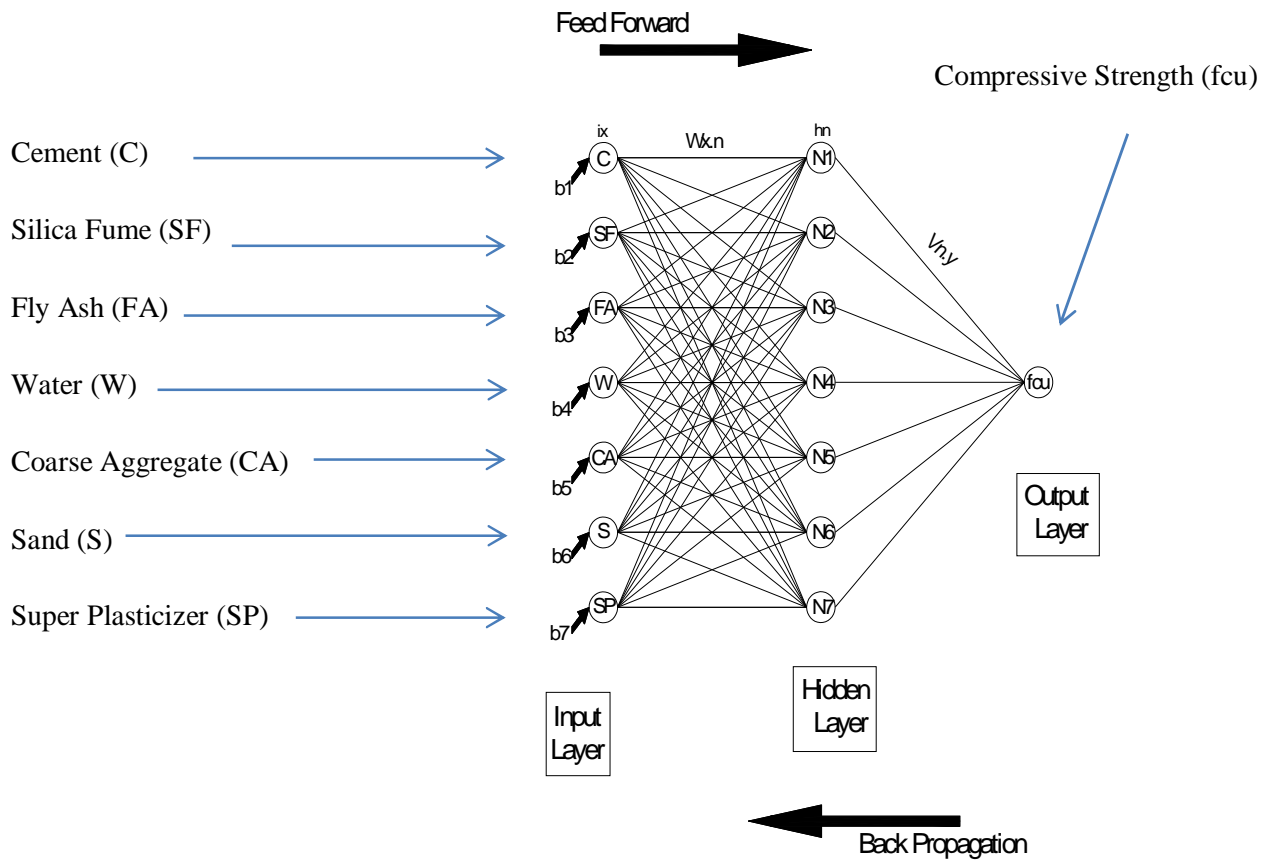




APPENDICES

Appendix A: Artificial Neural Network Model: Architecture, Weights and Biases.



weight	wi1	wi2	wi3	wi4	wi5	wi6	Wi7	Vi1	BIAS
w1j	-2.490387	-1.251994	2.2633533	-0.4312406	1.55379764	1.3218645	-3.734475	0.3328272	5.74005374
w2j	0.9742005	-0.336713	1.9058815	-0.1296784	-0.7737077	0.5276251	-1.627903	-1.734772	3.56813604
W3j	1.4194863	-2.728547	-4.2247391	-1.0960639	0.61257985	1.8562197	0.9866486	0.4998835	-2.8920368
W4j	-2.322465	-0.12236	0.3825415	2.3324921	-4.6968895	0.0115141	1.0920925	3.2945255	7.65444373
W5j	-2.99841	-1.400824	1.4892267	-3.9730118	-1.2200427	1.5316088	-4.587274	2.8448677	0.81177753
W6j	-0.665216	-2.422694	1.5824882	-5.217652	-2.0618386	3.0981017	-9.097224	-1.636755	-3.531533
W7j	-6.30838	2.410404	2.1740722	2.8319378	-0.3393207	-3.031915	6.9547146	-0.255169	8.89920935



Appendix B: Training Data.

