of Specimens BCJ37, BCJ38 & BCJ39	85
Figure 4.20	Load-Deflection Curve of Specimens BCJ40, BCJ41 & BCJ42	87
Figure 4.21	Load-Deflection Curve of Specimens BCJ43, BCJ44 & BCJ45	88
Figure 4.22	Load-Deflection Curve of Specimens BCJ46, BCJ47 & BCJ48	90
Figure 4.23	Load-Deflection Curve of Specimens BCJ49, BCJ50 & BCJ51	91
Figure 4.24	Load-Deflection Curve of Specimens BCJ52, BCJ53 & BCJ54	93
Figure 4.25	Load-Deflection Curve of Specimens BCJ55, BCJ56 & BCJ57	94
Figure 4.26	Load-Deflection Curve of Specimens BCJ58, BCJ59 & BCJ60	96
Figure 4.27	Load-Deflection Curve of Specimens BCJ61, BCJ62 & BCJ63	97
Figure 4.28	Load-Deflection Curve of Specimens BCJ64, BCJ65 & BCJ66	99
Figure 4.29	Load-Deflection Curve of Specimens BCJ67, BCJ68 & BCJ69	100
Figure 4.30	Load-Deflection Curve of Specimens BCJ70, BCJ71 & BCJ72	102
Figure 4.31	Load-Deflection Curve of Specimens BCJ73, BCJ74 & BCJ75	105
Figure 4.32	Load-Deflection Curve of Specimens BCJ76, BCJ77 & BCJ78	106
Figure 4.33	Load-Deflection Curve of Specimens BCJ79, BCJ80 & BCJ81	108

Figure 4.34	Load-Deflection Curve of Specimens BCJ82, BCJ83 & BCJ84	109
Figure 4.35	Load-Deflection Curve of Specimens BCJ85, BCJ86 & BCJ87	111
Figure 4.36	Load-Deflection Curve of Specimens BCJ88, BCJ89 & BCJ90	112
Figure 4.37	Load-Deflection Curve of Specimens BCJ91, BCJ92 & BCJ93	114
Figure 4.38	Load-Deflection Curve of Specimens BCJ94, BCJ95 & BCJ96	115
Figure 4.39	Load-Deflection Curve of Specimens BCJ97, BCJ98 & BCJ99	117
Figure 4.40	Load-Deflection Curve of Specimens BCJ100, BCJ101 & BCJ102	118
Figure 4.41	Load-Deflection Curve of Specimens BCJ103, BCJ104 & BCJ105	120
Figure 4.42	Load-Deflection Curve of Specimens BCJ106, BCJ107 & BCJ108	121
Figure 4.43	Load-Deflection Curve of Specimens BCJ109, BCJ110 & BCJ111	125
Figure 4.44	Load-Deflection Curve of Specimens BCJ112, BCJ113 & BCJ114	127
Figure 4.45	Load-Deflection Curve of Specimens BCJ115, BCJ116 & BCJ117	129
Figure 4.46	Load-Deflection Curve of Specimens BCJ118, BCJ119 & BCJ120	131
Figure 4.47	Load-Deflection Curve of Specimens BCJ121, BCJ122 & BCJ123	133
Figure 4.48	Load-Deflection Curve of Specimens BCJ124, BCJ125 & BCJ126	135
Figure 4.49	Load-Deflection Curve of Specimens BCJ127, BCJ128 & BCJ129	137
Figure 4.50	Load-Deflection Curve of Specimens BCJ130, BCJ131 & BCJ132	139
Figure 4.51	Load-Deflection Curve of Specimens BCJ133, BCJ134 & BCJ135	141
Figure 4.52	Load-Deflection Curve of Specimens BCJ136, BCJ137 & BCJ138	143
Figure 4.53	Load-Deflection Curve of Specimens BCJ139, BCJ140 & BCJ141	145
Figure 4.54	Load-Deflection Curve of Specimens BCJ142, BCJ143 & BCJ144	147
Figure 4.55	Load-Deflection Curve of Specimens BCJ145, BCJ146 & BCJ147	150
Figure 4.56	Load-Deflection Curve of Specimens BCJ148, BCJ149 & BCJ150	153
Figure 4.57	Load-Deflection Curve of Specimens BCJ151, BCJ152 & BCJ153	155
Figure 4.58	Load-Deflection Curve of Specimens BCJ154, BCJ155 & BCJ156	157
Figure 4.59	Load-Deflection Curve of Specimens BCJ157, BCJ158 & BCJ159	159
Figure 4.60	Load-Deflection Curve of Specimens BCJ160, BCJ161 & BCJ162	161
Figure 4.61	Load-Deflection Curve of Specimens BCJ163, BCJ164 & BCJ165	163
Figure 4.62	Load-Deflection Curve of Specimens BCJ166, BCJ167 & BCJ168	165
Figure 4.63	Load-Deflection Curve of Specimens BCJ169, BCJ170 & BCJ171	167
Figure 4.64	Load-Deflection Curve of Specimens BCJ172, BCJ173 & BCJ174	169
Figure 4.65	Load-Deflection Curve of Specimens BCJ175, BCJ176 & BCJ177	171
Figure 4.66	Load-Deflection Curve of Specimens BCJ178, BCJ179 & BCJ180	173
Figure 4.67	Load-Deflection Curve of Specimens BCJ181, BCJ182 & BCJ183	177
Figure 4.68	Load-Deflection Curve of Specimens BCJ184, BCJ185 & BCJ186	179

