# The Sizing Optimization of Hospital Bed Structure for Independently Supporting Left and or Right Leg Using Genetic Algorithms

Rung Kittipichai and Atthaphon Ariyarit

***Abstract*—This paper deals with the new method to design the optimum design for hospital bed, which can support the left and or right leg for patient's leg splint. GAs as an optimization method was selected to search the minimum mass of bed structure whilst fulfilling some structure constraints such as stress, displacement and buckling. The GAs and FE code were developed to analyze the structure in MATLAB. Two optimization problems were set to search the minimum mass. In Problem I, the height and width of cross-section in each element was varied from 1 to 5 cm. Whilst the height and width of cross-section in Problem II were selected from 1, 2 and 5 cm. The minimum masses achieved from both problems were 57.31 and 49.25 kg, respectively. The minimum masses obtained from Problem II were more than that from Problem I but it practically made the bed structure easier. Therefore, this paper demonstrates that it is possible to design the hospital bed for independently supporting left and or right leg by using the concepts of GAs combined with FEM to search the optimum mass.**

***Index Terms*—finite element, Genetic Algorithms, hospital bed, optimization.**

## I. Introduction

At present, there are many types of the hospital bed with various functions, for example, it can lift the head section and/or leg section of the bed as shown in Fig. 1 or it can change between bed and chair as shown in Fig. 2. Unfortunately, the hospital bed cannot lift either a left leg or a right leg. That means when the patient's left leg or right leg is broken, the hospital bed need to lift both legs. It cannot lift independently. This paper will focus on the hospital bed design for independently separating the left and or right leg.

The structure of the hospital bed is typically complicate and heavy. This paper proposes the design method to reduce the mass of the bed structure. To reduce the bed mass, the optimization technique including the Finite Element Analysis (FEA) can be employed. In 1997, Jenkins [1] demonstrated the success of using the optimization technique with Genetic Algorithms (GAs) to reduce the sizes of multistory frame for the optimum mass. In 1998, Annicchaiarico and Cerrolaza [2] applied GAs including 2-D finite element shapes to a three-dimensional 25-bar truss tower to obtain the optimum mass subject to the stress and displacement and buckling constraints. Later, Coello and Christiansen [3] proposed the new GA-based multi-objective optimization problems to minimize mass and to meet the maximum displacement and stress of the structure using the cross-section area of each element as the design variables for a 25-bar truss tower similar to Annicchaiarico and Cerrolaza's work in 2000. In 2001, Deb and Gulati [4] applied the real-coded GAs to 2-D and 3D trusses to achieve minimum mass subject to stress, deflection and kinematic stability constraints.

Fig. 1 General hospital bed. [5]

Fig. 2 Hospital bed combined bed and chair. [6]

This paper will optimize the structural mass of the hospital bed for independently separating left and or right leg by using GAs combined with 2-D beam element in FEA. The results of FEA such as stress, deflection, and buckling are added in GAs procedure as the constraints to find the structural size of each element. All are done and developed the code in MATLAB program

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## II. Theory of Analysis

This section explains the theory of Finite Element Method (FEM) to apply to the bed structure to find the displacement, stress and buckling of the structure. And then GAs is demonstrated how to apply FE including GAs algorithm.

### *A. Finite Element Method for Structural Analysis*

The Finite element method is a numerical procedure for analyzing elastic structures. The structure is divided into a number of simple shaped elements called finite elements. Each element is interconnected at nodes. If the structure is under applied forces or loads, the displacement in each node is obtained by formulating the properties of each element then assembling all of the elements to obtain a global Finite Element (FE) model. Once the FE model is created, the equations of equilibrium can be solved by using the computer to get the displacement of each node after nodal forces or loads and boundary conditions are applied.