Square Error = (Prediction Results – Experiment result)²

Mean Square Error (MSE) = $\frac{1}{n} \sum_{i=0}^n (\text{Prediction Results} - \text{Experiment result})^2$

n = number of data for the two data sets, x and y.

Relative Error % = $\frac{\text{Prediction Results} - \text{Experiment result}}{\text{Experiment result}} * 100$

S/N	Main Components + Additives							Compressive Strength MPa		Error	
	Cement Kg/m ³	Silica Fume Kg/m ³	Fly aAsh Kg/m ³	Water Kg/m ³	Coares Aggregate Kg/m ³	Sand Kg/m ³	Super Plasticizer Liter/m ³	Experimental Results	Predicted Results	Square Error	Relative Error %
1	529.01	42.87	0.00	169.28	1171.80	594.58	9.23	67.00	60.77	38.83	(9.30)
2	514.72	57.16	0.00	169.86	1171.80	589.35	9.75	65.20	59.83	28.81	(8.23)
3	486.12	28.58	57.16	170.14	1171.80	577.28	16.72	66.00	60.41	31.20	(8.46)
4	457.53	57.16	57.16	169.29	1171.80	566.82	17.19	64.80	61.96	8.07	(4.38)
5	450.00	0.00	0.00	220.50	1228.50	616.50	0.00	46.60	44.14	6.04	(5.27)
6	475.00	0.00	0.00	199.50	1040.25	498.75	0.00	54.50	52.49	4.05	(3.69)
7	425.00	0.00	0.00	221.00	858.50	607.75	0.00	40.00	40.79	0.63	1.98
8	450.00	0.00	0.00	220.50	837.00	580.50	0.00	45.30	45.57	0.07	0.59
9	450.00	0.00	0.00	229.50	891.00	175.50	0.00	42.70	43.01	0.10	0.72
10	475.00	0.00	0.00	218.50	817.00	560.50	0.00	48.70	49.68	0.97	2.02
11	475.00	0.00	0.00	228.00	869.25	598.50	0.00	45.50	44.67	0.68	(1.81)
12	400.00	0.00	0.00	180.00	1080.00	440.00	0.00	47.90	50.13	4.98	4.66
13	425.00	0.00	0.00	191.25	1139.00	463.25	0.00	50.40	49.71	0.48	(1.38)
14	450.00	0.00	0.00	189.00	1102.50	441.00	0.00	54.10	54.57	0.22	0.87
15	400.00	0.00	0.00	200.00	884.00	528.00	0.00	44.00	43.12	0.77	(2.00)
16	425.00	0.00	0.00	199.75	862.75	505.75	0.00	47.40	46.82	0.33	(1.22)
17	425.00	0.00	0.00	208.25	926.50	548.25	0.00	44.70	44.83	0.02	0.30
18	450.00	0.00	0.00	198.00	837.00	481.50	0.00	50.90	50.62	0.08	(0.55)
19	450.00	0.00	0.00	211.50	900.00	526.50	0.00	48.10	48.94	0.71	1.75
20	475.00	0.00	0.00	199.50	798.00	451.25	0.00	54.10	54.05	0.00	(0.09)
21	475.00	0.00	0.00	209.00	874.00	503.50	0.00	51.30	53.11	3.28	3.53
22	411.00	102.20	0.00	143.85	1044.00	773.00	5.11	67.33	67.02	0.10	(0.46)
23	386.00	127.75	0.00	142.82	1044.00	773.00	5.11	63.11	63.99	0.78	1.40