Figure 4.69	Load-Deflection Curve of Specimens BCJ187, BCJ188 & BCJ189	181
Figure 4.70	Load-Deflection Curve of Specimens BCJ190, BCJ191 & BCJ192	183
Figure 4.71	Load-Deflection Curve of Specimens BCJ193, BCJ194 & BCJ195	185
Figure 4.72	Load-Deflection Curve of Specimens BCJ196, BCJ197 & BCJ198	187
Figure 4.73	Load-Deflection Curve of Specimens BCJ199, BCJ200 & BCJ201	189
Figure 4.74	Load-Deflection Curve of Specimens BCJ202, BCJ203 & BCJ204	191
Figure 4.75	Load-Deflection Curve of Specimens BCJ205, BCJ206 & BCJ207	193
Figure 4.76	Load-Deflection Curve of Specimens BCJ208, BCJ209 & BCJ210	195
Figure 4.77	Load-Deflection Curve of Specimens BCJ211, BCJ212 & BCJ213	197
Figure 4.78	Load-Deflection Curve of Specimens BCJ214, BCJ215 & BCJ216	199
Figure 5.1	SOLID 65 Element	202
Figure 5.2	LINK 8 Element	203
Figure 5.3	SOLID 45 Element	203
Figure 5.4	Stress-Strain Curve for Concrete	204
Figure 5.5	Typical View of Reinforcement Detail as per Code IS 456:2000	205
Figure 5.6	Typical View of Reinforcement Detail as per Code IS 13920:1993	206
Figure 5.7	Typical View of Model of Beam-Column Joint	206
Figure 5.8	Typical View of Model of Retrofitted Beam-Column Joint	207
Figure 5.9	Simplified Compressive Uniaxial Stress-Strain Curve for Concrete	208
Figure 5.10	Stress-Strain Curve for Steel	209
Figure 5.11	Ansys Model for the Specimen BCJ2	211
Figure 5.12	Ansys Model for the Specimen BCJ5	211
Figure 5.13	Ansys Model for the Specimen BCJ8	212
Figure 5.14	Load-Deflection Curve for Specimens BCJ2, BCJ5 & BCJ8	212
Figure 5.15	Ansys Model for the Specimen BCJ38	213
Figure 5.16	Ansys Model for the Specimen BCJ41	213
Figure 5.17	Ansys Model for the Specimen BCJ44	214
Figure 5.18	Load-Deflection Curve for Specimens BCJ38, BCJ41 & BCJ48	214
Figure 5.19	Ansys Model for the Specimen BCJ74	215
Figure 5.20	Ansys Model for the Specimen BCJ77	215
Figure 5.21	Ansys Model for the Specimen BCJ80	216
Figure 5.22	Load-Deflection Curve for Specimens BCJ74, BCJ77 & BCJ80	216
Figure 5.23	Ansys Model for M35 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 456:2000	217
Figure 5.24	Ansys Model for M35 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 13920:1993	217

