Chapter 5

Results

The validity and efficiency of the proposed ACO algorithm are investigated by solving four numerical examples. They are sizing optimization problems of three truss structures and one frame structure. To be able to clearly see the advantages of the proposed algorithm, the obtained results of the first two problems are compared in detail with those obtained by a GA. A GA is selected for comparison because it is well accepted that GAs are currently one of the best optimization techniques available. The comparison of the results from these two techniques includes not only the quality but also the uniformity of the results. In this way, the actual performance of the proposed algorithm can readily be discussed. Finally, the obtained results are also compared with those from the literature.

5.1 Six-Bar Truss

The first problem to be considered is the six-bar truss shown in Figure 5.1. Since only sizing optimization is considered, design variables are six sectional areas of the six members of the truss. The cross-sectional area of each member is taken from the following 32 discrete values, i.e. 1.62, 1.80, 2.38, 2.62, 2.88, 3.09, 3.13, 3.38, 3.63, 3.84, 3.87, 4.18, 4.49, 4.80, 4.97, 5.12, 5.74, 7.22, 7.97, 11.5, 13.5, 13.9, 14.2, 15.5, 16.0, 18.8, 19.9, 22.0, 22.9, 26.5, 30.0, and 33.5 in.^{2} There are two types of constraint in this problem, i.e. stress and displacement constraints. The design parameters used in the problem are shown in Table 5.1. Note that, in the calculation of stress and displacement responses, only the point loads shown in Figure 5.1 are considered as the applied forces, whereas the weight of the structure is neglected.

In this problem, the basic quality function Q_o and constraint-violation function E_r are defined as

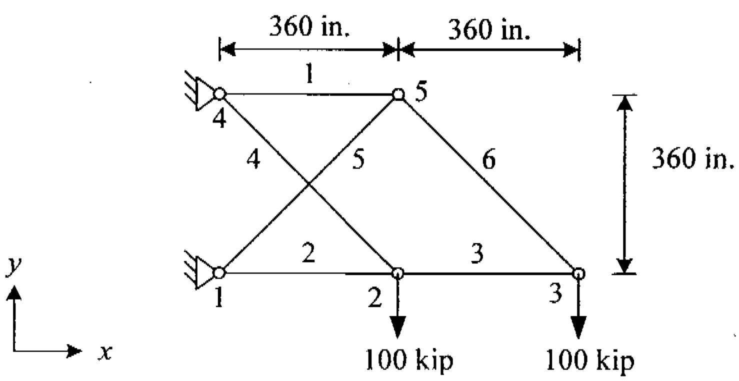

Figure 5.1 Six-bar truss

$$Q_o(\mathbf{A}) = \frac{1}{1+Weight} \ , \tag{5.1a}$$

$$E_r(\mathbf{A}) = \sum_{i=1}^{NE} \max\left(\frac{|\sigma_i| - \sigma_a}{\sigma_a}, 0\right) + \sum_{i=1}^{NN} \max\left(\frac{|v_i| - v_a}{v_a}, 0\right). \tag{5.1b}$$

Here, the unit of weight used is pound. In addition, σ and v represent the stress and the *y*-displacement, respectively. The subscript a denotes the allowable values. In addition, *NE* and *NN* represent the number of elements and the number of nodes, respectively. Note that, in this problem, there is no constraint on the horizontal displacement. Note further that the unit of area for the calculation of η in Equation 4.10 is in.^{2}

Table 5.1 also shows the ACO parameters used in this problem. To enable the efficiency of the proposed algorithm to be clearly discussed, various sets of calculations with different numbers of ants are performed. In addition, to allow the effect of the greedy heuristic to be identified, the value of β in Equation 4.9 is also varied. Note that when β is zero, it simply means that the greedy heuristic is not employed. For each set of calculations, 200 runs are carried out. The reason why many runs are required for each set of calculations is that the ACO technique includes probabilistic processes. As a result, even with the same problem and the same calculation parameters, different results may be obtained from different runs. Many test runs permit the efficiency of the technique, in terms of the quality as well as the uniformity of the results, to be discussed.