24	396.60	16.50	0.00	154.67	722.00	826.00	7.00	75.20	74.74	0.21	(0.61)
25	380.00	33.00	0.00	144.40	722.00	826.00	7.00	86.10	82.85	10.56	(3.77)
26	363.50	49.60	0.00	138.13	722.00	826.00	7.00	85.40	88.34	8.64	3.44
27	316.80	3.20	0.00	158.40	1040.00	840.00	4.75	40.20	47.64	55.38	18.51
28	388.00	24.00	0.00	186.24	915.00	811.00	2.32	56.50	58.31	3.29	3.21
29	564.00	0.00	0.00	157.92	1068.00	647.00	0.00	98.25	88.58	93.50	(9.84)
30	500.00	30.00	0.00	135.00	1100.00	700.00	14.00	93.00	93.13	0.02	0.14
31	481.28	30.72	0.00	163.64	1037.22	594.40	3.07	89.10	84.73	19.09	(4.90)
32	476.16	35.84	0.00	161.89	1037.22	594.40	3.58	90.60	86.29	18.54	(4.75)
33	471.04	40.96	0.00	160.15	1037.22	594.40	4.10	92.00	87.75	18.09	(4.62)
34	622.00	0.00	0.00	180.38	1235.00	490.00	0.00	72.46	67.62	23.39	(6.68)
35	560.00	0.00	62.00	184.80	1235.00	474.00	0.00	70.98	71.17	0.04	0.27
36	498.00	0.00	124.00	184.26	1235.00	446.00	0.00	71.23	68.50	7.48	(3.84)
37	435.00	0.00	187.00	182.70	1235.00	418.00	0.00	71.30	70.57	0.53	(1.02)
38	467.00	0.00	0.00	182.13	1235.00	633.00	0.00	60.52	56.88	13.21	(6.01)
39	420.00	0.00	47.00	184.80	1235.00	612.00	0.00	58.16	56.59	2.46	(2.70)
40	374.00	0.00	93.00	187.00	1235.00	591.00	0.00	58.74	59.63	0.79	1.52
41	327.00	0.00	140.00	183.12	1235.00	570.00	0.00	57.46	58.50	1.07	1.80
42	467.00	11.68	0.00	182.13	1235.00	619.00	0.00	61.13	61.36	0.05	0.37
43	467.00	23.35	0.00	182.13	1235.00	605.00	0.00	63.62	65.23	2.59	2.53
44	467.00	35.03	0.00	182.13	1235.00	691.00	0.00	64.32	64.74	0.17	0.65
45	361.30	0.00	63.70	202.33	968.00	394.00	0.00	41.10	42.35	1.57	3.05
46	403.80	0.00	71.00	201.90	884.00	424.00	0.00	47.30	46.29	1.02	(2.14)
47	403.80	0.00	71.00	209.98	993.00	480.50	0.00	43.60	42.67	0.86	(2.13)
48	361.30	0.00	63.70	191.49	968.00	394.00	0.00	42.00	43.21	1.46	2.87
49	382.50	0.00	67.50	191.25	937.00	375.00	0.00	47.30	46.82	0.23	(1.01)
50	382.50	0.00	67.50	198.90	711.50	409.00	0.00	43.20	43.49	0.09	0.68
51	403.80	0.00	71.00	201.90	678.00	383.60	0.00	47.90	45.40	6.27	(5.23)
52	403.80	0.00	71.00	218.05	694.50	472.50	0.00	40.30	43.10	7.82	6.94
53	379.00	0.00	126.00	151.60	1037.00	775.00	2.20	64.00	60.63	11.37	(5.27)
54	424.00	0.00	106.00	148.40	1040.00	767.00	2.00	67.40	70.06	7.10	3.95
55	397.00	0.00	133.00	150.86	1040.00	767.00	2.00	63.00	63.13	0.02	0.21
56	470.00	35.00	0.00	150.40	1037.00	775.00	2.00	65.00	65.49	0.24	0.76
57	454.00	51.00	0.00	149.82	1037.00	775.00	2.00	62.00	63.61	2.60	2.60
58	404.00	101.00	0.00	149.48	1037.00	775.00	2.00	52.90	57.46	20.77	8.61
59	477.00	53.00	0.00	147.87	1040.00	767.00	2.20	72.30	68.56	13.99	(5.17)
60	450.00	80.00	0.00	148.50	1040.00	767.00	2.20	66.10	64.29	3.28	(2.74)
61	424.00	106.00	0.00	148.40	1040.00	767.00	2.20	64.00	60.48	12.42	(5.51)