There are many methods to model elastic structures. One key method used to formulate FE model is the principle of minimum potential energy (PMPE). Hamilton's principle is an approach which can be used to obtain the PMPE [7]. Therefore, the equation of equilibrium for the $e^{th}$ element in the local coordinate system can be expressed as follows

$$\{F\}^e = \int_\Omega [B]^{eT}[D]^e[B]^e d\Omega \; \{d\}^e \qquad (1)$$

$$\{F\}^e = [K]^e\{d\}^e \qquad (2)$$

where $$[K]^e = \int_\Omega [B]^{eT}[D]^e[B]^e d\Omega \qquad (3)$$

and $[K]^e$ is called the element stiffness matrix. [D] is the constitutive matrix. [B] is called the strain-displacement matrix [8]. Note that [B] depends upon the prescribed shape functions. In this work, the type of element selected was the 2-D beam element to model the 3-D bed structure. The element stiffness for a beam element is written as [9]

$$[K] = \begin{bmatrix}
\frac{AE}{L} & 0 & 0 & 0 & 0 & 0 & \frac{-AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} & 0 & \frac{-12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\
0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{-6EI_y}{L^2} & 0 & 0 & 0 & \frac{-12EI_y}{L^3} & 0 & \frac{-6EI_y}{L^2} & 0 \\
0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 & 0 & 0 & 0 & \frac{-GJ}{L} & 0 & 0 \\
0 & 0 & \frac{-6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} & 0 & \frac{-6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} \\
\frac{-AE}{L} & 0 & 0 & 0 & 0 & 0 & \frac{AE}{L} & 0 & 0 & 0 & 0 & 0 \\
0 & \frac{-12EI_z}{L^3} & 0 & 0 & 0 & \frac{-6EI_z}{L^2} & 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{-6EI_z}{L^2} \\
0 & 0 & \frac{-12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 & 0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\
0 & 0 & 0 & \frac{-GJ}{L} & 0 & 0 & 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\
0 & 0 & \frac{-6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 & 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\
0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} & 0 & \frac{-6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L}
\end{bmatrix} \qquad (4)$$

Since (1) is the equation of equilibrium for the $e^{th}$ element in the local coordinate system, the equation of equilibrium for the whole structure is given by assembling the element equations of equilibrium. Since the matrices in the equation of equilibrium for the whole structure are in global coordinates, the matrix in (2) has to transform the local coordinate to the global coordinate system. The relationship between the local coordinate and the global coordinate can be written in terms of the nodal displacement matrix for the $e^{th}$ element as

$$\left\{d^{local}\right\}^e = [T]\left\{d^{global}\right\}^e \qquad (4)$$

where [T] is the transformation matrix which consists of the direction cosines between the global and local coordinate system. At each node for 6 DOFs, equation (4) can be rewritten as [9]

$$\begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}^{local} = \begin{bmatrix} l_{11} & l_{12} & l_{13} & 0 & 0 & 0 \\ l_{21} & l_{22} & l_{23} & 0 & 0 & 0 \\ l_{31} & l_{32} & l_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & l_{11} & l_{12} & l_{13} \\ 0 & 0 & 0 & l_{21} & l_{22} & l_{23} \\ 0 & 0 & 0 & l_{31} & l_{32} & l_{33} \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}^{global} = [T_d]\begin{Bmatrix} u \\ v \\ w \\ \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}^{global} \qquad (5)$$

where $l_{ij}$ is the direction cosine between the local axis $x_i$ and global axis $X_j$. Then, the element stiffness and force matrix as in (2) for the local coordinate system can be transformed to the global coordinate system as follows

$$\left[K^{global}\right]^e = [T]^T\left[K^{local}\right]^e[T] \qquad (6)$$

and $$\left\{F^{global}\right\} = [T]^T\left\{F^{local}\right\} \qquad (7)$$

Hence, the equation of equilibrium for the whole structure is obtained by assembling the global element equations of equilibrium and can be expressed as

$$\{F\} = [K]\{d\} \qquad (8)$$

where {F} is a matrix of external forces, {d} is a matrix of nodal displacements and [K] is the global stiffness matrix for the structure. Once, the element matrices of the system are modeled. To determine the unknown nodal displacements of the whole structure, the external forces and boundary conditions of the system have to be applied. The unknown nodal displacements for the system are obtained by solving (8) as follows