As mentioned earlier, the problem is also solved by using a GA. Here, a standard GA is used. The quality function for the ACO algorithm defined in Equation 4.3, with its components defined in Equation 5.1, is used as the fitness function in the GA. In addition,

Table 5.1 Design and ACO parameters for the six-bar truss problem

Design parameters		ACO parameters	
Item	Value		
Modulus of elasticity	10^7 psi	Number of ants	100, 200, 300
Weight density	0.1 lb/in.^{3}	Number of tours	100
Allowable tensile stress	25,000 psi	ρ	0.3
Allowable compressive stress	25,000 psi	λ	0.0002
Maximum *y*-displacement	2 in.	C	2
		Z	5
		α	1
		β	0, 0.001, 0.003, 0.005, 0.007, 0.009

Table 5.2 GA parameters for the six-bar truss problem

Item	Value
Population size	100, 200, 300
Number of generations	100
Crossover probability	0.85
Mutation probability	0.05
λ	0.0002
C	2
Z	5

Table 5.3 Comparison of the results obtained by the proposed algorithm and the standard GA for the six-bar truss problem

Number of ants / Population size		Proposed algorithm β 0	0.001	0.003	0.005	0.007	0.009	GA
100	Average weight (lb)	4990.0	4987.1	4990.3	4988.5	4994.4	4992.7	5022.3
	Minimum weight (lb)	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**
	Maximum weight (lb)	5285.4	5180.0	5347.0	5235.1	5334.7	5244.8	5418.4
	SD of weights (lb)	41.7	30.0	42.0	33.2	48.1	43.9	69.9
200	Average weight (lb)	4970.0	4968.9	4970.2	4969.7	4971.0	4969.7	4979.6
	Minimum weight (lb)	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**
	Maximum weight (lb)	5021.4	5018.3	5019.4	5018.3	5106.5	5019.4	5120.2
	SD of weights (lb)	10.8	9.8	11.6	10.9	16.0	10.5	20.6
300	Average weight (lb)	4966.0	4965.9	4965.3	4965.7	4966.1	4964.8	4969.5
	Minimum weight (lb)	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**	**4962.1**
	Maximum weight (lb)	5000.3	5014.8	4981.2	5003.9	5000.3	4984.8	5020.5
	SD of weights (lb)	7.1	7.7	5.7	7.5	7.6	5.6	10.8

Table 5.4 Comparison of the best result for the six-bar truss problem with the literature

Member	Size of member ($in.^2$) Proposed	GAs Rajan (1995)	Nanakorn and Meesomklin (2001)
1	30.0	30.0	30.0
2	19.9	19.9	19.9
3	15.5	15.5	15.5
4	7.22	7.22	7.22
5	22.0	22.0	22.0
6	22.0	22.0	22.0
Total weight (lb)	**4962.1**	**4962.1**	**4962.1**

the bilinear scaling techniques shown in Figure 4.2 are also used for fitness scaling in the GA. In the GA calculation, three sets of calculations with different population sizes are performed and, for each set, 200 runs are carried out. Note that GAs also contain probabilistic processes, and to investigate the efficiency of GAs, many runs are required. Table 5.2 shows the GA parameters used in this problem.

The best design is defined as an admissible design with the minimum weight. Consequently, the solution of a run is defined as the best design ever found in that run even though it may not be the best design of the last tour of the ACO algorithm or the last generation of the GA. For each set of calculations, after the 200 solutions of its 200 runs are obtained, the minimum, maximum, average and standard deviation values of the weights of the 200 solutions are found. Among the 200 solutions, the solution with the minimum weight is naturally the best solution for that particular set of calculations. Figure 5.2 schematically shows the process to obtain statistics of a calculation set.

Table 5.3 shows the results obtained from the proposed ACO algorithm for various numbers of ants and values of β. It can be seen that the best solutions obtained with 100, 200 and 300 ants and with different values of β are all the same. Nevertheless, the average and worst solutions are improved when the number of ants is increased from 100 to 300.