62	403.00	51.00	51.00	149.11	1037.00	775.00	2.00	62.80	63.16	0.13	0.58
63	379.00	76.00	51.00	151.60	1037.00	775.00	2.00	68.80	66.19	6.83	(3.80)
64	353.00	101.00	51.00	151.79	1037.00	775.00	2.00	65.00	67.94	8.62	4.52
65	394.00	12.00	0.00	181.24	915.00	811.00	1.68	53.80	52.10	2.90	(3.17)
66	403.80	0.00	71.00	209.98	993.00	480.50	0.00	44.00	42.67	1.76	(3.02)
67	403.80	0.00	71.00	218.05	1013.50	496.70	0.00	40.70	41.30	0.36	1.47
68	429.00	0.00	76.00	154.44	1037.00	775.00	2.00	61.40	64.30	8.42	4.73
69	404.00	0.00	101.00	149.48	1037.00	775.00	2.00	63.00	64.24	1.53	1.97
70	471.82	42.87	57.16	169.86	1171.80	572.05	17.19	57.33	61.43	16.84	7.16
71	571.19	0.00	0.00	171.36	1171.80	609.72	6.97	54.67	60.89	38.73	11.38
72	529.01	42.87	0.00	169.28	1171.80	594.58	9.23	61.33	60.77	0.31	(0.91)
73	486.12	28.58	57.16	170.14	1171.80	577.28	16.72	58.67	60.41	3.04	2.97
74	486.12	28.58	57.16	170.14	1171.80	577.28	16.72	56.00	60.41	19.49	7.88
75	471.82	42.87	57.16	169.86	1171.80	572.05	17.19	64.00	61.43	6.59	(4.01)
76	400.00	0.00	0.00	200.00	1128.00	572.00	0.00	43.10	44.17	1.15	2.49
77	425.00	0.00	0.00	199.75	1096.50	544.00	0.00	47.20	46.04	1.34	(2.45)
78	425.00	0.00	0.00	208.25	1177.25	590.75	0.00	45.10	47.98	8.27	6.38
79	450.00	0.00	0.00	198.00	1057.50	513.00	0.00	49.60	49.65	0.00	0.10
80	450.00	0.00	0.00	211.50	1143.00	562.50	0.00	47.40	46.14	1.59	(2.66)
81	475.00	0.00	0.00	199.50	1040.25	498.75	0.00	54.00	52.49	2.29	(2.80)
82	475.00	0.00	0.00	209.00	1168.50	565.25	0.00	50.10	50.45	0.12	0.70
83	400.00	0.00	0.00	200.00	1128.00	572.00	0.00	44.10	44.17	0.01	0.16
84	425.00	0.00	0.00	199.75	1096.50	544.00	0.00	47.50	46.04	2.12	(3.07)
85	425.00	0.00	0.00	208.25	1177.25	590.75	0.00	45.30	47.98	7.16	5.91
86	425.00	0.00	0.00	216.75	1253.75	641.75	0.00	42.50	43.77	1.60	2.98
87	450.00	0.00	0.00	198.00	1057.50	513.00	0.00	52.00	49.65	5.52	(4.52)
88	450.00	0.00	0.00	211.50	1143.00	562.50	0.00	48.70	46.14	6.56	(5.26)
89	580.00	0.00	0.00	162.40	1190.00	680.00	3.01	54.00	56.71	7.37	5.03
90	622.00	15.55	0.00	180.38	1235.00	471.00	0.00	72.88	70.51	5.63	(3.26)
91	622.00	31.10	0.00	180.38	1235.00	452.00	0.00	73.35	73.27	0.01	(0.11)
92	622.00	46.65	0.00	180.38	1235.00	434.00	0.00	73.87	75.82	3.78	2.63
93	622.00	62.20	0.00	180.38	1235.00	415.00	0.00	75.13	78.33	10.21	4.25
94	382.50	0.00	67.50	210.38	971.50	478.00	0.00	40.30	40.60	0.09	0.74
95	403.80	0.00	71.00	201.90	884.00	424.00	0.00	48.40	46.29	4.46	(4.36)
96	571.19	0.00	0.00	171.36	1171.80	609.72	6.97	54.67	60.89	38.73	11.38
97	317.00	0.00	0.00	133.00	1145.00	749.00	9.00	72.00	73.43	2.03	1.98
98	471.00	41.00	0.00	162.00	1037.00	594.00	4.00	74.00	86.36	152.71	16.70
99	385.00	165.00	83.00	194.00	1069.00	386.00	17.00	74.00	71.23	7.65	(3.74)



