TESIS

OPTIMASI UKURAN PENAMPANG, TOPOLOGI, DAN BENTUK STRUKTUR PADA STRUKTUR RANGKA KUDA-KUDA ATAP BAJA DENGAN MENGGUNAKAN ALGORITMA GENETIKA

RICHARD FRANS
No. Mhs: 135101978/PS/MTS

PROGRAM STUDI MAGISTER TEKNIK SIPIL
PROGRAM PASCASARJANA
UNIVERSITAS ATMA JAYA YOGYAKARTA
2014

INTRODUCTION

In order to minimize the weight of structures so many optimization methods have been used. One of the methods is using genetic algorithm for producing optimum structures (frames or truss). Optimum structure is not only a structure with lower in cost but also must produce a structure that must satisfy the rules of condition (strength, displacement, slenderness ratio). Many researches have been developed in structures optimization by using genetic algorithm. One of the researches is developed by Rajeev and Krishnamoorthy(1992) who optimize the 10-bar truss by using genetic algorithm, but in this research, the objective is minimize the weight of 10-bar truss just in sizing optimization case. Binary genetic algorithm is one kind of the genetic algorithm that has been used by Rajeev and Krishnamoorthy(1992) to optimize the 10-bar truss. The result of this research produce 10-bar truss with minimum weight and satisfy the rules of condition (stress, displacement). Other research came from Lin and Hajela (1992,1993), the objective of this research is same with Rajeev and Krishnamoorthy (1992) that to minimize the weight of the structure. Lin and Hajela used 8 bar-truss with stress and displacement become constraints variable. Sakamoto and Oda (1993) has successfully tried to optimize structure with using genetic algorithm , but the different with the previous two researcher is using genetic algorithm not only for sizing optimization but also for topology optimization, both of the optimization (sizing and topology optimization) used binary genetic algorithm. The next research is developed by Rajan (1995). In his research that combined the two kind of genetic algorithm (binary genetic algorithm and real genetic algorithm) to produce the optimum structure. Binary genetic algorithm used for sizing and topology optimization otherwise real genetic algorithm used for the optimum place for nodes which wanted to optimize.This paper will present the producing of optimum roof truss using hybrid genetic algorithm. Hybrid genetic algorithm is combination form from binary genetic algorithm and real genetic algorithm. Binary genetic algorithm will be used for sizing and topology optimization. Real genetic algorithm will be used for the optimum location of nodes which wanted to be optimized (shaping optimization).

GENETIC ALGORITHM

Genetic algorithm (GA) is a stochastic algorithm that mimics natural phenomena as operators in the processing. The idea behind the mechanics of GA is to resemble the adaptive process in natural based on Darwinian's survival of the fittest mechanism. GA gas been used to obtain the optimum design of the function and has shown its superiority in obtaining nearly global optimum solution of complex problems. (Arfiadi and Hadi, 2011). GA is differ from traditional optimization algorithms in many ways. According to Rajeev and Khrisnamoorthy (1992)based on Goldberg(1989), the different are:

a. Genetic algorithm do not require problem-specify knowledge to carry out a search. For instance, calculus-based search algorithms use derivative information to carry out a search. In contrast to this, GA are indifferent to problem-specific information.

b. GAs work on coded design variables, which are finite length strings. These strings represent artificial chromosomes. Every character in the string is an artificial gene. GAs process successive populations of these artificial chromosomes in successive generations.

c. GAs use a population of points at a time in contrast to the single-point approach by the traditional optimization methods. That means, at a given time, GAs process a number of design.

d. GAs use randomized operators in place of the usual deterministic ones.

SIZING OPTIMIZATION

Binary genetic algorithm used for sizing optimization. In this paper, 16 different randomly sections has been used for optimization. The first step to optimize the sections is initial randomly discrete variables based on possibility existing members. The simply equation for determining the possible existing members is

$$jb = (node - 1) * 0{,}5 * node \tag{1}$$

where:

jb : possible existing member

node : number of nodes which used in that structure

For example, if the plane truss have six nodes. The possible existing member for that plane truss structure is fifteen. So, sixty is the number of discrete variables which are randomly called to initial. The second step is to translate the discrete variables into real number for structural analysis. Because of that, we need a converter tools to translate the discrete variables. Equation (2) is used to transform the binary coded into real number based on Michalewics in Arfiadi (2011),

$$t_i = \sum_{j=0}^{r} h_j . 2^j \tag{2}$$

where:

h_j = string-j from right (0 or 1)

r = length of string

t_i = real number of the column in array contain the section properties

The result of this transforming is a real number of the section properties which are ready to combine with the other optimization variables such as topology optimization and shaping optimization in one matrix [G] for structural analysis. The next procedure is that the discrete variables will experience selection (roulette wheel), crossover according to crossover rate, mutation based on mutation rate, and the last thing of the genetic algorithm procedure is elitism strategy (keep the fittest population for next generation).

TOPOLOGY OPTIMIZATION

The methods of topology optimization is almost similar with sizing optimization, both used binary genetic algorithm to optimize the structure. The little difference between topology and sizing optimization is in topology optimization, not important to translate the discrete variables (binary coded) into real number because the discrete variables (binary coded) is just a representative of the existing member.

To make it more clearly, let us say, we have plane truss with four nodes. Thus, six possible existing member based on equation one (Figure 1). If the binary string present [0 1 1 0 0 1], the meaning is the first, the fourth, and the fifth members unavailable/absence otherwise the other members is available. So the layout of the 6-bar truss can be showed in figure 2.

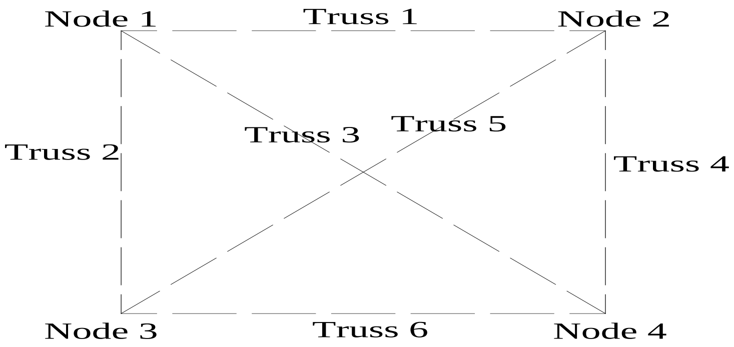


Figure 1. Possible Existing Members for 4 Nodes Plane Truss
Source: SesokdanBelivicius (2007)

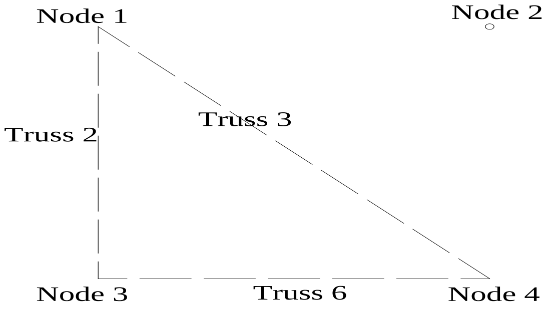


Figure 2.Layout of the Truss which have [0 1 1 0 0 1] Binary Coded
Source: SesokdanBelivicius (2007)

So, the number of discrete variables which must called randomly to initial are the number of possible existing member (jb), for this case we must call six randomly binary coded. Other example, if we have seven nodes on structure, so 21 is a possible existing member and also the number of discrete variables which called randomly. After doing that, the discrete will be combined with the other optimization variables such as sizing optimization and shaping optimization in one matrix [G] for structural analysis. The next procedure is that the discrete variables will experience selection (roulette wheel), crossover according to crossover rate, mutation based on mutation rate, and the last thing of the genetic algorithm procedure is elitism strategy (keep the fittest population for next generation).

SHAPING OPTIMIZATION

In this shaping optimization have a different thing with other shaping optimization developed by other researcher. The different is in this shaping optimization does not change the shape of the structure. Shaping optimization just change the location of the nodes which wanted to be optimized. This is because the plane truss which optimized is roof truss where the pitch angles are usually governed by roof covering types. In this optimization, the pitch angle is set to constant according to ratio of the height of the structure and the length of the structure. Real genetic algorithm used for this optimization. The first step is to call random value of the nodes location which wanted to be optimized and then, we must make a boundary condition for location of the nodes. After doing that, the location of the nodes will be combined with the other optimization variables such as sizing optimization and topology optimization in one matrix [G] for structural analysis. The next procedure is that the real number variables will experience selection (roulette wheel), crossover according to crossover rate, mutation based on mutation rate, and the last thing of the genetic algorithm procedure is elitism strategy (keep the fittest population for next generation).

FITNESS FUNCTION, CONSTRAINTS, AND PENALTY FUNCTIONS

Equation (3) used for determining the weight of structure.Because objective function is to minimize the weight of the structure than the fitness function will be used (4):

$$W = \sum_{i=1}^{k} \rho A_i l_i \tag{3}$$

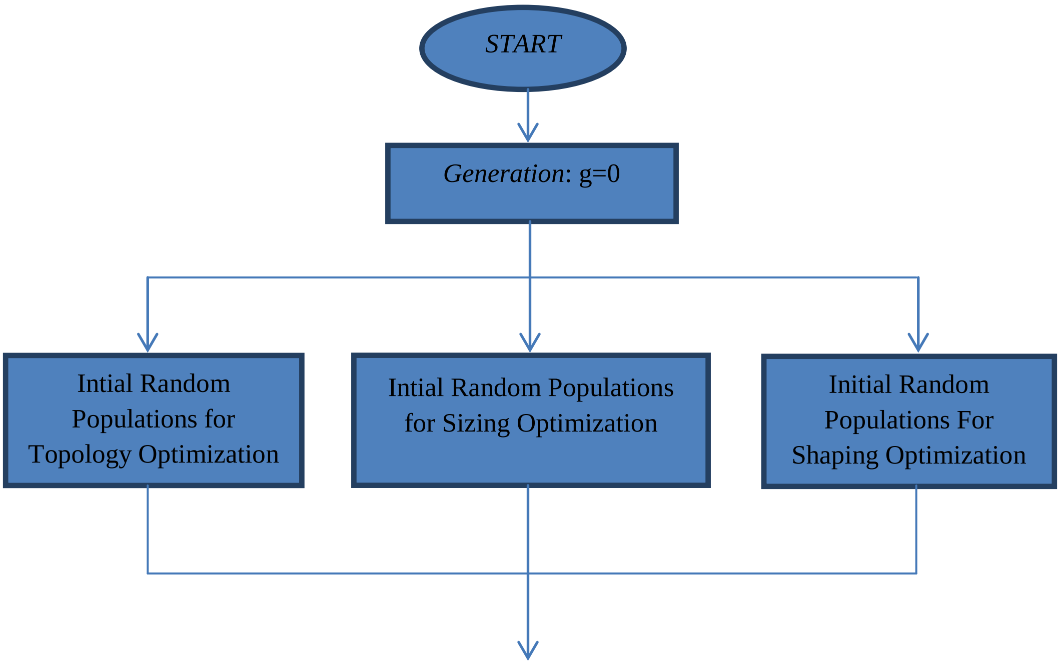
$$F = \frac{1}{W} \tag{4}$$

where:

W = weight of structure (kg)
ρ = density for steel (7650 kg/m^3)
A_i = the profile section -i (m^2)
l_i = length of member -i (m)

There are three constraints used in this paper (stress, displacement, slenderness ratio). Limit of the slenderness ratio of this paper used SNI 03-1729-2002 code for design procedures for steel structures. Because of genetic algorithm has freely to choose the possible members. Penalty function is used to eliminate instability structuremoreover penalty function is used for structure which has excessive stress, displacement, and slenderness ratio too.

GENERAL STEPS FOR USING GENETIC ALGORITHM



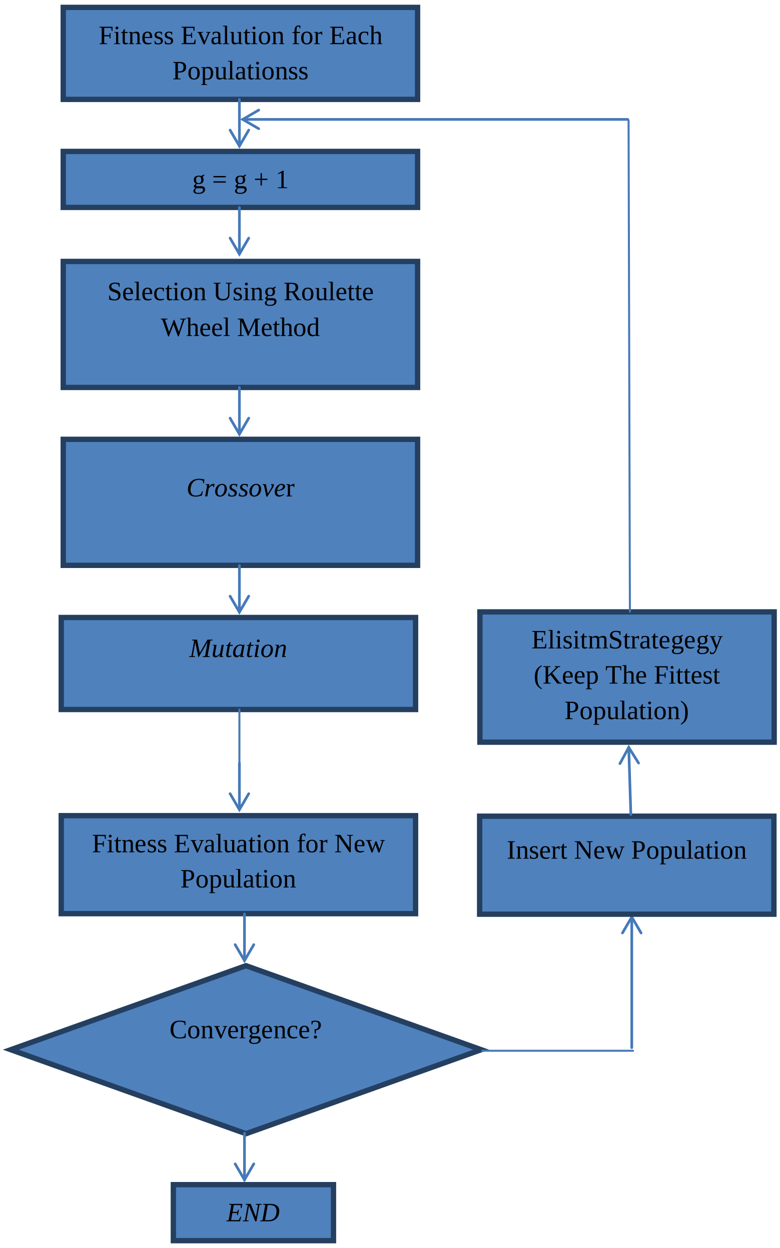


Figure 3.*Flowchart Application of Using Genetic Algorithm*

APPLICATION

BENCHMARK PROBLEM

This ten-bar truss is often used as a benchmark problem in structural optimization. Rajeev and Krisnamoorthy (1992), Rajan (1995), Max Hultman (2010), all of them used this benchmark problem before they present the problem of their research. In this paper, the ten-bar truss is used for programming validation and for comparing the result with the other result which have gotten by other researchers.The truss has two vertical supports with a distance of 9.144 metres (360 inches) and two loads of 445,374 kN (100 kips) at 9.144 and 18.288 metres from the lower support, see in Figure 4.

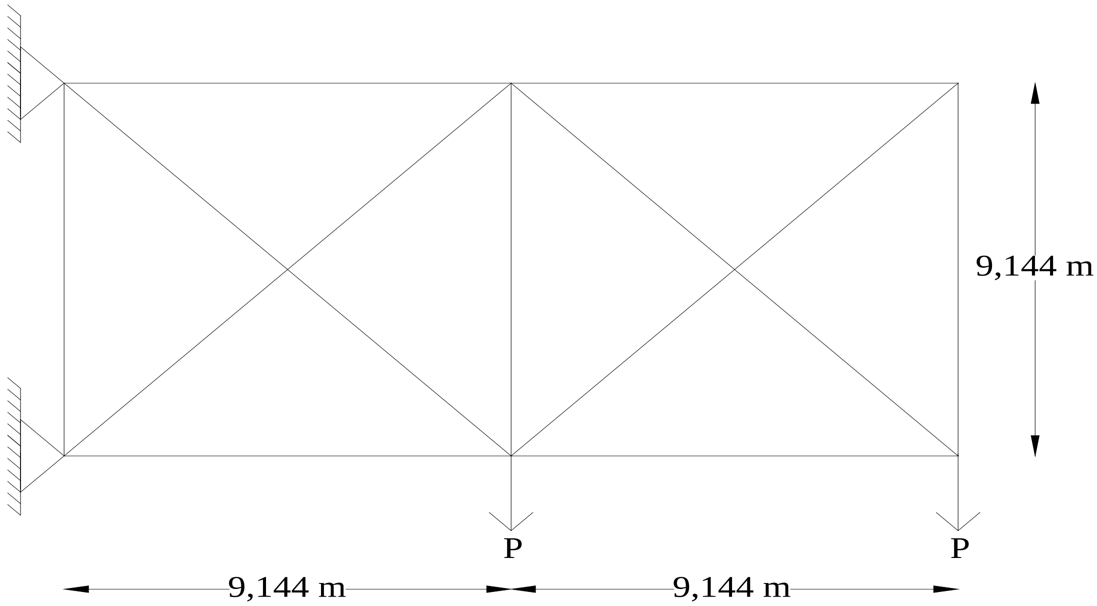


Figure 4.*Benchmark Problem (Ten-Bar Truss)*
***Source: Hultman (2010)**

The material is made by Aluminium with elasticity modular (E) = 68,95GPa, ρ = 2768 kg/m^3, the limit of stress for all members is 172,37 MPa for both compression and tension members, i.e. buckling is ignored. The displacement are limited to 50,8 mm (2 inch) both horizontally and vertically. Some good results from other researchers were:

1. **2222.22 kg** (4899.15 lbs**)** by Deb and Gulati (2001). Size and topologyoptimization by a genetic algorithm.
2. **2241.97 kg** (4942.7 lbs) by Hajela and Lee (1995). Size and topologyoptimization by a genetic algorithm.

3. **2295.59 kg** (5060.9 lbs) by Li, Huang and Liu (2006). Size optimization by aparticle swarm optimizer.
4. **2301.09 kg** (5073.03 lbs) by Kripakaran, Gupta and Baugh Jr. (2007) [19]. Sizeoptimization by a hybrid search method.
5. **2322.08 kg** (5119.3 lbs) by Galante (1996) [11]. Size and shape optimization by agenetic algorithm.

For this case, two running are made. The firstresultshows that the weight of the structure is 2262,702 kg. If we compare it with the result which were gotten by other researches above (some good parameters), this result has rank 3, below the result from Hajela and Lee (1995) and Deb and Gulati (2001). Shape of the structure can be seen in Figure 5. Stress, displacement, section of members, and the location of the nodes are shown in Table 1.

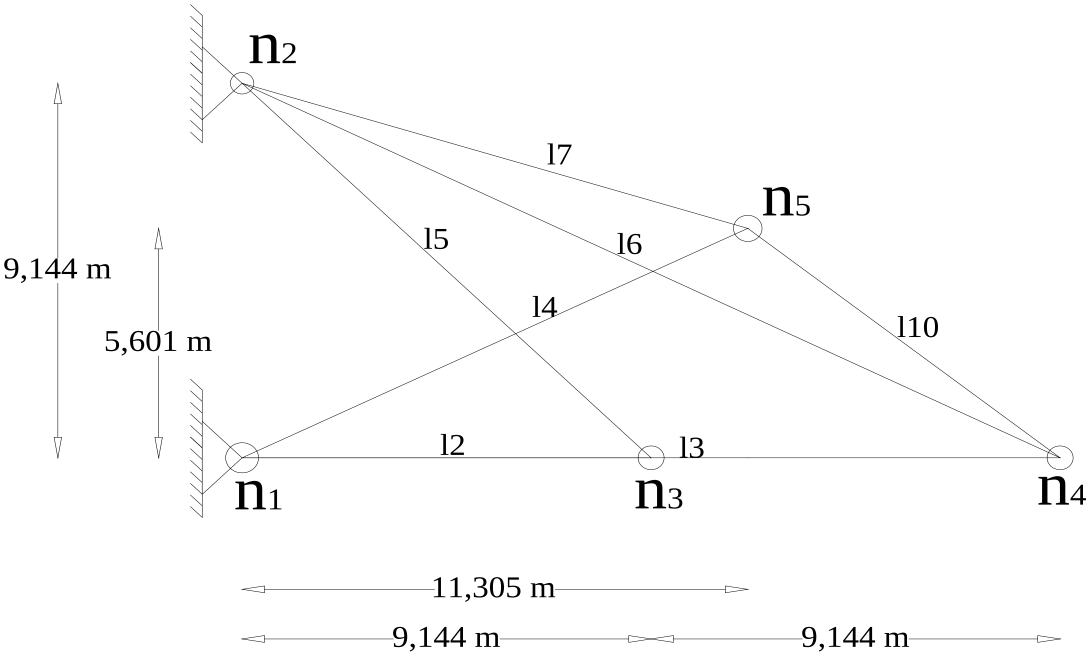


Figure 5. The Result of Ten-Bar Truss Optimization Using Hybrid Genetic Algorithm for First Run

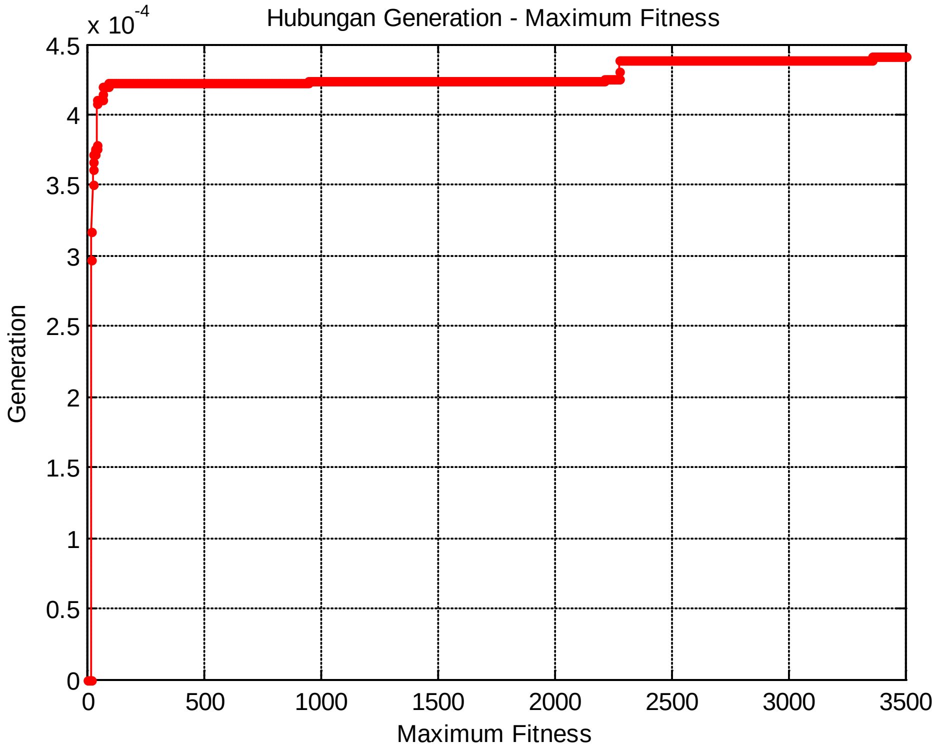


Figure 6. Relationship between Maximum Fitness-Generation for First Run Using Hybrid Genetic Algorithm

The first run use 20 populations with 3500 maximum generations, crossover rate=0,8, mutation rate=0,1, node-5 is optimized where the axis of node can be moved 20 mm horizontally (x) each generation and the location of ordinat (y) for node-5 can be moved from elevation 0 to elevation 9.144 m for each generation. The section properties are used 16 different section properties (A). Maximum actual displacement is 50,7917mm and maximum actual stress is 129,3 MPa. Validation of this program used sub-sub program developed by Arfiadi (2013) on structural analysis for plane truss using MATLAB R-2013. The result show that maximum actual displacement is 99,98% of the limit for vertically displacement.

Table 1.Section Properties, Stress, Displacement, and Weight of The Structure for First Run Using Hybrid Genetic Algorithm

Members	Start Coordinates (mm)	End Coordinates (mm)	A (mm^2)	l (m)	m (kg)	Stress (N/mm^2)	Displacement (mm)
2	(0;0)	(9144;0)	4870	9144	123.2626	-91.5	46.4321
3	(0;0)	(18288;0)	13500	18288	683.386	-46	50.69
4	(0;0)	(11305;5601)	6350	12616.4	221.7564	-47.5	21.7952
5	(0;9144)	(9144;0)	4870	12931.6	174.3196	129.3	41.4084
6	(0;9144)	(18288;0)	4870	20446.6	275.6235	39.7	50.7917
7	(0;9144)	(11305;5601)	14700	11847.2	482.0574	51.2	21.7556
10	(11305;5601)	(18288;0)	12200	8951.73	302.2964	47	47.1701
Weight of Structure (kg)					**2262.702**	**129.3**	**50.7917**
Best Fitness					**0.000442**	Maximum Stress	Maximum Displacement

The second run is showed that the result is better than the first run or other result which have gotten from other researchers. In the second run, we can find that the weight of the structure is 2122,622 kg. It has a good result, but need more number of populations, more maximum generation, and more time to run the program. Comparing with the first run, the second run used 25 number of populations and 8000 maximum generations, crossover rate=0,8, mutation rate=0,1. Stress, displacement, section properties, weight of the structure can be seen in Table 2.

Table 2. Section Properties, Stress, Displacement, and Weight of The Structure for Second Run Using Hybrid Genetic Algorithm

Members	Start Coordinates (mm)	End Coordinates(mm)	A (mm^2)	l (m)	m (kg)	Stress (N/mm^2)	Displacement (mm)
2	(0;0)	(9144;0)	4620	9144	116.9349	-96.4	48.9446
3	(0;0)	(18288;0)	10900	18288	551.7709	45.3	50.7995
4	(0;0)	(9650;7789)	12200	12401	418.7768	41.8	18.8784
5	(0;9144)	(9144;0)	4620	12931.6	165.371	-136.3	43.6491
7	(0;9144)	(9650;7789)	14700	9744.7	396.5079	61.2	18.3884
10	(9650;7789)	(18288;0)	14700	11631	473.2607	45.2	45.7754
Weight of Structure(kg)					**2122.622**	**136.3**	**50.7995**
Best Fitness					**0.000471**	Maximum Stress	Maximum Displacement

The shape of structure can be seen in Figure 7. Table 2 shows that the maximum actual stress is 136,3MPaand the maximum actual displacement is 50,7995 mm, it is about 99,9999% of its limit (50,8 mm). Thus, we can say that the ten-bar truss for the second run is very optimum shape.

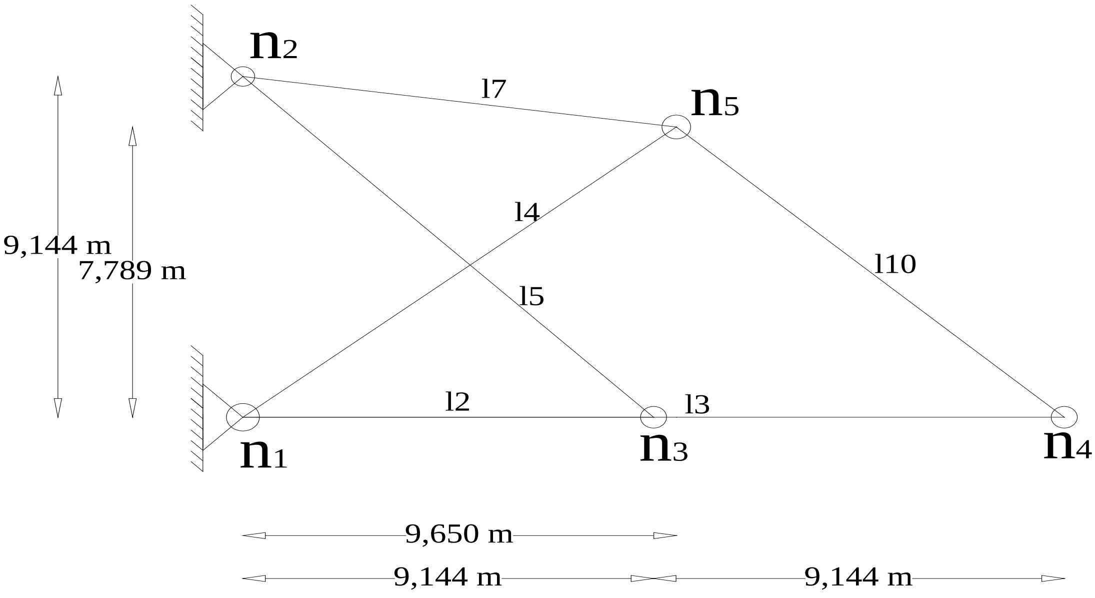


Figure 7. The Result of Ten-Bar Truss Optimization Using Hybrid Genetic Algorithm for Second Run

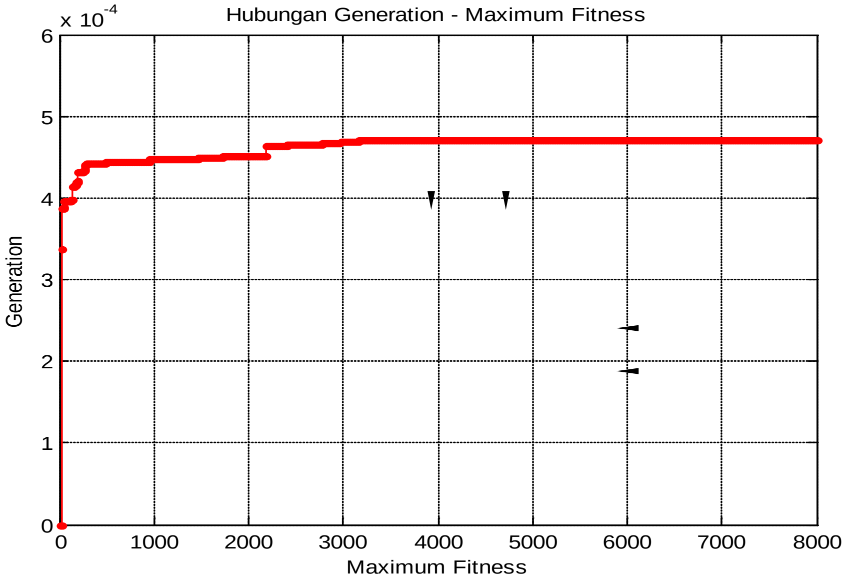


Figure 8. Relationship between Maximum Fitness-Generation for Second Run Using Hybrid Genetic Algorithm

SPESIFICATION OF MATERIAL

Considering the optimizing result above, the next structure which tried to optimize are two roof truss with 8-nodes and one roof truss with 10-nodes, and next we will call it, first model, second model, and third model. In this roof truss, we use steel as the structure material with specification below:

Elasticity Modular (E_s)	: 200.000 MPa
Stress Limit (σ_i)	: 2400 kg/cm^2
Density (ρ_s)	: 7650 kg/m^3
Horizontal/Vertical Displacement Limit	: 5 mm

Limit of slenderness ratio for compression and tensile members based on SNI 03-1729-2002 code for design procedures for steel structures. The location of loading are at all nodes except at restrains. Point loads which are used 200 kg. The roof truss is analyzed using stiffness matrix method and the roof truss is assumed pure truss, thus every members just experience axial tensile force or axial compression force.

THE FIRST MODEL OF ROOF TRUSS WITH 8-NODES

The first model of roof truss tried to optimize is a roof truss with 8-nodes and length of the structure is 10 m, height of the structure is 3 m. Node-5, 6, 7, and 8 will be experienced optimization (shaping optimization). Steel profile used symmetrical angle profile. The area of this profiles are [1410 1670 1230 1510 1790 2060 1550 1870 2180 1920 2270 2620 2120 2510 2900 2540] mm^2. Point loads are at node-2, 4, 5, 6, 7, and 8. The shape of first model can be seen in Figure 9 below.

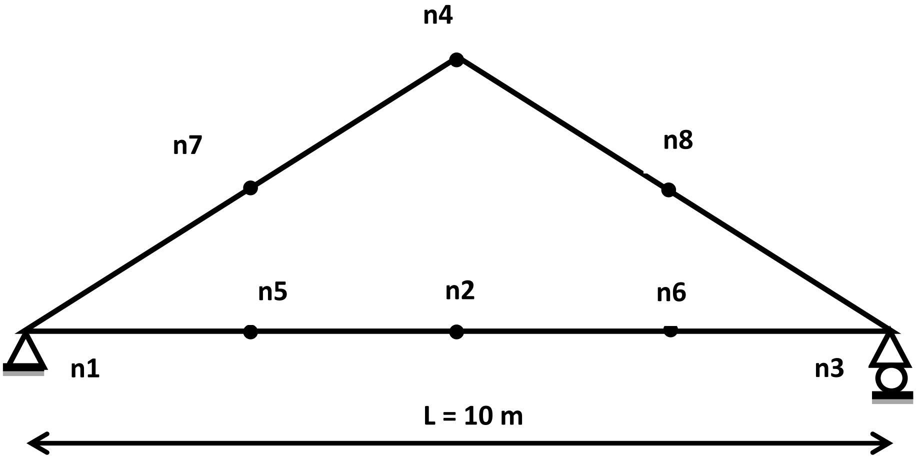


Figure 9.First Model of Roof Truss with 8-Nodes

The result of first model truss using hybrid genetic algorithm can be seen in Figure 10. Number of populations are 20 with 2000 maximum generations, crossover rate=0,8, mutation rate=0,1. The location of optimized nodes (5,6,7, 8) are limited to 20 mm vertical and horizontal for node-7,8 each generation and 20 mm horizontal for node-5, 6 each generation.Stress, displacement, area section, and location of nodes can be seen in Table 3.

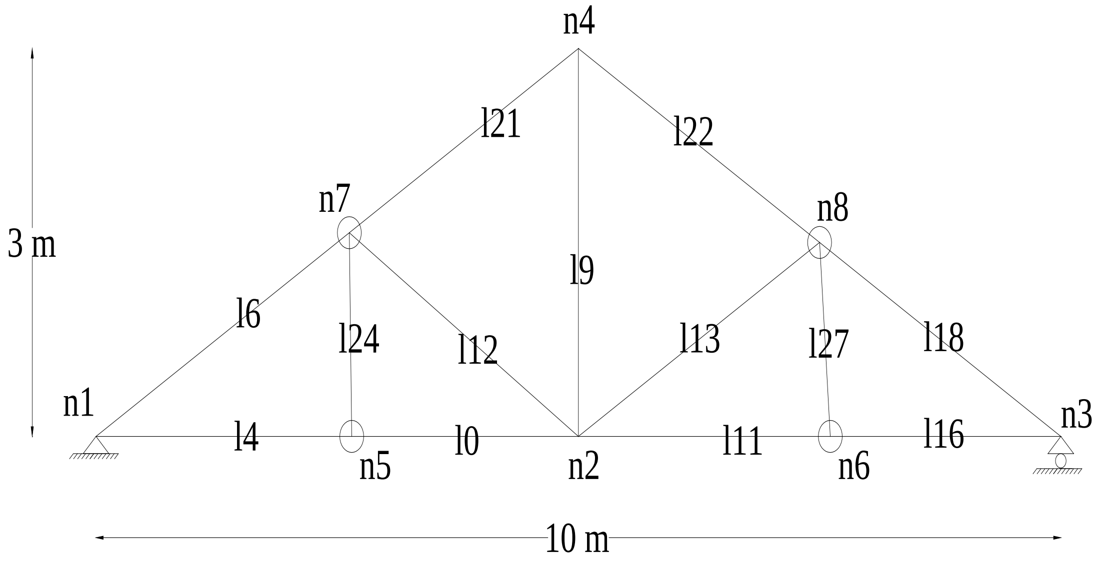


Figure 10.Result of First Model Using Hybrid Genetic Algorithm

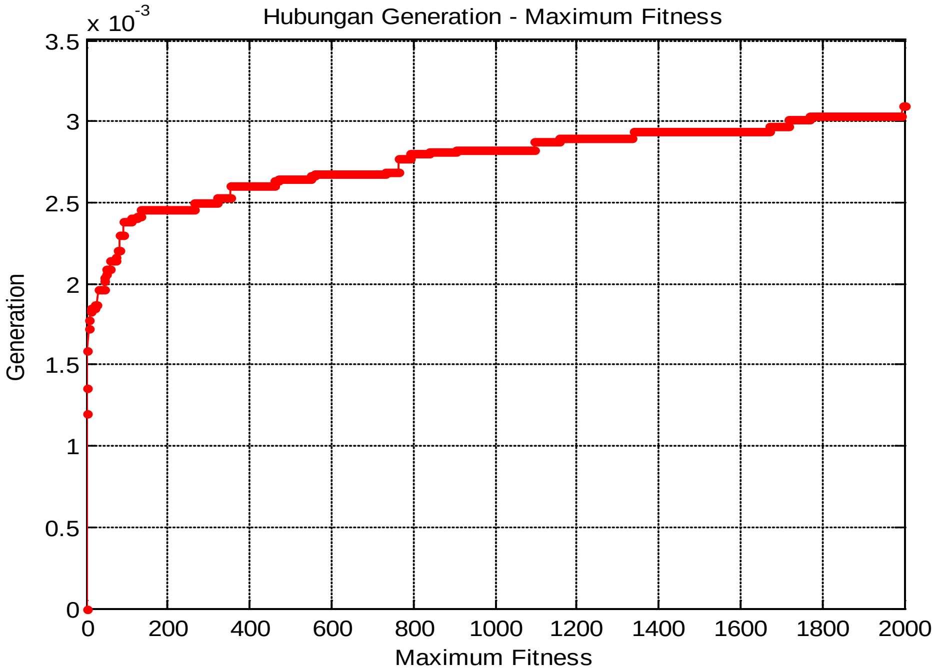


Figure 11. Evolving Best Fitness Each Generation for First Model

Table 3.Area Section, Stress, Displacement, Location of Nodes, Weight of Structure of the First Model Using Hybrid Genetic Algorithm

Members	Start Coordinates (mm)	End Coordinates (mm)	A (mm^2)	l (mm)	m (kg)	Stress (kN/mm^2)	Displacement (mm)
4	(0;0)	(2650,5;0)	1230	2650.5	24.9399	0.0080	0.7937
6	(0;0)	(2625,4;1575.24)	1230	3061.7	28.8091	0.0198	0.8256
9	(5000;0)	(5000;3000)	1230	3000	28.2285	0.0049	0.8531
10	(5000;0)	(2650,5;0)	1230	2349.5	22.1076	0.0081	0.8531
11	(5000;0)	(7610,7;0)	1230	2610.7	24.5654	0.0080	0.8531
12	(5000;0)	(2625,4;1575.24)	1230	2849.6	26.8133	0.0060	0.6835
13	(5000;0)	(7449,1;1530,54)	1230	2888	27.1746	0.0060	0.8301
16	(10000;0)	(7610,7;0)	1230	2389.3	22.4821	0.0082	0.7703
18	(10000;0)	(7449,1;1530,54)	1230	2974.8	27.9914	0.0195	0.6149
21	(5000;3000)	(2625,4;1575.24)	1410	2769.2	29.8700	0.0114	0.8256
22	(5000;3000)	(7449,1;1530,54)	1230	2856.1	26.8745	0.0124	0.6149
24	(2650,5;0)	(2625,4;1575.24)	1790	1575.4	21.5727	0.0011	0.7953
27	(7610,7;0)	(7449,1;1530,54)	1230	1539	14.4812	0.0016	0.7982
Weight of Structure (kg)					**325.9103**	**0.0198**	**0.8531**
Best Fitness (kg)					**0.0031**	Maximum Stress	Maximum Displacement

To fix the structure reach the optimum shape (topology, sizing, shape). Second run made where using 30 to be number of populations with 2000 generations, in Figure 11 can be seen that the structure have reached the optimum shape with value of best fitness same with the first run.

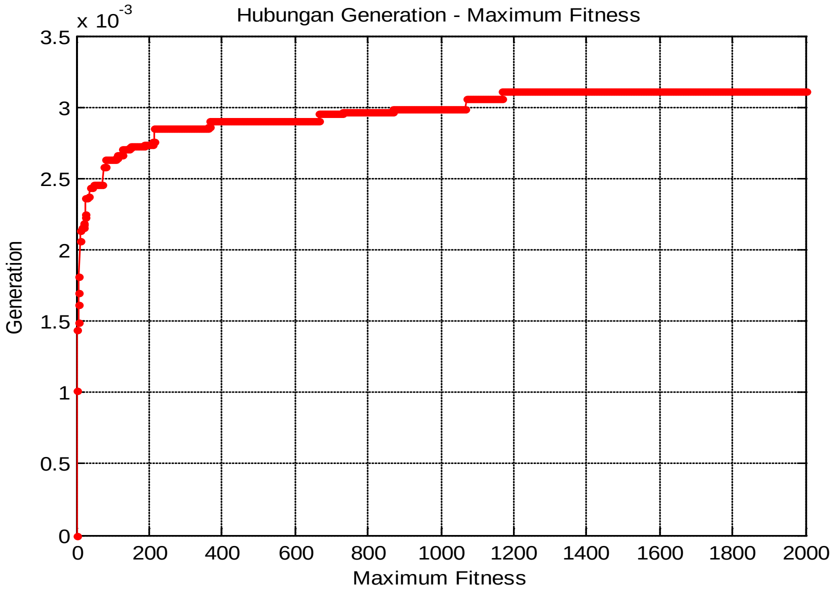


Figure 12. Evolving Best Fitness Each Generation for First Model on Second Run

THE FIRST MODEL OF ROOF TRUSS WITH 8-NODES FOR CERTAIN POINT LOAD BASED ON STRUCTURE CONFIGURATION

For this case, roof truss structure is considered having certain point load on each joint according to structure configuration. This assumption is more realistic than before which have constant point load on each joint (200 kN). Assumptions of this case are:

Construction Dimension (The Distance Between Roof Truss)	: 6 m
Load Mass For Roof and Plafond	: 50 kg/m^2
Live Point Load each Nodes	: 200 kg

In Figure 13, we can see the increasing of fitness for each generation. The curve shows that the maximum fitness value is 0,0031 which is similar with the first model in constant point load. This is because of smaller actual stress and smaller actual displacement if compared with the limit of stress and the limit of displacement.

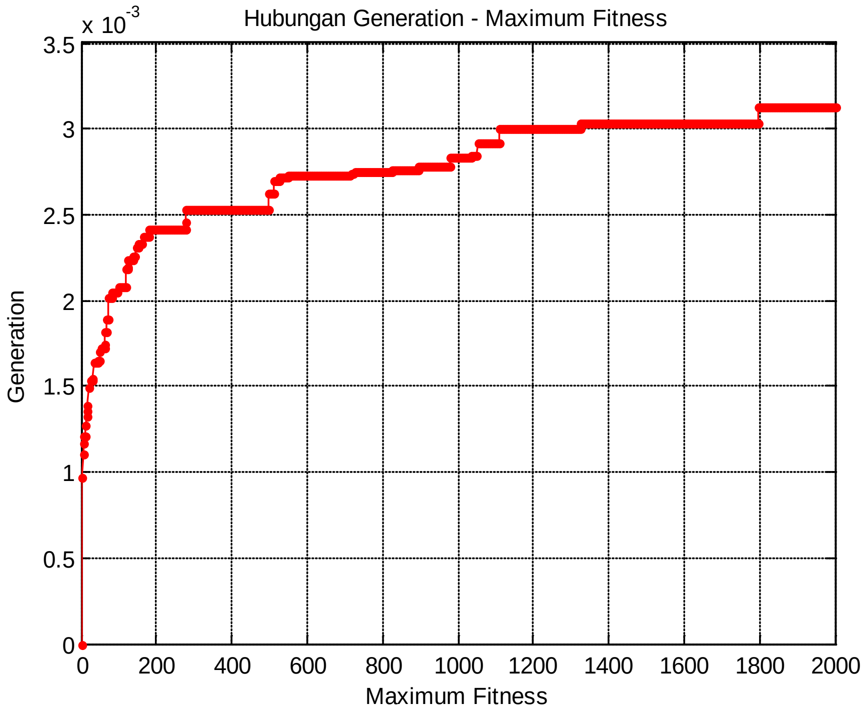


Figure 13. Evolving Best Fitness Each Generation for First Model for Certain Point Load

THE SECOND MODEL OF ROOF TRUSS WITH 8-NODES

The second model of roof truss is almost similar with the first model. The different is just the location of the nodes and the length of structure. The length of structure is taken 6 m and height of structure is 2 m. Area section used similar with the first model.The second model and the result of second model using genetic algorithm can be respectively seen in Figure 14 and Figure 15. Stress, displacement, area section of each member, location of nodes can be seen in Table 4. As we can see, all of the members have 1230 mm^2 for area section (smallest of the profile list). It means, the structure have reached the optimum shaped.

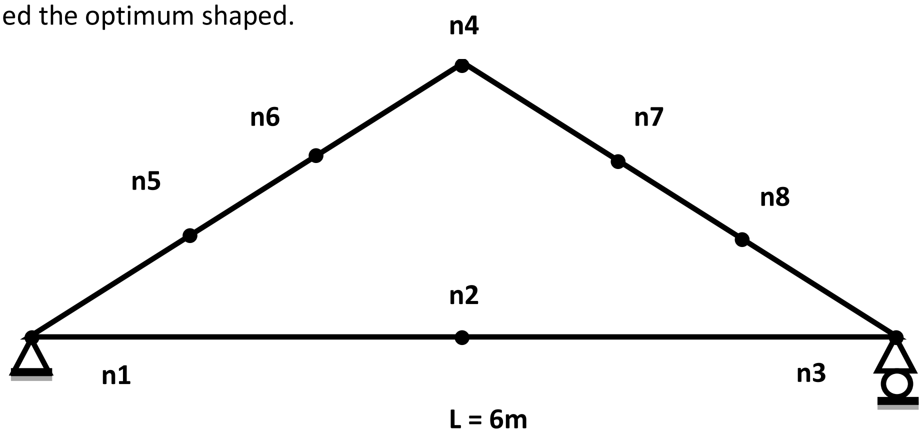


Figure 14.Second Model of Roof Truss (8-Nodes)

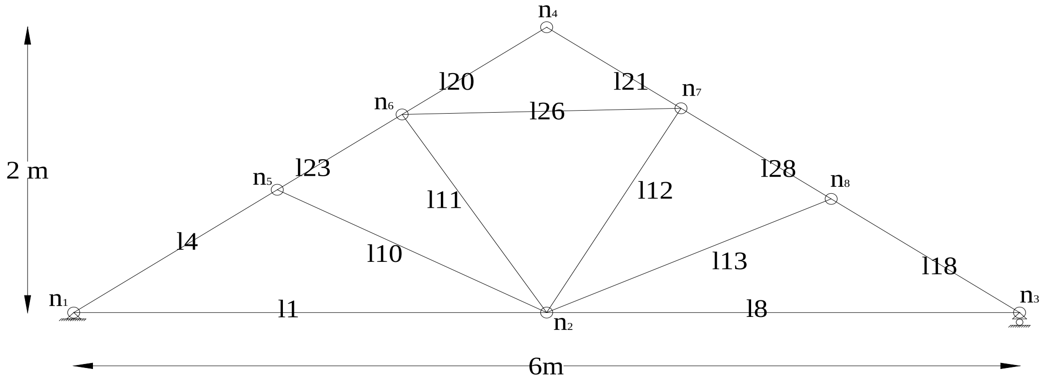


Figure 15. The Result of Second Model Optimized Using Hybrid Genetic Algorithm

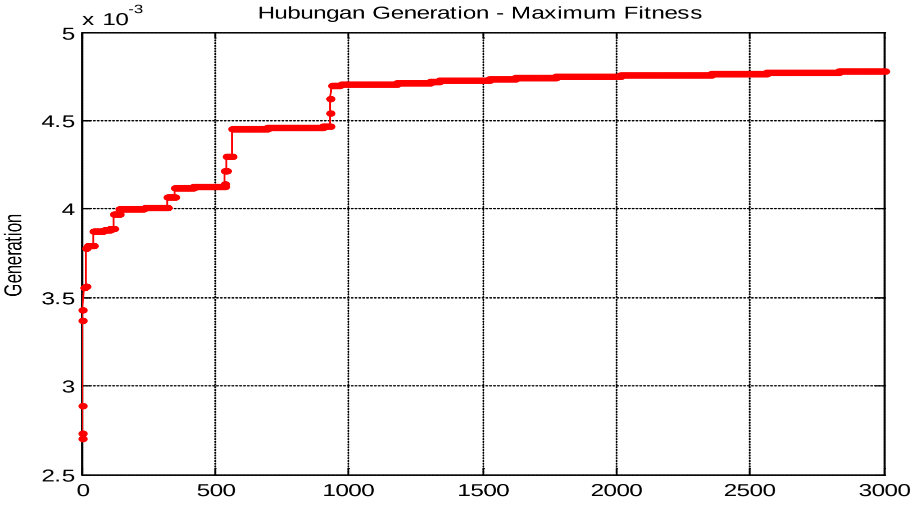


Figure 16.Evolving Best Fitness Each Generation for Second Model

Table 4.Area Section, Stress, Displacement, Location of Nodes, Weight of Structure of the Second Model Using Hybrid Genetic Algorithm

No Batang	Letak Node Awal (mm)	Letak Node Akhir (mm)	A (mm^2)	l (mm)	m (kg)	Stress (kN/mm^2)	PerpindahanMaksimum (mm)
1	(0;0)	(3000;0)	1230	3000	28.2285	0.0073	0.4166
4	(0;0)	(1291,1;865.037)	1230	1554.1	14.6233	0.0111	0.3826
8	(3000;0)	(6000;0)	1230	3000	28.2285	0.0073	0.4166
10	(3000;0)	(1291,1;865.037)	1230	1915.4	18.0230	0.0022	0.3224
11	(3000;0)	(2083;1395.61)	1230	1669.9	15.7129	0.0016	0.408
12	(3000;0)	(3852,3;1438,959)	1230	1672.4	15.7364	0.0019	0.3061
13	(3000;0)	(4804,9;800,717)	1230	1974.5	15.7364	0.0023	0.425
18	(6000;0)	(4804,9;800,717)	1230	1438.5	18.5791	0.0108	0.2549
20	(3000;2000)	(2083;1395.61)	1230	1098.3	13.5356	0.0017	0.3942
21	(3000;2000)	(3852,3;1438,959)	1230	1020.4	10.3345	0.0016	0.2902
23	(1291,1;865.037)	(2083;1395.61)	1230	953.2121	9.6015	0.0077	0.3934
26	(2083;1395.61)	(3852,3;1438,959)	1230	1769.8	8.9692	0.0074	0.3867
28	(3852,3;1438,959)	(4804,9;800,717)	1230	1146.6	8.9692	0.0080	0.2849
BeratStruktur (kg)					**206.2781**	**0.0111**	**0.425**
Best Fitness (kg)					**0.0048**	Maximum Stress	Maximum Displacement

THE SECOND MODEL OF ROOF TRUSS WITH 8-NODES FOR CERTAIN POINT LOAD BASED ON STRUCTURE CONFIGURATION

The second model is tried to be optimized using hybrid genetic algorithm with similar assumption with the first model of roof structure for certain point load.

Construction Dimension (The Distance Between Roof Truss)	: 6 m
Load Mass For Roof and Plafond	: 50 kg/m^2
Live Point Load each Nodes	: 200 kg

The result can be seen on Figure 17. Maximum fitness reaches 0,0048 which is similar with the second model for constant point load described above. Same reason with the first model, theactual stress and actual displacement are more smaller if compared with the limit of stress and the limit of displacement.

Figure 17. Evolving Best Fitness Each Generation for Second Model for Certain Point Load

THE THIRD MODEL OF ROOF TRUSS WITH 10-NODES

The last model tried to be optimized of roof truss model is roof truss with 10-nodes and length of structure is 25 m and height of the structure is about 3 m (Shown in Figure 16). In Figure 17 can be seen result of the optimum structure using hybrid genetic algorithm where all of the members used the smallest of area section which provided. Table 5 shows the value of stress, displacement, area sections, and location of nodes.

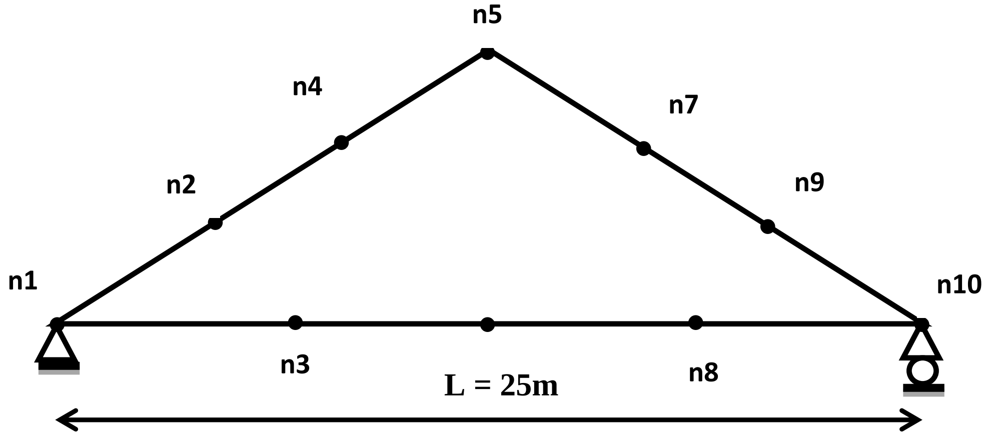


Figure 16.Third Model of Roof Truss (10-Nodes)

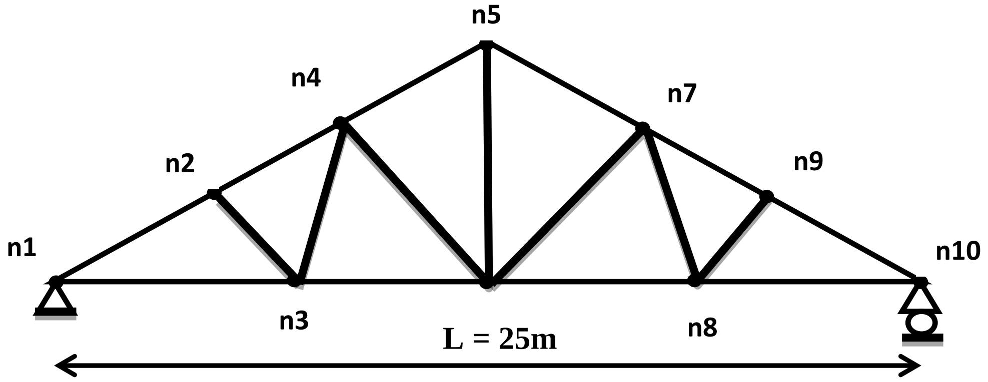


Figure 17. The Result of Third Model Optimized Using Hybrid Genetic Algorithm

Table5. Area Section, Stress, Displacement, Location of Nodes, Weight of Structure of the Third Model Using Hybrid Genetic Algorithm

Members	Start Coordinates (mm)	End Coordinate (mm)	A (mm^2)	l (mm)	m (kg)	Stress (N/mm^2)	Displacement (mm)
1	(0;0)	(4429;1062,96)	3500	4554.8	121.9548	1.6000	0.55
2	(4429;1062,96)	(8063;1935,12)	3500	3737.2	100.0635	0.7043	0.6685
3	(8063;1935,12)	(12500;3000)	3500	4563	122.1743	0.5275	0.6685
4	(8063;1935,12)	(17980;1924,8)	3500	5584.5	149.5250	0.2833	0.529
5	(17980;1924,8)	(20192,2273;1153,9135)	3500	2342.7	62.7258	0.4074	0.388
6	(20192,2273;1153,9135)	(25000;0)	3500	4944.3	132.3836	0.8897	0.3305
7	(18750,0)	(25000,0)	3500	6250	167.3438	2.3000	0.4472
8	(12500;3000)	(18750,0)	3500	6250	167.3438	4.2000	0.5731
9	(6250;0)	(12500;0)	3500	6250	167.3438	7.8000	0.5815
10	(0;0)	(6250;0)	3500	6250	167.3438	10.0000	0.5815
11	(12500;3000)	(12500;3000)	3500	3000	80.3250	0.0158	0.5734
14	(4429;1062,96)	(6250;0)	3500	2108.5	56.4551	0.1928	0.4438
20	(6250;0)	(8063;1935,12)	3500	2651.7	70.9993	0.1662	0.5742
24	(8063;1935,12)	(12500;0)	3500	4840.6	129.6071	0.3428	0.5159
30	(12500;0)	(17980;1924,8)	3500	5808.2	155.5146	1.1000	0.6089
32	(17980;1924,8)	(18750,0)	3500	2073.1	55.5073	0.0791	0.5105
33	(18750,0)	(20192,2273;1153,9135)	3500	1847	49.4534	0.1309	0.5082
Weight of Structure (kg)					**1956.0637**	**10.0000**	**0.6685**
Best Fitness (kg)					**0.0005**	Maximum Stress	Maximum Displacement

Conclusion

References

Arfiadi, Y. (2000). *"Optimal Passive and Active Control Mechanisms for Seismically Excited Buildings".University of Wollongong Thesis Collection.*

Arfiadi, Y. and Hadi, M. N. S. (2011) .*"Optimum Placement and Properties of Tuned Mass Dampers Using Hybrid Genetic Algorithms."Int. J. Optim. Civil Eng.*, 2011; 1:167-187.

Arfiadi,Y. (2013). "LaporanPenelitian: Pengembangan Program Bantu RealinuntukPembelajaranMetodeMatriksKekakuandengan FREEMAT". Yogyakarta: UniversitasAtma Jaya Yogyakarta.

Arfiadi, Y. (2013). "Pengembangan Program Berbasis*Open Source REALIN*untukAnalisisStruktur ", JurnalKonfrensiNasionalTeknikSipil ke-7 (KoNTeks-7),Solo, nomormakalah 046S, 2013.

Deb, K. and Gulati, S. (2001). "Design of Truss-Structures for Minimum Weight Using Genetic Algorithms."*Finite Elements in Analysis and Design*, 37, 447-465.

Galante, Miguel. (1996). "*Genetic Algorithms ss an Approach To Optimize Real-World Trusses". International Journal for Numerical Methods in Engineering.Volume 39, issue 3. Pages 361-382.*

Goldberg, D.E. (1989). "*Genetic Algorithms in Search, Optimization, and Machine Learning*.", Addison-Wesley, Reading, MA.

Hadi, M. N. S. and Arfiadi, Y. (1999a). "*Application of genetic algorithms for optimum design of rigid pavements.*" In. Toping, B. H. V. and Kumar, B. (eds.) *Optimization and control in civil and structural engineering,* Civil-Comp Press, Edinburgh, 41-46.282

Hajela, P. Lee, E. (1995). "*Genetic Algorithms in Truss Topological Optimization".International Journal of Solids and Structures. Volume 32, issue 22. Pages3341-3357.*

Hultman, M. (2010)."*Weight Optimization of Steel by a Genetic Algorithm*", *Master Thesis from Department of Structural Engineering of Lund University*.

Kripakaran, Prakash. Gupta, Abhinav. Baugh Jr. John W. (2007).*A novel optimization approach for minimum cost design of trusses.Computers & Structures.Volume 85, issue 23-24. Pages 1782-1794.*

Li, Lijuan. Huang, Zhibin. Liu, Feng. (2006). "*An Improved Particle Swarm Optimizer for Truss Structure Optimization".2006 International Conference on Computational Intelligenceand Security.Volume 1.Pages 924-928.*

Lin,C.-Y, and Hajela, P. (1992). "*Genetic Algorithms in Optimization Problems with Discrete and Integer Design Variables", Journal of Engineering Optimization, Vol*19*, pp.*309-327, 1992*.*

Lin,C,-Y, and Hajela,P. (1993). "*Genetic Search Strategies in Large Scale Optimization", proceedings of the 34th AIAA/ASME/ASCE/AHS/AHS/ASC SDM Conference, La Jolla, California, pp.* 2437-2447, 1993*.*

Rajan, S.D. (1995)."*Sizing, Shape, and Topology Design Optimization of Trusses Using Genetic Algorithm."Journal of Structural Engineering*, 121(10), 1480-1487.

Rajeev, S. and Krishnamoorthy, C.S. (1992) "*Discrete Optimization of Structures Using Genetic Algorithms."Journal of Structural Engineering*, 118(5), 1233-1250.

Sakamoto, J., and Oda,J. (1993)."*A Technique of Optimal Layout Design for Truss Structures Using Genetic Algorithm."Proc.,35th AIAA/ASCE/ASME/AHS SDM Conf., ASCE, New York, N.Y.,* 2402-2408.

Sesok, D. and Belivicius, R. (2007).*"Use of Genetic Algorithms in Topology Optimization of Truss Structure."*ISSN 1392-1207.*Mechanica*. 2007. Nr 2(64)