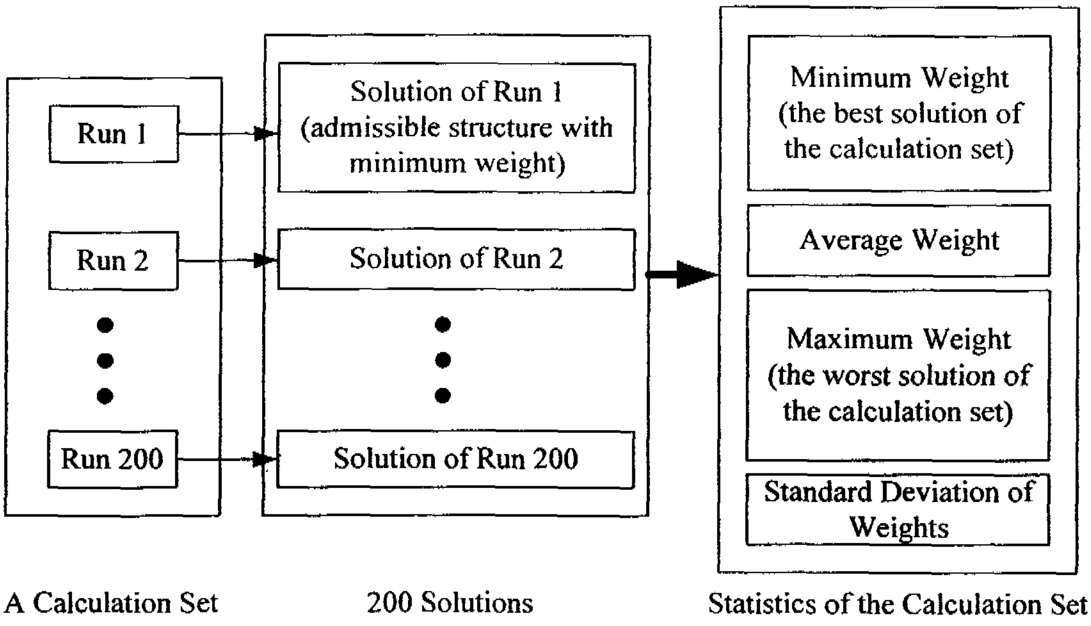

Figure 5.2 Calculation set and its extracted information

Table 5.5 Constrained displacements and stresses of the best result for the six-bar truss problem

Node/Element	y-displacement (in.)	Stress (ksi)
1	0	6.67
2	-1.77	-10.1
3	**-2.00**	-6.45
4	0	19.6
5	-0.703	-6.43
6	–	6.43

For the worst solutions, the improvements are rather significant. In addition, the standard deviation of the weights of the solutions also decreases drastically when more ants are used. This indicates that the quality of the solutions obtained with more ants is more consistent. In this problem, the greedy heuristic does not improve the quality of the results and its effect is insignificant.

Table 5.3 also shows the results obtained by the GA. The GA also gives the same best solutions as those of the ACO algorithm regardless of the population size. Moreover, increasing the population size also increases the quality of the average and worst solutions. Nonetheless, the average and worst solutions from the GA are inferior to those from the ACO algorithm. This inferiority is more pronounced when the number of ants and the population size are small. The standard deviations of the weights of the GA solutions are also larger than those of the ACO solutions. This clearly shows that the ACO algorithm yields solutions that are more uniform than the GA solutions.

The best result obtained from the proposed ACO algorithm is compared with results reported in the literature in Table 5.4. The results from the literature are obtained by GAs. It can be seen that these results are the same. Table 5.5 shows the constrained displacements and stresses of this best result. It can be clearly seen that the critical constraint is the y-displacement constraint.

5.2. Ten-Bar Truss

The next problem to be considered is the ten-bar truss shown in Figure 5.3. This problem is one of the benchmark problems used to test structural optimization methods. Also in this problem, only sizing optimization is considered. Therefore, design variables are ten sectional areas. The cross-sectional areas of members 1, 3, 4, 7, 8 and 9 are taken

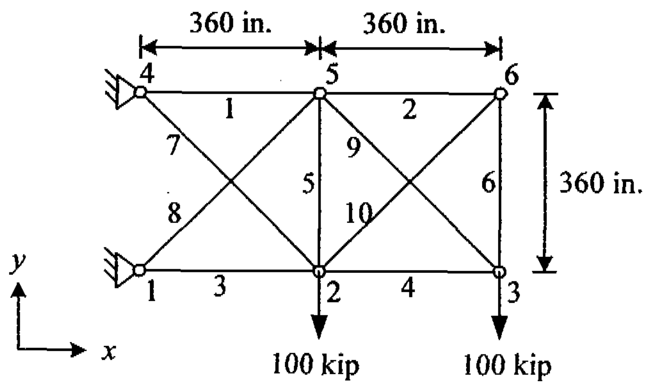

Figure 5.3 Ten-bar truss

Table 5.6 Design and ACO parameters for the ten-bar truss problem

Design parameters		ACO parameters	
Item	Value		
Modulus of elasticity	10^7 psi	Number of ants	100, 200, 300
Weight density	0.1 lb/in.^{3}	Number of tours	200
Allowable tensile stress	25,000 psi	ρ	0.3
Allowable compressive stress	25,000 psi	λ	0.0002
Maximum x- and y-displacements	2 in.	C	2
		Z	5
		α	1
		β	0, 0.1, 0.2, 0.3, 0.4