100	385.00	165.00	55.00	175.00	1133.00	409.00	17.00	75.00	75.95	0.90	1.26
101	466.00	46.00	0.00	161.00	1037.00	594.00	5.00	77.00	86.85	97.03	12.79
102	385.00	165.00	28.00	153.00	1198.00	433.00	17.00	77.00	77.95	0.90	1.23
103	560.00	0.00	0.00	153.00	981.00	764.00	8.00	78.00	76.84	1.33	(1.48)
104	360.00	0.00	150.00	148.00	1157.00	603.00	4.00	80.00	81.34	1.80	1.67
105	532.00	28.00	0.00	152.00	975.00	760.00	10.00	80.00	78.15	3.41	(2.31)
106	449.00	39.00	0.00	130.00	1149.00	758.00	14.00	82.00	81.72	0.08	(0.35)
107	315.00	36.00	0.00	145.00	1130.00	745.00	7.00	82.00	76.60	29.20	(6.59)
108	385.00	165.00	0.00	135.00	1256.00	454.00	17.00	83.00	81.58	2.01	(1.71)
109	560.00	70.00	70.00	154.00	1014.00	522.00	14.00	100.00	102.56	6.55	2.56
110	517.00	58.00	0.00	126.00	1126.00	641.00	31.00	107.00	106.29	0.50	(0.66)
111	550.00	60.00	0.00	122.00	1120.00	620.00	16.00	125.00	123.59	2.00	(1.13)
112	550.00	60.00	0.00	122.00	1120.00	620.00	12.00	127.00	124.93	4.27	(1.63)
113	400.00	0.00	0.00	160.00	1204.00	678.00	10.00	51.00	53.09	4.38	4.11
114	360.00	40.00	0.00	160.00	1212.00	666.00	10.00	63.00	63.58	0.34	0.93
115	405.00	0.00	0.00	175.00	1120.00	695.00	0.00	52.00	50.84	1.34	(2.23)
116	247.00	0.00	125.00	143.00	1087.00	801.00	12.00	53.00	51.71	1.67	(2.44)
117	385.00	0.00	136.00	158.00	903.00	768.00	20.00	56.00	58.76	7.62	4.93
118	525.00	0.00	0.00	189.00	1125.00	613.00	0.00	56.00	63.45	55.46	13.30
119	528.00	0.00	0.00	185.00	920.00	720.00	7.00	57.00	57.32	0.10	0.56
120	285.00	0.00	133.00	159.00	1054.00	744.00	2.00	50.00	49.51	0.24	(0.98)
121	478.00	0.00	60.00	142.00	980.00	650.00	6.00	100.00	101.81	3.27	1.81
122	637.00	0.00	0.00	150.00	936.00	711.00	23.00	97.00	99.64	6.98	2.72
123	475.00	0.00	158.00	150.00	924.00	681.00	23.00	106.00	101.61	19.27	(4.14)
124	488.00	0.00	0.00	205.00	1160.00	497.00	5.00	43.00	43.86	0.74	1.99
125	459.00	26.00	0.00	204.00	1118.00	736.00	10.00	44.00	47.23	10.45	7.35
126	421.00	59.00	0.00	198.00	1118.00	736.00	10.00	47.00	50.21	10.29	6.82
127	433.00	51.00	0.00	204.00	1118.00	736.00	10.00	48.00	47.84	0.03	(0.34)
128	470.00	49.00	0.00	198.00	1118.00	736.00	5.00	48.00	48.66	0.44	1.38
129	488.00	39.00	0.00	205.00	1160.00	497.00	5.00	49.00	51.16	4.66	4.41
130	510.00	74.00	0.00	204.00	1118.00	736.00	10.00	49.00	45.40	12.93	(7.34)
131	390.00	0.00	0.00	179.00	1102.00	798.00	3.00	50.00	48.00	3.98	(3.99)
132	450.00	25.00	0.00	198.00	1118.00	736.00	10.00	50.00	48.00	4.02	(4.01)
133	474.00	0.00	0.00	180.00	1419.00	342.00	0.00	51.00	51.70	0.49	1.37
134	436.00	45.00	0.00	198.00	1118.00	736.00	10.00	52.00	49.15	8.14	(5.49)
135	467.00	0.00	0.00	160.00	1067.00	667.00	0.00	54.00	66.35	152.52	22.87
136	232.00	0.00	105.00	162.00	1035.00	696.00	11.00	56.00	56.02	0.00	0.03
137	419.00	0.00	47.00	163.00	1119.00	746.00	4.00	60.00	54.95	25.49	(8.41)