Figure 5.25	Ansys Model for M35 Concrete Beam-Column Joint Specimen Retrofitted with GFRP sheets	218
Figure 5.26	Load-Deflection Curve for M35 Concrete Specimens Retrofitted with GFRP Sheets	218
Figure 5.27	Ansys Model for M40 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 456:2000	219
Figure 5.28	Ansys Model for M40 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 13920:1993	219
Figure 5.29	Ansys Model for M40 Concrete Beam-Column Joint Specimen Retrofitted with GFRP sheets	219
Figure 5.30	Load-Deflection Curve for M40 Concrete Specimens Retrofitted with GFRP Sheets	220
Figure 5.31	Ansys Model for M45 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 456:2000	220
Figure 5.32	Ansys Model for M45 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 13920:1993	221
Figure 5.33	Ansys Model for M45 Concrete Beam-Column Joint Specimen Retrofitted with GFRP sheets	221
Figure 5.34	Load-Deflection Curve for M45 Concrete Specimens Retrofitted with GFRP Sheets	221
Figure 5.35	Ansys Model for M50 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 456:2000	222
Figure 5.36	Ansys Model for M50 Concrete Beam-Column Joint Specimen Reinforcement Detail as per Code IS 13920:1993	222
Figure 5.37	Ansys Model for M50 Concrete Beam-Column Joint Specimen Retrofitted with GFRP sheets	223
Figure 5.38	Load-Deflection Curve for M50 Concrete Specimens Retrofitted with GFRP Sheets	223
Figure 5.39	Ansys Model for M20 Concrete Specimen Retrofitted with AFRP Sheets	224
Figure 5.40	Load-Deflection Curve for M20 Concrete Specimen Retrofitted with AFRP Sheets	224
Figure 5.41	Ansys Model for M25 Concrete Specimen Retrofitted with AFRP Sheets	225
Figure 5.42	Load-Deflection Curve for M25 Concrete Specimen Retrofitted with AFRP Sheets	226
Figure 5.43	Ansys Model for M30 Concrete Specimen Retrofitted with AFRP Sheets	226
Figure 5.44	Load-Deflection Curve for M30 Concrete Specimen Retrofitted with AFRP Sheets	227
Figure 5.45	Ansys Model for M35 Concrete Specimen Retrofitted with AFRP Sheets	228
Figure 5.46	Load-Deflection Curve for M35 Concrete Specimen Retrofitted with AFRP Sheets	228
Figure 5.47	Ansys Model for M40 Concrete Specimen Retrofitted with AFRP Sheets	229

Figure 5.48	Load-Deflection Curve for M40 Concrete Specimen Retrofitted with AFRP Sheets	229
Figure 5.49	Ansys Model for M45 Concrete Specimen Retrofitted with AFRP Sheets	230
Figure 5.50	Load-Deflection Curve for M45 Concrete Specimen Retrofitted with AFRP Sheets	230
Figure 5.51	Ansys Model for M50 Concrete Specimen Retrofitted with AFRP Sheets	231
Figure 5.52	Load-Deflection Curve for M50 Concrete Specimen Retrofitted with AFRP Sheets	231
Figure 5.53	Ansys Model for M20 Concrete Specimen Retrofitted with CFRP Sheets	232
Figure 5.54	Load-Deflection Curve for M20 Concrete Specimen Retrofitted with CFRP Sheets	233
Figure 5.55	Ansys Model for M25 Concrete Specimen Retrofitted with CFRP Sheets	233
Figure 5.56	Load-Deflection Curve for M25 Concrete Specimen Retrofitted with CFRP Sheets	234
Figure 5.57	Ansys Model for M30 Concrete Specimen Retrofitted with CFRP Sheets	235
Figure 5.58	Load-Deflection Curve for M30 Concrete Specimen Retrofitted with CFRP Sheets	236
Figure 5.59	Ansys Model for M35 Concrete Specimen Retrofitted with CFRP Sheets	236
Figure 5.60	Load-Deflection Curve for M35 Concrete Specimen Retrofitted with CFRP Sheets	237
Figure 5.61	Ansys Model for M40 Concrete Specimen Retrofitted with CFRP Sheets	237
Figure 5.62	Load-Deflection Curve for M40 Concrete Specimen Retrofitted with CFRP Sheets	238
Figure 5.63	Ansys Model for M45 Concrete Specimen Retrofitted with CFRP Sheets	238
Figure 5.64	Load-Deflection Curve for M45 Concrete Specimen Retrofitted with CFRP Sheets	239
Figure 5.65	Ansys Model for M50 Concrete Specimen Retrofitted with CFRP Sheets	239
Figure 5.66	Load-Deflection Curve for M50 Concrete Specimen Retrofitted with CFRP Sheets	240
Figure 5.67	Load carrying Capacity Vs Grade of Concrete for the Specimens Retrofitted with GFRP sheets	241
Figure 5.68	Load carrying Capacity Vs Grade of Concrete for the Specimens Retrofitted with AFRP sheets	242
Figure 5.69	Load carrying Capacity Vs Grade of Concrete for the Specimens Retrofitted with CFRP sheets	242
Figure 5.70	Grade of Concrete Vs Deflection for GFRP, AFRP & CFRP Sheets	243

LIST OF TABLES

		Page No.
Table 3.1	Mix Proportion for M20 Concrete	46
Table 3.2	Mix Proportion for M20,M25 & M30 Concrete	47
Table 3.3	Details of the Retrofitting Sheets	47
Table 4.1	Details of the Number of Specimen Tested	54
Table 4.2	Details of the Specimens	54
Table 4.3	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M20 Concrete Specimens subjected to Static Load	82
Table 4.4	Cost of Retrofitting Materials	84
Table 4.5	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M25 Concrete Specimens subjected to Static Load	102
Table 4.6	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M30 Concrete Specimens subjected to Static Load	122
Table 4.7	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M20 Concrete Specimens subjected to Reversal Load	148
Table 4.8	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M25 Concrete Specimens subjected to Reversal Load	174
Table 4.9	Percentage Increase in Load Carrying Capacity & Energy Absorption Capacity of M30 Concrete Specimens subjected to Reversal Load	199
Table 5.1	Details of the Element	205
Table 5.2	Material Properties of Reinforced Cement Concrete	210
Table 5.3	Percentage Error between Experimental Results and Ansys Results for M20 Concrete Specimens Retrofitted with GFRP Sheets	212
Table 5.4	Percentage Error between Experimental Results and Ansys Results for M25 Concrete Specimens Retrofitted with GFRP Sheets	214
Table 5.5	Percentage Error between Experimental Results and Ansys Results for M30 Concrete Specimens Retrofitted with GFRP Sheets	216
Table 5.6	Percentage Error between Experimental Results and Ansys Results for M20 Concrete Specimens Retrofitted with AFRP Sheets	224
Table 5.7	Percentage Error between Experimental Results and Ansys Results for M25 Concrete Specimens Retrofitted with AFRP Sheets	225
Table 5.8	Percentage Error between Experimental Results and Ansys Results for M30 Concrete Specimens Retrofitted with AFRP Sheets	227

Table 5.9	Percentage Error between Experimental Results and Ansys Results for M20 Concrete Specimens Retrofitted with CFRP Sheets	232
Table 5.10	Percentage Error between Experimental Results and Ansys Results for M25 Concrete Specimens Retrofitted with CFRP Sheets	234
Table 5.11	Percentage Error between Experimental Results and Ansys Results for M30 Concrete Specimens Retrofitted with CFRP Sheets	235