Table 5.7 GA parameters for the ten-bar truss problem

Item	Value
Population size	100, 200, 300
Number of generations	200
Crossover probability	0.85
Mutation probability	0.05
λ	0.0002
C	2
Z	5

Table 5.8 Comparison of the results obtained by the proposed algorithm and the standard GA for the ten-bar truss problem

		Proposed algorithm					GA
		β					
		0	0.1	0.2	0.3	0.4	
Number of ants / Population size							
100	Average weight (lb)	5632.6	5602.7	5601.3	5680.5	6344.6	5953.6
	Minimum weight (lb)	5531.0	5530.6	5509.7	5502.5	5550.2	5780.0
	Maximum weight (lb)	5816.7	5844.1	5791.3	6877.4	7994.7	6371.6
	SD of weights (lb)	47.3	45.1	48.2	176.2	443.6	106.3
200	Average weight (lb)	5590.2	5557.5	5554.0	5600.1	6321.8	5854.6
	Minimum weight (lb)	5532.1	5530.7	**5490.7**	5505.1	5541.8	5758.1
	Maximum weight (lb)	5683.3	5639.0	5659.5	6255.4	7439.4	6040.3
	SD of weights (lb)	29.0	21.6	23.0	92.6	386.7	58.7
300	Average weight (lb)	5574.3	5547.2	5542.8	5573.2	6279.2	5822.8
	Minimum weight (lb)	5531.0	5531.0	**5490.7**	**5490.7**	5533.7	5750.8
	Maximum weight (lb)	5629.2	5601.3	5591.6	5973.2	7673.0	5963.9
	SD of weights (lb)	22.1	15.2	14.9	77.4	444.0	35.7

Table 5.9 Comparison of the best result for the ten-bar truss problem with the literature

Member	Size of member (in.^{2})			
	Proposed	GAs		
		Nanakorn and Meesomklin (2001)	Rajeev and Krishnamoorthy (1992)	Galante (1996)
1	33.5	33.5	33.5	33.5
2	1.62	1.62	1.62	1.62
3	22.9	22.9	22.0	22.0
4	14.2	15.5	15.5	14.2
5	1.62	1.62	1.62	1.62
6	1.62	1.62	1.62	1.62
7	7.97	7.22	14.2	7.97
8	22.9	22.9	19.9	22.9
9	22.0	22.0	19.9	22.0
10	1.62	1.62	2.62	1.62
Total weight (lb)	**5490.7**	5499.4	5613.6	5458.3

from the following 32 discrete values, i.e. 3.13, 3.38, 3.47, 3.55, 3.63, 3.84, 3.87, 3.88, 4.18, 4.22, 4.49, 4.59, 4.80, 4.97, 5.12, 5.74, 7.22, 7.97, 11.5, 13.5, 13.9, 14.2, 15.5, 16.0, 16.9, 18.8, 19.9, 22.0, 22.9, 26.5, 30.0, and 33.5 in.^{2} For the rest of the members, the cross-sectional areas are taken from the following 32 discrete values, i.e. 1.62, 1.80, 1.99, 2.13, 2.38, 2.62, 2.63, 2.88, 2.93, 3.09, 3.13, 3.38, 3.47, 3.55, 3.63, 3.84, 3.87, 3.88, 4.18, 4.22, 4.49, 4.59, 4.80, 4.97, 5.12, 5.74, 7.22, 7.97, 11.5, 13.5, 13.9, and 14.2 in.^{2} The constraints considered in this problem are stress and displacement constraints. The design parameters and ACO parameters are shown in Table 5.6. Similar to the previous problem, in the calculation of stress and displacement responses, only the point loads shown in Figure 5.3 are considered as the applied forces, whereas the weight of the structure is neglected. The components of the quality function shown in Equation 5.1 are also used for this problem and the unit of weight used is also pound. However, in this problem, the constraint on the horizontal displacement has to be added to Equation 5.1b. In addition, the unit of area for the calculation of η in Equation 4.10 is in.^{2}

This problem is also solved by the standard GA. Similar to the previous problem, the quality function for the ACO algorithm defined in Equation 4.3, with its components defined in Equation 5.1, is also used as the fitness function in the GA. Also, the bilinear scaling techniques shown in Figure 4.2 are used for fitness scaling in the GA. The GA parameters for this problem are shown in Table 5.7.

In this problem, 200 runs are also carried out for each set of calculations. From the results shown in Table 5.8, it can be seen that the effect of the greedy heuristic is still not very significant. Nevertheless, the best solutions obtained from these calculation sets, using β equal to 0.2 and 0.3, are better than the best solutions obtained from the calculation sets using the other values of β. When β is equal to 0.4, the quality of the obtained solutions deteriorates significantly. It can also be seen that, similar to the previous problem, the quality of the obtained solutions is generally improved when the numbers of ants is increased from 100 to 300. For the worst solutions, the improvements are the most noticeable. In addition, the standard deviation of the weights of the solutions decreases considerably when more ants are used except for those calculation sets that employ β equal to 0.4.

Table 5.8 also shows the results obtained by the GA. It can be observed that the ACO algorithm always outperforms the GA in terms of the quality of the best solutions regardless of the value of β. In addition, when β is not greater than 0.2, the average and worst solutions from the ACO algorithm are also better than those from the GA. Also,

Table 5.10 Constrained displacements of the results for the ten-bar truss problem

Node	Displacement (in.)							
	Proposed		Nanakorn and Meesomklin (2001)		Rajeev and Krishnamoorthy (1992)		Galante (1996)	
	x-disp	y-disp	x-disp	y-disp	x-disp	y-disp	x-disp	y-disp
1	0	0	0	0	0	0	0	0
2	-0.281	-1.29	-0.277	-1.35	-0.319	-0.998	-0.292	-1.29
3	-0.530	**-2.00**	-0.506	**-2.00**	-0.538	**-2.00**	-0.541	**-2.01**
4	0	0	0	0	0	0	0	0
5	0.238	-0.777	0.241	-0.792	0.221	-0.759	0.238	-0.778
6	0.278	-1.96	0.267	-1.97	0.344	-1.88	0.277	-1.97

Table 5.11 Constrained stresses of the results for the ten-bar truss problem

Element	Stress (ksi)			
	Proposed	Nanakorn and Meesomklin (2001)	Rajeev and Krishnamoorthy (1992)	Galante (1996)
1	6.60	6.68	6.13	6.61
2	1.11	0.740	3.43	1.08
3	-7.81	-7.69	-8.85	-8.11
4	-6.92	-6.37	-6.09	-6.92
5	14.2	15.5	6.65	14.4
6	1.11	0.740	3.43	1.08
7	14.0	14.9	9.44	13.9
8	-7.49	-7.65	-7.48	-7.50
9	6.31	6.35	6.71	6.32
10	-1.57	-1.05	-3.00	-1.52

when β is not greater than 0.2, the standard deviations of the weights of the ACO solutions are much lower that those of the GA solutions. This means that, for this group of β, the ACO algorithm yields solutions that are more uniform than the GA solutions. This conclusion cannot be applied to those cases where β is greater than 0.2. In these cases, the GA provides solutions that are more uniform.

The best result of this study is compared with results reported in the literature in Table 5.9. The results from the literature are obtained by GAs. It can be seen that the quality of the result obtained from the proposed algorithm is comparable with that of the results from the literature although it seems not to be the best. However, if the results from the literature are carefully investigated, it is found that one of these results slightly violates the given displacement constraint. Table 5.10 and Table 5.11 show the displacements and stresses of the results in Table 5.9. It can be seen that the critical constraint is the y-displacement constraint. In this study, the constraints are strictly enforced and only admissible results can be considered as solutions. If the result in Table 5.9 that is inadmissible is excluded from the comparison, the quality of the result from the proposed algorithm and the quality of the results from the literature become even more indistinguishable. The result from the proposed algorithm does, in fact, become the best.