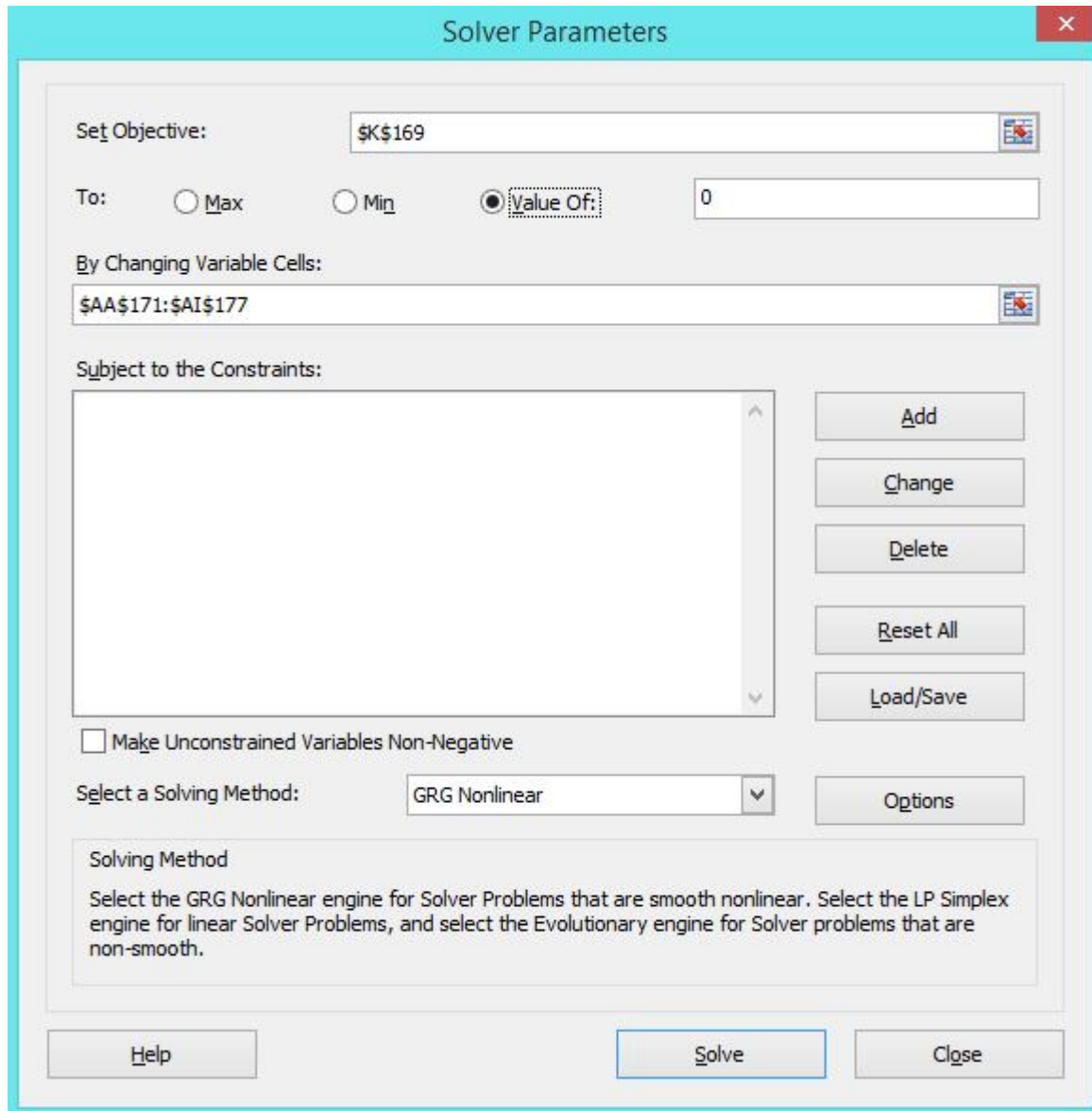


138	505.00	51.00	0.00	151.00	1037.00	775.00	18.00	61.00	64.09	9.58	5.07
139	386.00	128.00	0.00	143.00	1044.00	773.00	5.00	63.00	63.43	0.19	0.68
140	495.00	77.00	0.00	171.00	1033.00	689.00	10.00	64.00	66.52	6.34	3.94
141	550.00	0.00	0.00	181.00	1120.00	620.00	4.00	64.00	58.05	35.45	(9.30)
142	505.00	101.00	0.00	151.00	1037.00	775.00	18.00	64.00	65.37	1.88	2.14
143	505.00	0.00	51.00	151.00	1037.00	775.00	18.00	65.00	63.84	1.34	(1.78)
144	505.00	101.00	51.00	151.00	1037.00	775.00	19.00	65.00	65.27	0.07	0.41
145	500.00	0.00	60.00	178.00	1068.00	608.00	0.00	65.00	67.80	7.83	4.30
146	390.00	0.00	100.00	161.00	1141.00	575.00	0.00	65.00	65.00	0.00	(0.00)
147	436.00	59.00	0.00	183.00	1033.00	689.00	10.00	62.00	60.10	3.63	(3.07)
148	505.00	0.00	76.00	151.00	1037.00	775.00	18.00	62.00	63.66	2.76	2.68
149	505.00	51.00	51.00	151.00	1037.00	775.00	18.00	63.00	65.51	6.30	3.99
150	505.00	0.00	126.00	151.00	1037.00	775.00	18.00	63.00	63.18	0.03	0.28
151	505.00	76.00	0.00	151.00	1037.00	775.00	18.00	63.00	64.61	2.58	2.55
152	530.00	0.00	0.00	150.00	1040.00	767.00	19.00	70.00	69.40	0.36	(0.86)
153	485.00	0.00	0.00	130.00	1143.00	762.00	4.00	70.00	69.60	0.16	(0.58)
154	486.00	54.00	0.00	173.00	1089.00	667.00	7.00	70.00	68.44	2.44	(2.23)
155	530.00	53.00	0.00	150.00	1040.00	767.00	19.00	71.00	66.56	19.69	(6.25)
156	530.00	80.00	53.00	150.00	1040.00	767.00	19.00	71.00	70.01	0.98	(1.39)
157	436.00	77.00	0.00	143.00	1044.00	773.00	5.00	71.00	69.60	1.97	(1.98)