$$\{d\} = [K]^{-1}\{F\} \qquad (9)$$

Once the nodal displacements are obtained by (9). The strain and stress of each element are determined. To determine the strain and stress of each element, the process of calculating the strain-displacement matrix in each element is repeated. Then the strain matrix in each element is obtained as follows

$$\{\varepsilon\} = [B]^e\{d\}^e \qquad (10)$$

Then the stress matrix in each element is obtained by

$$\{\sigma\}^e = [D]^e\{\varepsilon\}^e \qquad (11)$$

Note that stresses in each element can be evaluated. To determine the stresses in each element, the Von Mises stress for 2D case can be used as follows

$$\sigma_v = \sqrt{\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2} \quad (12)$$

Yielding of material occurs when the stress exceeds the yield strength of material. Hence, to prevent the failure of structure due to yielding, the Von Mises stress is less than the yield strength of material and is written as

$$\sigma_v \leq \sigma_y \quad (13)$$

where $\sigma_y$ is the yield strength of the material. In cases where a safety factor is applied to the design, Equation (13) can be rewritten as follows

$$\sigma_v \leq \frac{\sigma_y}{SF} \quad (14)$$

where SF is the safety factor.

*B. Buckling Analysis*

This section describes the analysis of a compressed member under an axial loading which is called column. The strength of column depends upon its geometry i.e. the length and cross-section of the column and the modulus of elasticity. In general, the column that is long and slender tends to fail by buckling rather than by yielding. The column will be collapsed when the load P reaches a critical point. This is called critical buckling load ( $P_{cr}$ ). The critical buckling load can be calculated by using Euler equation. Euler equation can be given as [10], [11]

$$\frac{P_{cr}}{A} = \frac{C\pi^2 E}{(L/k)^2} \quad (15)$$

where L is the length of column, k is the radius of gyration, A is the cross-section area, E is the modulus of elasticity and C is the constant depending upon the end conditions.

*C. Genetic Algorithms*

Genetic Algorithms is a stochastic search method based upon the theory of natural selection. It was developed by Holland [12] at the University of Michigan between 1960's and 70's and then Goldberg [13] extended the theoretical foundations and applications of GAs. GAs as Evolution Algorithms method are famous because it is easy to apply to optimization problems and can be seen as a black box method [14].

The search procedure starts with an initial population as parents. The initial population of individual is randomly created. Note that weighting the probability of a gene is applied for breeding in terms of its fitness. The characteristics that give the best solutions are passed on from one generation to the next generation. This strategy is called elitism. The procedure is repeated until an optimum is achieved. Therefore the success of GAs depends upon a population consisting of feasible and infeasible points. The Genetic operators such as selection, crossover and mutation are applied to the parents to create the offspring.

Strings of the integers are typically used as genes represented as design variables. The classical representation of real-number design parameters is binary string. Each bit position is either "1" or "0". In order to find the fitness values of genes, the strings are to be converted to real values. A matrix of binary-string b can be converted to be the decimal number $x_i$ as follows [15]

$$x_i = x_{l,i} + (x_{u,i} - x_{l,i})\frac{bt}{2^{N_b}-1} \quad (16)$$

where b is a matrix size $1\times N_b$ having either '1' or '0' as the elements, t is a transformation matrix size $N_b\times 1$, $t_{i,1} = 2^{(Nb-i)}$, $x_{l,i}$ is the lower limit of $x_i$, and $x_{u,i}$ is the upper limit of $x_i$.

As above description, the offspring are created by using the genetic operators from parents. The genetic operators such as selection, crossover and mutation can be explained as

*D. Selection*

Genes in the current population are to be randomly selected so that they will be taken to a mating pool to create offspring. The selection of each individual gene for breeding is based upon its fitness function value. The probability of the $s^{th}$ gene being selected $w_s$ can be written as follows [16]

$$w_s = \frac{f_s}{\sum_{i=1}^{N_g} f_i} \quad (17)$$

where $N_g$ as a number of genes in a population, $f_i$ fitness of the $i^{th}$ gene and $f_s$ is the fitness of the $s^{th}$ gene. Using (17), if the fitness of the best gene is considerably more than the average fitness, there will be a risk of self-breeding of the best gene producing identical solutions in the next generation and that leads to the procedure stalling. To relax the extreme domination of some genes, the probability function is modified so that after sorting the order of genes based upon their fitness. Then the probabilities of the $s^{th}$ gene being selected are obtained using the following [16]

$$w_s = \frac{2s}{N_g(N_g+1)} \quad (18)$$

By using Eq. (18), the fitness values always has an opportunity $1/(N_g+1)$ of being selected, whilst the best gene always has an opportunity $2/(N_g+1)$, approximately twice of the others. On each generation, not-so-good genes still have chances to be selected.

*E. Crossover*

Crossover is an operator to generate offspring from parent strings. For a one-point crossing over, two offspring are created from a pair of parents by randomly cutting the parents into two parts. The offspring are the genes that copy the first part of the parent while the second parts are interchanged. With the same idea as operating one-point crossover, multiple-point crossover can be carried out.

*F. Mutation*

A mutation is an operator which each element in a gene of offspring is chosen at random. An element (i.e. "0" or "1") is flipped the value from 0 to 1 or vice versa. An idea of mutation is used to prevent the solution which converses to a poor local optimum because of the lack of population diversity. In general, the mutation is applied with a small probability of mutation in the simple GAs.

Each of these operations (crossover, and mutation) takes place with some given probability. Crossover is operated with high probability whilst the mutation will have rare chances to be operated. Furthermore, an elitist strategy is employed by the best gene or elite from each generation being directly saved to the next generation, ensuring that the best solution is not lost.

### G. Penalty function

Genetic Algorithms is classically employed to solve unconstrained optimization problem. To deal such a problem, the constrained optimization problem has to be transformed to an unconstrained optimization problem by adding a penalty term of constraints to the objective function. Static penalty is a technique which the penalized objective function consists of the unpenalized objective function and a penalty term as follows

$$f_p(x) = f(x) + \sum_{i=1}^{m+p} C_i d_i^k \tag{19}$$

where

$d_i = 0$ , if constraint $g_i(x)$ is satisfied for i=1,…,m

$d_i = g_i(x)$ , if constraint $g_i(x)$ is violated for i=1,…,m

$d_i = |h_i(x)|$ , if constraint $h_i(x)$ is violated for i=m+1,...,p

$C_i$ is the penalty coefficients corresponding to $i^{th}$ constraint and k is normally defined as 1 or 2. Therefore, Equation (19) is based upon the number of constraint violations. The algorithm of GAs including FEA is showed in Fig. 3.

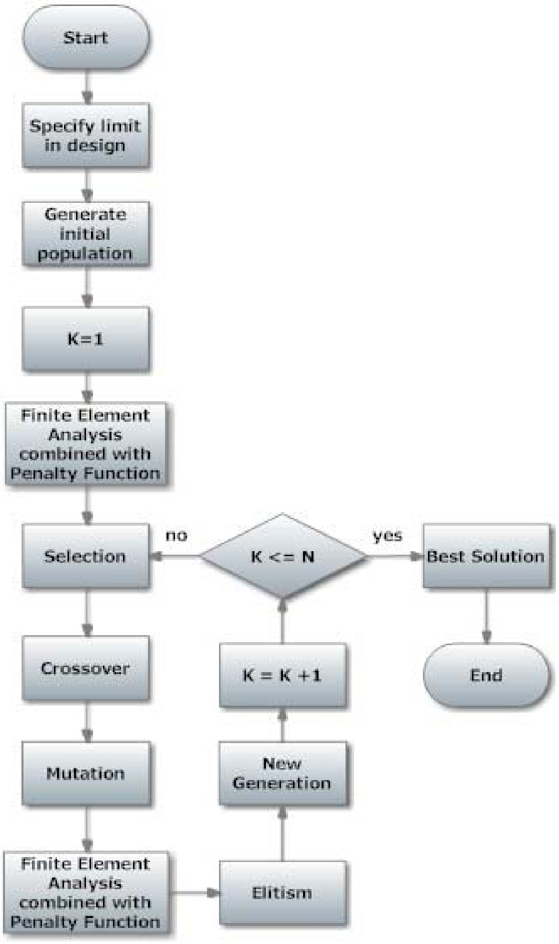


Fig. 3 Algorithm of GAs including FE Procedure.

## III. Problem and Result

The goal of the problem is to reduce the structural mass of a hospital bed whilst fulfilling some structure constraints. Fig. 4 shows a structural model of the hospital bed for independently supporting left and or right leg. The bed structure was modeled by using the concept of the beam element in FE process. The bed size was the width of 0.8 m and the length of 2 m. The FE model consists of 54 beam elements for rectangular bar with 38 nodes. The 54 beam elements were treated as design variables of the optimization problem. The bed structure was made of steel alloy 4140 [17]. The material properties of such steel were the density of 7850 kg/m$^3$, the modulus of elasticity of 207 GN/m$^2$ and the yield strength of 655 MN/m$^2$. The bed structure can support the vertical load as the patient or human mass and the horizontal load as thrust load. Such loads were treated as the distribution loads as shown in Fig. 4. The sum of vertical and horizontal loads were 4.2 and 2.5 kN, respectively. The node of 2, 3, 10 and 12 was supported and transferred force to the structural base.

*Problem I: Optimization with varying sizes of cross-section of rectangular beam.*

To solve the optimization problem using the GAs including FE, all codes were developed and run in MATLAB program. The mass of bed structure was minimized by reducing the size of cross-section area in each element. The search limits of the width and height in each cross-section area of the element was defined between 1 and 5 cm. For the displacement constraint, the displacement in each node of structure was allowed less than 1 cm. Therefore, the optimization problem may be written as follows

Minimize f(x) = the mass of 54-beam structure

Subject to

$1 - R_i \le 0;\ i = 1, \dots, 54$

$\lambda_i - 1 \le 0;\ i = 1, \dots, 54$

$-\left(1 - \dfrac{\nu_j}{0.01}\right) \le 0;\ j = 1, \dots, 34$

and $0.01 \le x_k \le 0.05;\ k = 1, 2, \dots, 108$

where $R_i$ is the ratio of the applied axial stresses to the allowable stress in each beam, $\lambda$ is the ratio of stress due to axial load to the critical stress in the compressed bar. $\nu_j$ is the displacement in y-direction at each nodal point, and $x_k$ is the design variable of the width and height in each cross-section of the i$^{th}$ rectangular beam. The safety factor applied to the structures was set to 2. In GAs strategy, design variables were coded to be binary strings. Each design variable contains 10 binary bits and the number of population in each generation was set to 500. The number of generation was set to 1500. The probabilities of operating crossover and mutation on each generation were 0.8 and 0.2, respectively. One elite gene was saved to the new generation, and a new blood that was created randomly was also included in the new generation.

The results of searching the minimum mass in the Problem I are shown in Fig. 5 and 6. Figure 5 shows the graph of the relation between the average and best fitness against the number of generation. Whilst Figure 6 shows the zoom of graph in Fig. 5 which considers only the best fitness against the number of generation. The results show that the minimum mass is 49.25 kg whilst the buckling constraint at the minimum mass is accepted. Table I demonstrates the results of searching the structural sizes of rectangular beam element in the height and width of cross-section at the minimum mass subject to stress, displacement and buckling constraints. As shown in Table I, the smallest width of cross-section is 1.01 cm of the 3$^{rd}$ and 5$^{th}$ elements. Whilst the largest width of cross-section is 4.03 cm of the 20th and 39th elements. The smallest and largest heights of cross-section are 1.00 cm of the 30th and 50th elements and 4.6 cm of the 22nd and 37th elements, respectively. The smallest cross-section area is 1.54 $cm^2$ of the 24th and 43rd elements whereas the largest cross-section area is 10.21 $cm^2$ of the 22nd and 37th elements. Figure 7 shows the displacement of bed structure when the size of cross-section area in each element was analyzed by using FEA. The results showed that the maximum displacement was 0.20 cm at the 5th node. The maximum stress was 194.44 $MN/m^2$ on the 44th element; whilst, the 45th element may be damaged by the buckling effect.

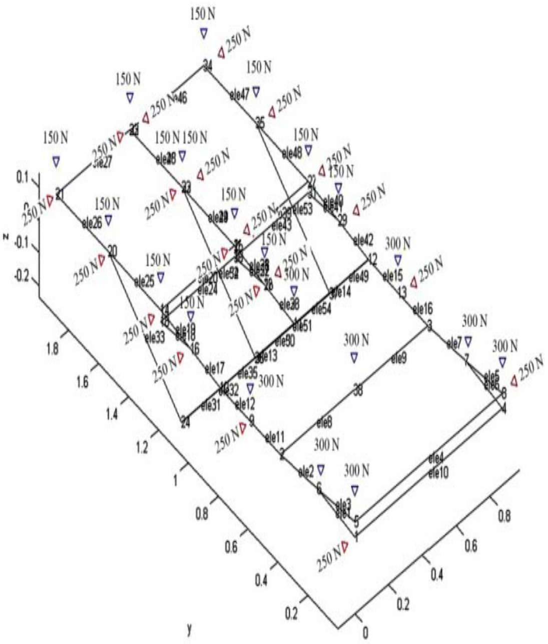

Fig. 4 FE model of hospital bed.

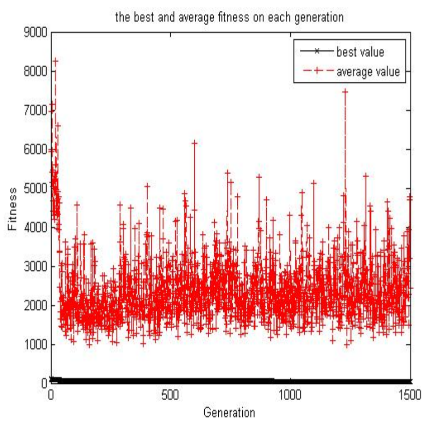


Fig. 5 Average and best fitness on each generation in Problem I.

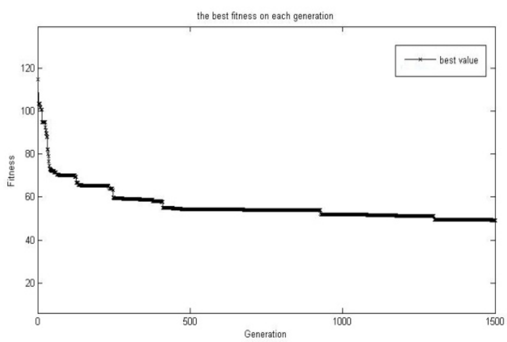


Fig. 6 Best fitness on each generation in Problem I.

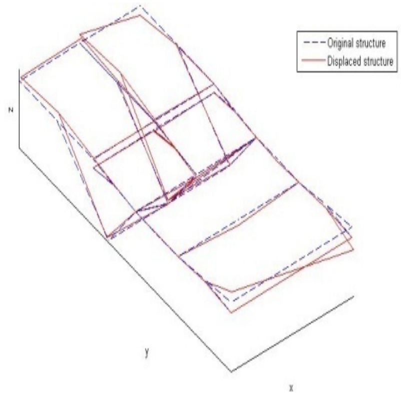


Fig. 7 Displacement of bed structure at optimum in Problem I.

TABLE I RESULTS OF SEARCHING STRUCTURAL SIZES OF RECTANGULAR BEAM ELEMENT IN THE HEIGHT AND WIDTH OF CROSS-SECTION AT MINIMUM MASS IN PROBLEM I.

| Element No. | Cross-section | | Element No. | Cross-section | |
|---|---|---|---|---|---|
| | Width (m) | Height (m) | | Width (m) | Height (m) |
| 1,6 | 0.0296 | 0.0170 | 22,37 | 0.0222 | 0.0460 |
| 2,7 | 0.0210 | 0.0126 | 23,36 | 0.0108 | 0.0288 |
| 3,5 | 0.0101 | 0.0267 | 24,43 | 0.0140 | 0.0110 |
| 4 | 0.0141 | 0.0110 | 25,48 | 0.0278 | 0.0167 |
| 8,9 | 0.0120 | 0.0258 | 26,47 | 0.0279 | 0.0203 |
| 10 | 0.0132 | 0.0150 | 27,46 | 0.0125 | 0.0209 |
| 11,16 | 0.0256 | 0.0116 | 28,45 | 0.0152 | 0.0376 |
| 12,15 | 0.0182 | 0.0175 | 29,44 | 0.0202 | 0.0218 |
| 13,14 | 0.0156 | 0.0231 | 30,50 | 0.0165 | 0.0100 |
| 17,42 | 0.0292 | 0.0157 | 31,49 | 0.0140 | 0.0180 |
| 18,41 | 0.0102 | 0.0288 | 32,51 | 0.0171 | 0.0143 |
| 19,40 | 0.0268 | 0.0101 | 33,53 | 0.0107 | 0.0179 |
| 20,39 | 0.0403 | 0.0114 | 34,52 | 0.0102 | 0.0211 |
| 21,38 | 0.0150 | 0.0382 | 35,54 | 0.0108 | 0.0237 |

In the problem I, the result shows the success in searching the minimum mass with varying the size of width and height in each cross-section subject to displacement, structural stress and buckling constraints. However, the sizes in cross-section of element at optimum are too different. It is practically difficult to construct. To reduce such a difficulty, it should be specified in some size such as 1, 2 or 5 cm etc.

*Problem II: Optimization with specifying sizes of cross-section of rectangular beam.*

Similar to Problem I, the size of width and height in each cross-section of rectangular beam is used only 1, 2 and 5 cm. Then, the optimization problem can be expressed as follows

Minimize f(x) = the mass of 54-beam structure

Subject to

$$1 - R_i \leq 0; \; i = 1, \ldots, 54$$

$$\lambda_i - 1 \leq 0; \; i = 1, \ldots, 54$$

$$-\left(1 - \frac{\nu_j}{0.01}\right) \leq 0; \; j = 1, \ldots, 34$$

and $x_k = 0.01, 0.03$ or $0.05$; $k = 1, 2, \ldots, 108$

where $x_k$ is the design variable of the width and height in each cross-section of the $i^{th}$ rectangular beam. In GAs strategy, design variables were coded to be binary strings. Each design variable contained 10 binary bits and the number of population in each generation was set to 200. The number of generation was set to 500. The probabilities of crossover and mutation on each generation were set to 0.8 and 0.2, respectively. The elitism was still used.

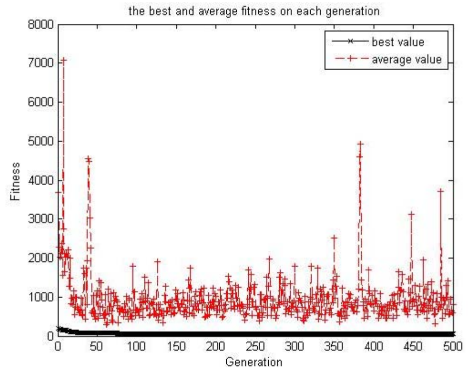


Fig. 8 Average and best fitness on each generation in Problem II.

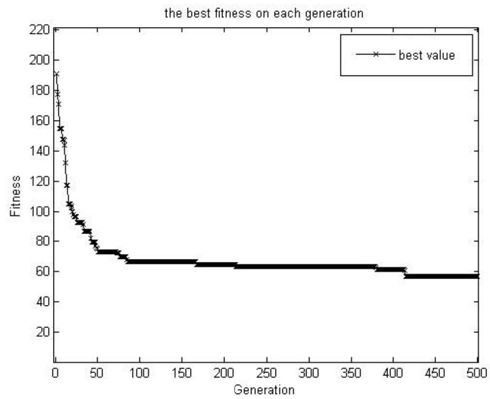


Fig. 9 Best fitness on each generation in Problem II.

The results of searching the minimum mass in Problem II are shown in Fig. 8 and 9. The relation between average and best fitness on each generation is shown in Fig. 8 whereas Figure 9 shows the zoom of graph in Fig. 8 to consider only the best fitness on each generation. The mass at optimum was 57.31 kg whereas the buckling constraint at the minimum is accepted. The results of searching the structural sizes of rectangular beam element in the height and width of cross-section at minimum mass are shown in Table II. The smallest and largest width of cross-section are 1 and 5 cm, respectively. The smallest and largest height of cross-section are 1 and 5 cm, respectively. Figure 10 shows the displacement of structure when the size of cross-section in each element was analyzed. The result demonstrated that the maximum displacement was given as 0.15 cm at the $7^{th}$ node. The maximum stress was 236.95 MN/$m^2$ on the $3^{rd}$ element. Whilst the $17^{th}$ element can be damaged by buckling.

From the results in each problem, the minimum mass in Problem I is less than that in Problem II as 8.06 kg. This results shows that the structural mass is increased because the sizes of height and width of cross-section are selected from three defined sizes. This idea will make the structural mass increase; nevertheless, building the bed structure is easier.

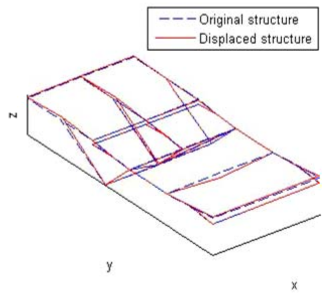


Fig. 10 Displacement of bed structure at optimum in Problem II.

TABLE II RESULT OF SEARCHING STRUCTURAL SIZES OF RECTANGULAR BEAM ELEMENT IN THE HEIGHT AND WIDTH OF CROSS-SECTION AT MINIMUM MASS IN PROBLEM II.

| Element No. | Cross-section | | Element No. | Cross-section | |
|---|---|---|---|---|---|
| | Width (m) | Height (m) | | Width (m) | Height (m) |
| 1,6 | 0.02 | 0.01 | 22,37 | 0.05 | 0.02 |
| 2,7 | 0.01 | 0.01 | 23,36 | 0.02 | 0.02 |
| 3,5 | 0.05 | 0.02 | 24,43 | 0.01 | 0.02 |
| 4 | 0.01 | 0.02 | 25,48 | 0.02 | 0.02 |
| 8,9 | 0.02 | 0.02 | 26,47 | 0.02 | 0.05 |
| 10 | 0.01 | 0.01 | 27,46 | 0.02 | 0.01 |
| 11,16 | 0.01 | 0.02 | 28,45 | 0.02 | 0.05 |
| 12,15 | 0.05 | 0.02 | 29,44 | 0.02 | 0.02 |
| 13,14 | 0.02 | 0.02 | 30,50 | 0.02 | 0.02 |
| 17,42 | 0.01 | 0.01 | 31,49 | 0.01 | 0.02 |
| 18,41 | 0.02 | 0.02 | 32,51 | 0.01 | 0.01 |
| 19,40 | 0.02 | 0.05 | 33,53 | 0.02 | 0.02 |
| 20,39 | 0.02 | 0.01 | 34,52 | 0.02 | 0.01 |
| 21,38 | 0.02 | 0.02 | 35,54 | 0.01 | 0.02 |

## IV. CONCLUSIONS

This paper proposed the idea of designing the hospital bed for independently separating left and or right leg. Due to the structure of bed is typically complicate and heavy, GAs as an optimization technique was used to reduce the structural mass of bed whilst fulfilling some structure constraints. To analysis the bed structure, FE code was developed and combined with GAs code by using MATLAB program. Two optimization problems were set to search the minimum mass of structure with varying and selecting the sizes of width and height in cross-section of each element due to the difficulty in building the bed in the real lift. The results showed the success in searching the minimum mass whilst the displacement of each node and the stress and buckling in each element at the optimum were accepted. Therefore, there is the possibility in designing the hospital bed for independently supporting left and or right leg by using GAs combined with FEM to search the minimum mass.

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