5.3 Fifty-Two-Bar Truss

Next, the fifty-two-bar truss shown in Figure 5.4 is considered. The 52 members of the truss are categorized into 12 groups as also shown in Figure 5.4. Only sizing optimization is considered in this problem. Therefore, design variables are 12 sectional areas. The cross-sectional areas are taken from the 64 discrete values in Appendix A. The constraint considered in this problem is only the stress constraint. The design parameters and ACO parameters are shown in Table 5.12. In the calculation of stress responses, only the point loads shown in Figure 5.4 are considered as the applied forces, whereas the weight of the structure is neglected. The components of the quality function shown in Equation 5.1 are still used for this problem. However, only the term related to the stress constraint is used in Equation 5.1b. In addition, the unit of weight used is kilogram force. The unit of area for the calculation of η in Equation 4.10 is mm^2.

Table 5.13 shows the results from the proposed algorithm. In this problem, the performance of the algorithm is improved significantly by the greedy heuristic. With only a few exceptions, the worse, average and best solutions are all improved when the greedy heuristic is used. It can also be observed that the quality of the best solutions is most improved when β is equal to 0.05, 0.07 and 0.09. The quality of the obtained solutions is still generally improved when the number of ants is increased and the improvements of the worst solutions are still the most evident. The standard deviation also decreases drastically when more ants are used.

The best result from the proposed ACO algorithm is compared with a result reported in literature (Wu and Chow, 1995) in Table 5.14. The result from the literature (Wu and Chow, 1995) is obtained by steady-state GAs. It can be seen that the best result obtained from the proposed algorithm is better than the result from the literature (Wu and Chow, 1995). The maximum stresses of these solutions are also shown in Table 5.14.

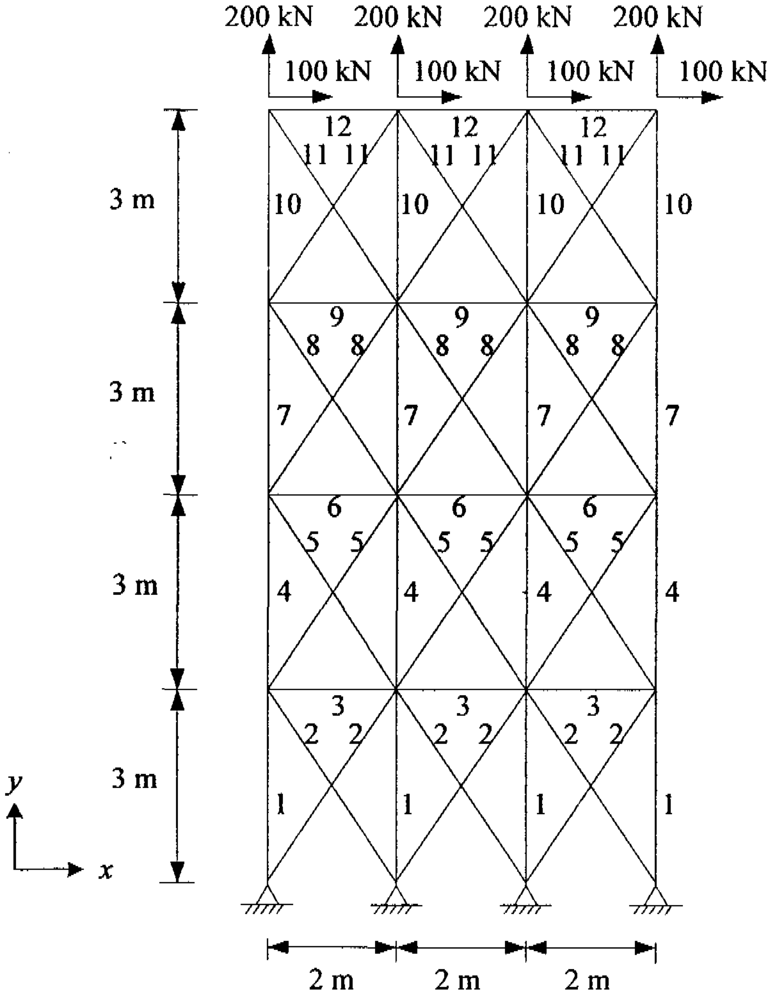

Figure 5.4 Fifty-two-bar truss

5.4 One-Bay Eight-Story Frame

The last problem is the one-bay eight-story frame shown in Figure 5.5. Still, only sizing optimization is considered in this problem. The 24 members of the structure are categorized into eight groups as indicated in Figure 5.5. In this problem, 278 W-sections from the AISC-ASD manual of steel construction (American Institute of Steel Construction 1989) are used for the optimization. All available 278 W-sections are also listed in Appendix B. There is only a displacement constraint in this problem that is the maximum x-displacement at the top of the structure. In fact, with this type of constraint, the vertical point loads described in Figure 5.5 will not affect the optimization results at all and they can actually be removed. Nevertheless, the vertical loads are considered here since they are included in the problem given in the literature (Camp et al., 1998). The design parameters and ACO parameters are shown in Table 5.15. The components of the quality function shown in Equation 5.1 are also used for this problem and the unit of weight used is pound. Nevertheless, only the horizontal displacements at the two nodes at the top of the structure are considered in Equation 5.1b. Note that the unit of area for the calculation of η in Equation 4.10 is $in.^2$

Table 5.12 Design and ACO parameters for the fifty-two-bar truss problem

Design parameters		ACO parameters	
Item	Value		
Modulus of elasticity	2.07×10^5 MPa	Number of ants	100, 200, 300
Weight density	7860.0 kg/m^3	Number of tours	200
Stress limit	±180 MPa	ρ	0.3
		λ	0.0002
		C	2
		Z	5
		α	1
		β	0, 0.01, 0.03, 0.05, 0.07, 0.09

Table 5.13 The results obtained by the proposed algorithm for the fifty-two-bar truss problem

		β					
		0	0.01	0.03	0.05	0.07	0.09
Number of ants							
100	Average weight (kgf)	2265.5	2247.7	2199.9	2154.6	2137.4	2119.4
	Minimum weight (kgf)	1970.5	1956.8	1949.7	1929.1	1910.0	1921.2
	Maximum weight (kgf)	2891.7	2814.3	2774.8	2721.0	2535.2	2860.0
	SD of weights (kgf)	147.6	158.2	145.6	135.7	132.7	134.4
200	Average weight (kgf)	2130.7	2095.4	2052.1	2005.5	2006.4	2014.7
	Minimum weight (kgf)	1943.2	1930.2	1909.0	1905.0	1909.6	1903.9
	Maximum weight (kgf)	2589.7	2486.1	2466.4	2323.1	2593.4	2455.4
	SD of weights (kgf)	121.9	108.3	108.1	82.6	81.5	86.1
300	Average weight (kgf)	2080.5	2042.8	1998.4	1965.0	1960.4	1978.8
	Minimum weight (kgf)	1924.2	1909.2	1910.4	**1902.6**	**1902.6**	1905.9
	Maximum weight (kgf)	2326.9	2351.5	2363.9	2182.6	2247.3	2286.3
	SD of weights (kgf)	86.5	78.5	69.5	49.3	52.5	59.8

Table 5.14 Comparison of the best result for the fifty-two-bar truss problem with the literature

Group number	Size of member (mm^2)	
	Proposed	Wu and Chow (1995)
1	4658.055	4658.055
2	1161.288	1161.288
3	494.193	645.160
4	3303.219	3303.219
5	940.000	1045.159
6	494.193	494.193
7	2238.705	2477.414
8	1008.385	1045.159
9	494.193	285.161
10	1283.868	1696.771
11	1161.288	1045.159
12	494.193	641.289
Total weight (kgf)	**1902.6**	1972.7
Maximum stress (MPa)	179.8	178.9

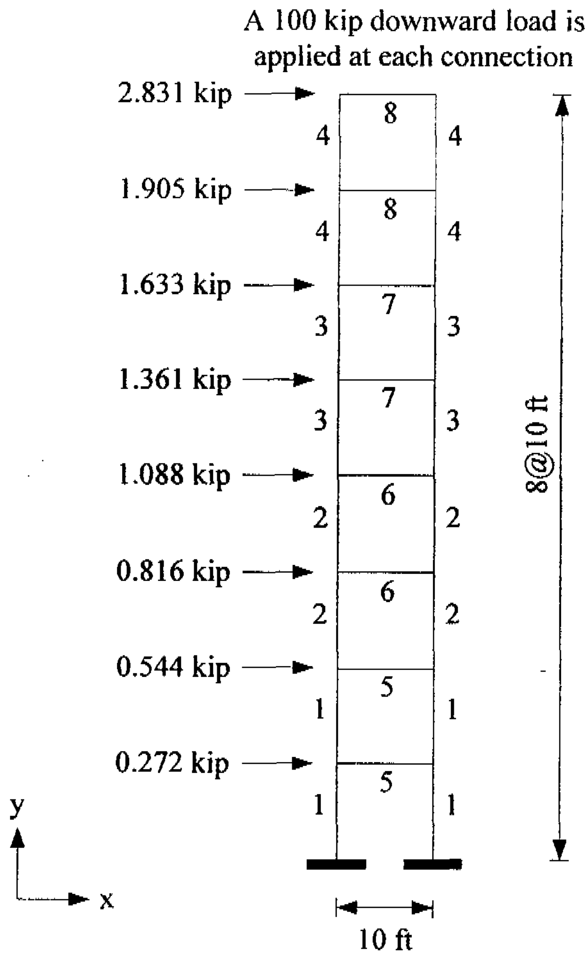

Figure 5.5 One-bay eight-story frame

Table 5.15 Design and ACO parameters for the one-bay eight-story frame problem

Design parameters		ACO parameters	
Item	Value		
Modulus of elasticity	29×10^3 ksi	Number of ants	100, 200, 300
Weight density	2.83×10^{-4} kip/in.^{3}	Number of tours	200
Maximum x-displacement at the top of the structure	2 in.	ρ	0.3
		λ	0.0002
		C	2
		Z	5
		α	1
		β	0, 0.01, 0.03, 0.05, 0.07, 0.09

After 200 runs for each set of calculations are carried out, the obtained results from the proposed algorithm are shown in Table 5.16. In this problem, the greedy heuristic improves the average solutions. As for the best and worst solutions, mixed performances are observed. Similar to all of the previous examples, the quality of the obtained solutions, in general, becomes better when the number of ants is increased and the improvements of the worst solutions are the most apparent. The standard deviation also decreases significantly when more ants are used.

The best result from the proposed algorithm is compared with a result reported in the literature (Camp et al., 1998) in Table 5.17. The result from the literature (Camp et al., 1998) is obtained by GAs. It can be seen that the best result obtained from the proposed algorithm is better than the result from literature (Camp et al., 1998). The maximum x-displacements at the top of the structure of these solutions are also shown in Table 5.17.

Table 5.16 The results obtained by the proposed algorithm for the one-bay eight-story frame problem

		β					
		0	0.01	0.03	0.05	0.07	0.09
Number of ants							
100	Average weight (lb)	8137.2	8031.4	8010.1	8017.9	8014.9	7967.9
	Minimum weight (lb)	7328.6	7185.9	7202.2	7261.3	7190.7	7363.2
	Maximum weight (lb)	9335.6	8898.9	9700.3	9080.2	9923.1	8931.5
	SD of weights (lb)	391.6	325.5	378.0	361.8	388.0	338.4
200	Average weight (lb)	7618.8	7609.7	7567.3	7565.8	7575.1	7542.1
	Minimum weight (lb)	7070.5	7104.4	**7032.4**	7094.2	7158.8	7036.5
	Maximum weight (lb)	8473.0	8415.3	8236.0	8238.0	8195.2	8229.9
	SD of weights (lb)	247.1	253.5	223.4	204.4	232.3	225.5
300	Average weight (lb)	7479.8	7473.7	7437.2	7438.8	7436.9	7424.1
	Minimum weight (lb)	7061.0	7103.8	7080.0	7037.9	7084.1	7118.0
	Maximum weight (lb)	8070.3	7984.7	8170.8	8168.7	8028.1	8049.9
	SD of weights (lb)	189.3	170.1	175.4	193.5	160.4	169.4

Table 5.17 Comparison of the best result for the one-bay eight-story frame problem with the literature

Member	Size of member	
	Proposed	Camp et al. (1998)
1	W 18× 35	W 18× 46
2	W 18× 35	W 16× 31
3	W 16× 26	W 16× 26
4	W 12× 14	W 12× 16
5	W 18× 35	W 18× 35
6	W 21× 44	W 18× 35
7	W 16× 26	W 18× 35
8	W 16× 26	W 16× 26
Total weight (lb)	**7032.4**	7376.1
Maximum x-displacement at the top of the structure (in.)	1.98	1.84