158	505.00	0.00	60.00	195.00	1030.00	630.00	0.00	64.00	64.27	0.07	0.42
159	540.00	0.00	0.00	173.00	1125.00	613.00	0.00	67.00	71.66	21.69	6.95
160	500.00	0.00	0.00	140.00	966.00	853.00	4.00	68.00	72.46	19.87	6.55
161	522.00	0.00	0.00	146.00	896.00	896.00	0.00	75.00	72.37	6.94	(3.51)
162	540.00	0.00	0.00	162.00	1040.00	676.00	3.00	80.00	78.41	2.52	(1.98)
163	500.00	30.00	0.00	143.00	1100.00	700.00	0.00	81.00	81.22	0.05	0.27
164	416.00	0.00	0.00	153.00	1030.00	737.00	3.00	82.00	67.11	221.80	(18.16)

Sum Mean Square Error	10.67	Max Error%	22.87
Max Square Error	221.8	Min Error%	-18.16
Min Square Error	0.00		
Arith.Mean	10.66		
St.Dev.	26.89		



Appendix C: Solver Parameters & Options





Options ? x

All Methods | GRG Nonlinear | Evolutionary

Convergence: 0.0001

Mutation Rate: 0.075

Population Size: 165

Random Seed: 0

Maximum Time without improvement: 30

Require Bounds on Variables

OK Cancel

Options ? x

All Methods | GRG Nonlinear | Evolutionary

Convergence: 0.0001

Derivatives
 Forward Central

Multistart
 Use Multistart

Population Size: 165

Random Seed: 0

Require Bounds on Variables

OK Cancel



Options ? ✕

All Methods | GRG Nonlinear | Evolutionary

Constraint Precision:

Use Automatic Scaling

Show Iteration Results

Solving with Integer Constraints

Ignore Integer Constraints

Integer Optimality (%):

Solving Limits

Max Time (Seconds):

Iterations:

Evolutionary and Integer Constraints:

Max Subproblems:

Max Feasible Solutions: