OPTIMUM OPENING SIZE AND LAYOUT OF ELASTIC CELLULAR STEEL BEAMS

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ABSTRACT

Research on castellated beams has in the past focused on beams with hexagon shaped web openings. Field experience has shown that damage on castellated beams are mostly due to cracks occurring at opening corners. Therefore research on castellated steel beams with smooth sided openings is felt necessary. In this study the behavior of beams with circular or elliptical web openings are considered. The shape, size, and layout of the openings are required to meet optimum conditions, such that the best economic solution may be achieved. Optimum conditions are acquired applyi Genetic Algorithms simulating the Darwinian theory of evolution. It is hoped that results of th investigation may further develop the current tradition of designing castellated steel I-beams.

Keywords: castellated, celullar. Genetic Algorthm.

1. INTRODUCTION

Castellated Steel beams are I-section beams with web openings in the form of square, hexagonal, circular, or their modifications. Castellated steel beams are in general utilized in bulidings to economically place utiliy systems through web openings rather than draping them under the beams. Originally the web openings are of hexagonal form. Later developments also use circular web openings. To improve even further, developers later place pieces of steel strips in the web post area producing elongated hexagonal or circular openings.

Castellated beams are usually constructed by cutting steel I-beams longitudinally into two halves according to a certain pattern. These two halves are then separated, shifted over each other, and then welded together, to form a beam with openings, which is deeper, stiffer than the original one. This process is illustrated in Figure 1.

Numerical control technology has lately become the method of cutting steel structural elements. It facilitates the cutting of varying shapes and sizes of web openings. Therefore, an optimum layout of such openings could easily be included in the construction of castellated beams. Hence optimum solutions also become an important point of interest in this study.

2. LITERATURE REVIEW

Theoretical and experimental studies on castellated beams with hexagonal openings have been heavily performed by early researchers. Kerdall and Nethercot (1984) investigated the failure modes of castellated beams. Zaarour and Redwood (1996), studied the failure of hexagonal castellated beams where additional plates have been added at the web-post. Redwood and Demirdjian (1998) investigated the shear failure of the web-post. Delesquez (1968) performed a theoretical study applying elastic structural analysis. Aglan and Redwood (1974) studied the failure of the web area considering elastic-plastic conditions and strain hardening effects in the web-post region of hexagonal castellated beams, applying finite difference analysis.

The above works addressed problems frequently met in practice, where hexagonal castellated beams are applied. The problems arise from cracks due to the development of high stress concentration at the corners of hexagonal web openings. Therefore, a study on castellated beams with smooth sided openings, such as circular or elliptical holes, where crack problems are eliminated, would enriched the current knowledge of castellated beam design.

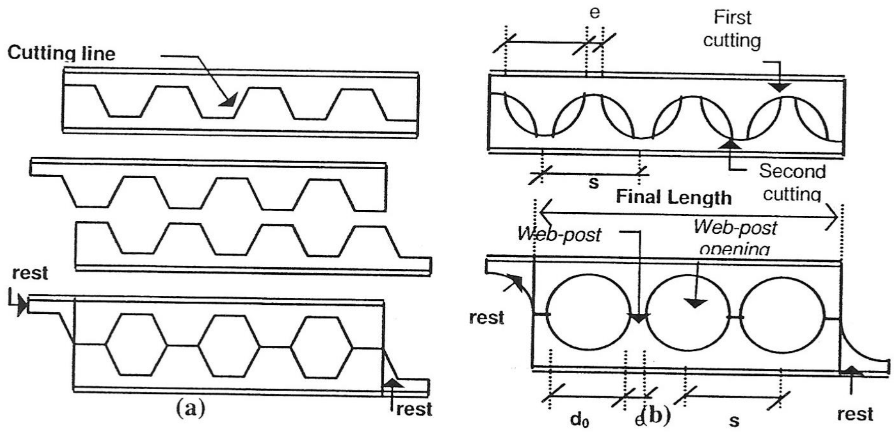


Figure 1. Manufacture of Castellated Beams
(a) Hexagonal web openings, (b) Circular of Elliptical Web Openings

Non-linear mathematical programming in structural optimization frequently leads to problems of iteration divergence. This may be due to inaccurate derivatives of complicated objective and constraint functions. To alleviate such problems, random heuristic optimization processes have been applied. Many research in structural optimization have used such approach by applying Genetic Algorthims.

Besari and Wibowo (1994) investigated the optimum shapes of trusses by Genetic Algorithms. Wibowo (1996) applied genetic algorithms in his study of optimum shapes of oval axially symmetrical shells. Hamit Saruhan (2004) studied the optimum geometrical design of three lobes journal bearings including stability, thickness, temperature, and pressure constraints.

The authors of this paper applied genetic algorithms to study the design of castellated elastic steel beams with optimum elliptical or circular shape and layout of web openings. Dimensions defining opening shapes and sizes were defined as independent variables, while stresses and deflections were taken as dependent variables appearing in the constraint functions. Those dependent variables were determined by finite element analysis. Simple plane triangular elements were considered in the analysis for stresses and deflections. For the purpose of this study, a computer program was written utilizing the available MATLAB Programming Language and Toolbox (Bodenhofer 2003, Chipperfield 2004, Silva 2004, Anon 2006).

3. BASIC CONCEPTS AND THEORY

3.1. Genetic Algorithm

Genetic algorithm, first developed by Holland (1975), address the problem of adaptation—natural as well as artificial—in terms of genetic terminologies. It simulates Darwin's Theory of Evolution based on the principle of natural selection, where individuals with high fitness would survive and breed, while the weaker ones would perish. Individuals are represented by their genetic chromosomes on which the principle of crossover breeding, mutation and inversion are operated. Genetic changes taking place in one generation of a population are transmitted to the next generation through crossover breeding.

In real problems, such as the optimization of structures, each individual in genetic algorithm is representing a structure. For this purpose, a code appropriately representing the problem shall first be designed. Solution points of the problem are coded in the form of chromosomes consisting of genes containing the unique charcteristics of the structure. This charcteristics are usually represented by symbols.

A population is constructed consisting of randomly generated individuals. The process of breeding among these individuals also proceeds in a random manner. The principle of natural selection was applied on members of this population to determine their fitness to be counted as members of the next generation.

3.2 Problem Formulation

The optimization problem considered in this paper is to seek the maximum of the cut away web area. It may be formulated in general mathematical terms as follows

Maximize $F(x)$

Subject to $g_j(x) \leq 0$, $j = 1, 2, \ldots, m$

Where
x = independent design variables,
X = design space of variable x,
$F(x)$ = objective function,
$g_j(x)$ = constraint functions,
m = number of inequality constraints.

3.2.1 Design Variables

The independent design variables in the problem being considered are a and b, which consecutively represent the half width and the half height of the web opening. These variables are illustrated in fig, 3.1. The design space of these varibles are $0.35\,hw \leq a \leq 0.65\,hw$ and $0.35\,hw \leq b \leq 0.65\,hw$. Figure 3.1(a) shows the cutting pattern.

The relation between the variables a and b are given by the following equation

$$\frac{r^2}{a^2} + \frac{z^2}{b^2} = 1$$

Rearranging this equation gives

$$z = f(r) = b\sqrt{1 - \left(\frac{r}{a}\right)^2}$$

From Detail A the following may be derived

$$z_c = b - z_{r=1/2e} = b - b\sqrt{1 - \left(\frac{1/2.e}{a}\right)^2} = b - b\sqrt{1 - 0.25\left(\frac{e}{a}\right)^2}$$

The web height of the castellated beam is then

$$H = b + h_w - z_c = h_w + b\sqrt{1 - 0,25\left(\frac{e}{a}\right)^2}$$

If L is the length of the castellated beam and n the number of the openings, then

$$L = (n)(2a) + (n + 1)e = 2an + ne + e$$

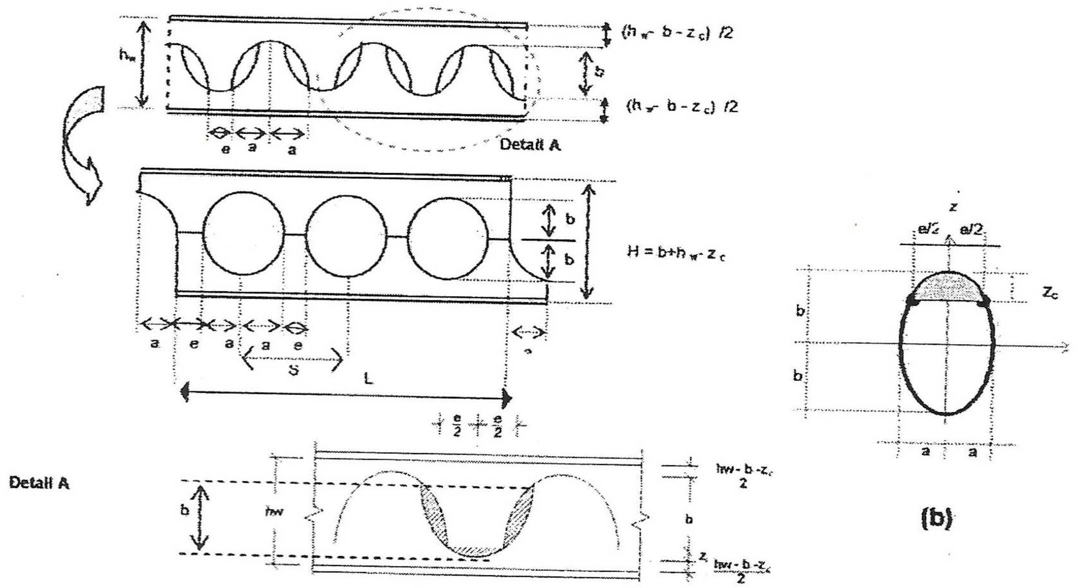
Or

$$n = \frac{L-e}{2a+e}$$

The number of holes n at the left hand side of the above equation shall be an integer. Since L, a and e are real numbers, then the value of the right hand side of the equation is in general no integer. Therefore, this number needs to be rounded to the two closest integers, resulting in one even integer and the other an odd one. Hence, in the process of optimization, each of these integers needs to be considered. Accepting these integers as solutions of the problem, then the distance e between the openings needs be corrected according to the following equation

$$e_{koreksi} = \frac{L - 2.a.n_{int\,eger}}{n_{int\,eger} + 1}$$

However, experience from practice requires that $0.16a \leq e \leq 1.6\,a$ (Macsteel), where the independent variables a and e are both randomly generated.



(a)

Figure 2. (a) Process of Constructing Cellular Holes
(b) Elliptic Curve

3.2.2. The Objective Function

The mathematical form of the objective function may be derived as follows.
The basic equation of the ellipse gives

$$r = f(z) = a\sqrt{1 - \frac{z^2}{b^2}}$$

The total area of the web openings is here considered as

$$A_{hole} = \frac{L-e}{2a+e}\int_{z_1}^{z_2} a\sqrt{1 - \frac{z^2}{b^2}}dz$$

The objective function then becomes

$$F(x) = A_{hole} = \frac{L-e}{2a+e}\int_{z_1}^{z_2} a\sqrt{1 - \frac{z^2}{b^2}}dz$$

3.2.3. The Constraints

The independent variables are generated randomly meeting their respective constraint requirements. The dependent stress and deflection variables are required to meet the following constraints

$$\sigma_{wp} \leq \sigma_{all}$$

$$\tau_{wp} \leq \tau_{all}$$

$$\delta \leq L/200$$

Where

σ_{wp} = working principal stress

σ_{all} = allowable stress

τ_{wp} = working principal shear

τ_{all} = allowable shear stress = $\tau_{all} = \frac{\sigma_{all}}{\sqrt{3}} = \frac{0.67\sigma_y}{\sqrt{3}} = 0.37\sigma_y$

δ = maximum beam deflection

L = length of the beam.

4. RESEARCH METHODOLOGY

In this research, Genetic Algorithm is applied to the optimization of castellated beams, simply supported, with elliptical (circular) web openings. The beams are given the following loading conditions

1. One concentrated load applied at midspan
2. Two concentrated loads, each applied at 1/3 points of span
3. A uniformly distributed load over the whole length of the beam
4. A condition where the above loads are applied in an alternating manner.

The first three loading conditions are shown on fig. 4.1. Spans with both even and odd numbers of web openings are considered.

The objective of this research is to achieve castellated beams with maximum area of web openings.

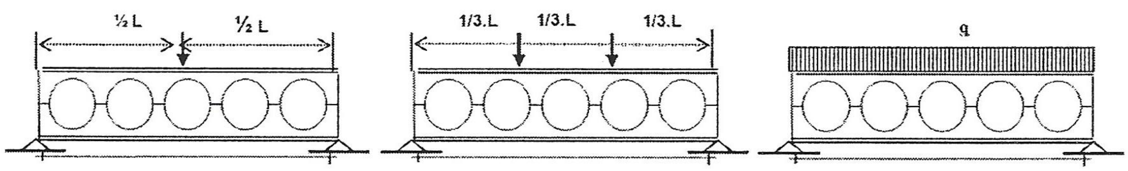


Figure 3. Types of loading condition

4.1. The Genetic Algorithm

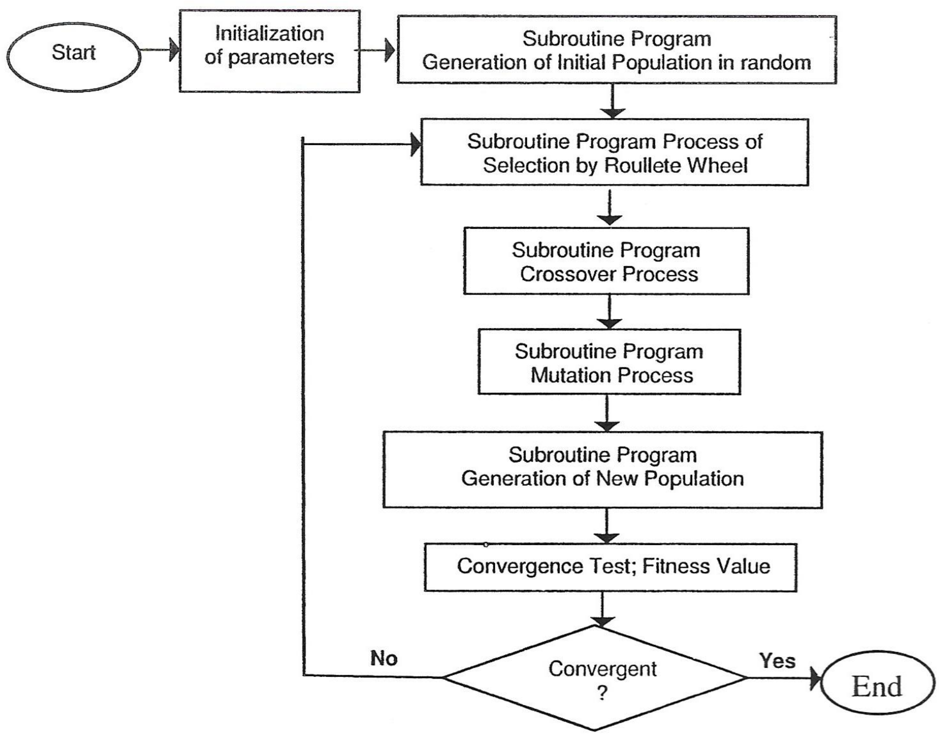


Figure 4. Flowchart of Genetic Algorithm

The optimization process is carried out according to the simplified flowchart shown in figure 4.2. At the start a population consisting of randomly generated individuals is constructed according to the roulette wheel principle, and followed by the process of crossover breeding and mutation. There after construction of the next population generation consisting of the best individuals and followed by the fitness test. Individuals with bad fit are eliminated and replaced by new randomly generated individuals. After going through the process of crossover and mutation, a fitness test is carried out. A convergence test is there after carried out. If convergence is not achieved, then the whole process is repeated. Otherwise the iteration process is terminated and the last result is accepted as the final optimum solution.

To facilitate the crossover and mutation processes, genes representing the structural characteristics, i.e. the variables a and b, are coded in binary numbers. To acquire the largest area possible of web openings, the distance e between those openings are given an initial value of $e_{min} = 0{,}16.a$.

4.2.1. Initial Input Values

To initialize the program, the following parameters are given as first input

1. The cross sectional dimensions of the original I-beam, the length of the beam, the loading conditions, type of supports, steel material properties, and the domain of the independent variables a and b. The size of these domains are determined by the available cutting technique.
2. Program parameters

(a). The value of the precision exponent α appearing in the formula below. This value indicates the number of decimal digits considered and is determined by the desired accuracy of the iteration results of Genetic Algorithm. It also determines the length of the genetic string, i.e. the number of bits representing the value of the variable in the genes. The length of the genetic string is determined according to the formula given by Gen and Cheng (1997) as follows

$$L_{bg} = {}^{2}\log\{(U_b - L_b)\times 10^{\alpha} + 1\}$$

with upward rounding,
where

L_{bg} = genetic bit length

$[L_b, U_b] = [0.35; 0.65]h_w$ = lower and upper bounds of the independent variables a and b.

α = precision exponent = 3

Enumeration of the above equation gives a genetic bit length L_{gb} = 16 bits for each of the variables a and b, thence producing chromosome lengths of 32 bits.

(b) Other genetic parameters (Greffenstette) are

Popsize = size of population = 30
p_c = crossover probability = 0.95
p_m = mutation probability = 0.01
maxgen = maximum number of population generation = 100

3. Constraint parameter

The allowable working tensile stress $\leq 0.6\sigma_y$

The allowable working compressive stress $\leq 0.6\sigma_y$

The allowable shear stress $\leq 0.36\sigma_y$

The allowable maximum beam deflection $\leq L/200$ (Macsteel Recommendation)

4.2.2. Generation of Initial Population

The random generation of the initial population needs three initial inputs
1. The population size of 30 individuals (Greffenstette),
2. The 16 bits genetic length,
3. $[L_b, U_b] = [0.35; 0.65]*h_w$ = lower and upper bounds of the independent variables a and b.

The randomly generated real numbers of the variables a and b are converted into binary numbers according to the following equation (Gen and Cheng)

$$R_b = L_b + D_s \frac{U_b - L_b}{2^{L_{bg}} - 1}$$

where, R_b = real value of variable.

D_s = decimal value of independent variable in binary string.

Consider the following example illustrating the conversion of a real numbered variable into a binary coded one according to the above equation. For an I-section beam 150x75x5x7 mm, the lower and upper bounds of variable a are $[L_b, U_b]$ = [52.5, 97.5]. Suppose a real number 89.1619363698787 was randomly generated representing variable a. Then R_b = 89,1619363698787. Substituting these values into the above equation,

$$D_s = (89{,}1619363698787 - 52{,}5)\frac{2^{16} - 1}{97{,}5 - 52{,}5} = 53392$$

Hence the real numbered variable a = 89.1619363698787 is converted into the binary number 1101000010001000.

4.2.3. Member Selection of Posterior Generations

Individuals are given the opportunity to reproduce proportional to their degree of fitness. Individuals with greater fitness will have greater opportunity to reproduce. Random generation of new individuals replacing discarded ones proceeds by the roulette wheel principle. To accommodate proper appropriation of production opportunities as outlined above, individuals are mapped as line segments with lengths proportional to their degree of fitness. This method, also known as stochastic sampling, generates a random number r(k) which fall into one of the line segments. A new individual having the same genetic string as that represented by that particular line segment is accepted to replace one of the discarded members. There is a possibility that more than one such individual be generated by the roulette wheel principle. This process is repeated until the necessary number of individuals is reached.

The fitness of individuals are appropriated according to the following formula

$$f = C_1A + C_2G$$

Where f = fitness of the individual

A = percentage of the total opening area with respect to the total web area of the castellated beam. More specifically it is according to following formula

$$A = \frac{A_t}{L \times \left(h_w + b_v\sqrt{1 - 0.25\left(\frac{e}{a}\right)^2} \right)} \times 100\%$$

where A_t = the total area of the web opening.

C_1, C_2 = weights, $C_1 + C_2 = 1$, $C_1 \geq 0$ and $C_2 \geq 0$. The correct combination of C_1 and C_2 is determined by doing trial runs until the maximum of f is found.

G = the maximum value of either one of the following equations

$$G_1 = \frac{\sigma_{wp}}{0.6.\sigma_y} \times 100\% \quad , \text{if} \quad \sigma_{wp} \leq 0.6\sigma_y$$

$$G_2 = \frac{\tau_{max}}{0{,}36\sigma_y} \times 100\% \text{ , if } \tau_{max} \leq 0.36\sigma_y \text{, where } \tau_{max} = \text{maximum working shear}$$

$$G_3 = \frac{\delta}{\left(\frac{L}{200}\right)} \times 100\% \text{ , if } \delta \leq L/200$$

Otherwise G = 0 and f = 0.

Stresses and deflections are determined by finite element analysis. Simple constant strain triangular elements are applied. Plane triangular elements meet satisfactorily the purpose of this study. PDETOOL of MATLAB is utilized for the analysis. The generated refined triangular network is shown in figure 4.3. Figure 4.4 illustrates the deflection and stress contours of the castellated beam under one concentrated load at mid span.

4.2.4. Crossover

Crossover is a genetic operator that combines (mates) two parent chromosomes to produce a new chromosome of two offspring. The idea behind crossover is that the new chromosome may be better than those carried by both parents. Crossover occurs during evolution according to a user-defined mode of combining. The simplest method of crossover in binary coded genetic strings is the one point crossover. In this method a point in the genetic string is randomly selected as the boundary where genetic interchanges may take place. A random number k = 1, 2……., N - 1, where N = length of chromosome, is generated indicating the place of the boundary point. Figure 4.5 illustrates the principle of one point crossover. The intersection cut point is randomly generated. The genes of both parents to the right of the cut point are interchanged, producing new chromosomes of two offspring.

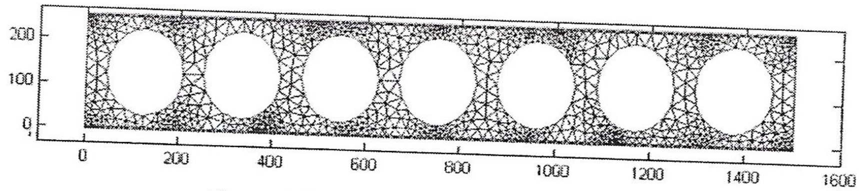


Figure 5. Meshing along Cellular Beam Length

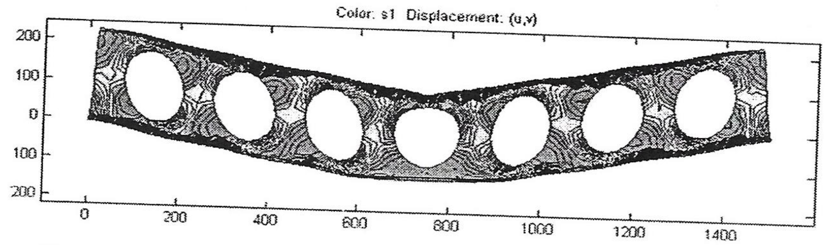


Figure 6. Principal Stress Contours; Result of Plane Stress Analysis by Finite Element Method for Beam with One Point Loading

There is, however, one important parameter in the crossover process, i.e. the crossover probability number $p_c < 1.0$. A random number $r(p_c)$ is generated for each individual. If the generated number $r(p_c) > p_c$, in this case $p_c = 0.95$, then the concerned individual may not function as a parent.

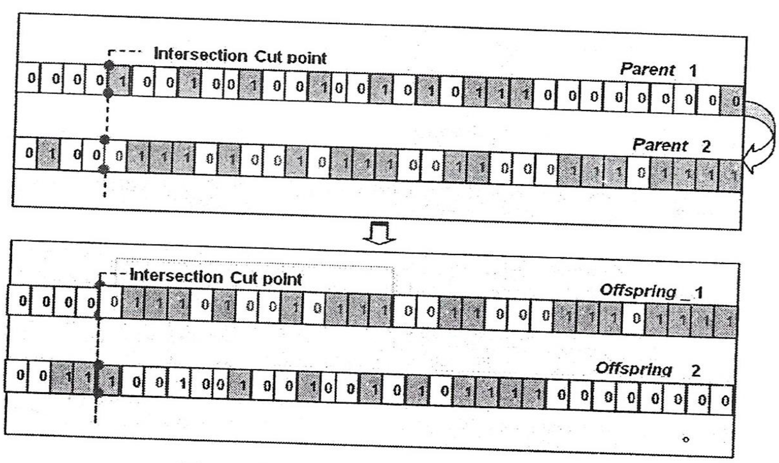


Figure 7. Principle of One-point Crossover

4.2.5. Mutation

Mutation is a genetic operator used to maintain genetic diversity in one population generation. It is analogous to a biological mutation. The purpose of mutation in is to avoid local minima by preventing the population chromosomes from becoming too similar to each other too soon, which may slow down or even completely stop the process of evolution prematurely. This is also to avoid only taking the fittest chromosomes in generating the next population, but rather adopting a weighted random selection toward those that are fitter. There is, however, one parameter which is of vital importance in mutation, i.e. the mutation probability p_m. It controls the number of mutated genes that needs evaluation. Too small mutation probability would overlook useful possible genes. The resulting mutated genes need to be investigated for their acceptability, i.e. if they are still in the solution domain or otherwise. A refinement process may be applied to genes which are unacceptable.

Mutation takes place within one generation of a population. Therefore all the bits of the generation concerned need to be examined. In this case, where the population consists of 30 individuals, each carrying 32 bits chromosomes, then a total 30x32 examinations need to be carried out. For this purpose a random number $r(k,l) < 1.0$ is generated, where k indicates the number of the individual and l indicates the bit number. If $r(k,l) < p_m$, where $p_m = 0.01$, then the bit at location (k,l) undergoes mutation, i.e. the bit changes from 0 to 1 or vice versa. Mutation may replace genes which disappear from a population due to the process of natural selection. Figure 8. illustrates mutation of individual k at three different gene location l.

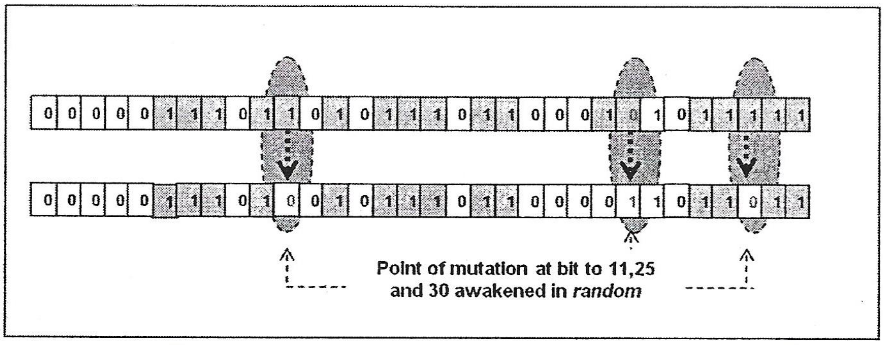


Figure 8. Illustrates mutation of individual k at three different gene location l.

4.2.6. Raising the Next Generation

After the process of crossover and mutation, a new population is then constructed by taking only individuals with best fitness from parent's generation augmented by individuals possessing best fitness from offspring's generation, substituting those with inferior fitness from parent's generation. This may be achieved easily by listing in descending order the fitness of members of parent's population and compare it to a list in ascending order the fitness of members of the population of offspring's generation. Where the fitness of the offspring starts to surpass that of the parent's, then all individuals of the offspring's generation below that particular member will replace individuals of the parent's generation.

4.2.7. Convergence Test

Convergence test is meant to provide a criterion when to terminate the optimization process. It is produce by comparing the average fitness value of the current generation with that of the preceding one. If after running several comparisons the value change is negligible, or the average fitness value gradient is close to zero, then the process is terminated and the last acquired value is accepted as the final solution. Figure 4.7 illustrates the history of fitness change versus elapsing generations.

5. RESULTS AND DISCUSSIONS

Material mechanical properties were acquired from tests carried out on specimens cut from the flange and web of the I-section beam. Two specimens were prepared for each case. The tests are carried out according to ASTM D2209-00(2004). The resulting stress-strain diagrams indicate a modulus of elasticity E = 232 593 MPa and a yield stress of $\sigma_y = 438.5597$ MPa.

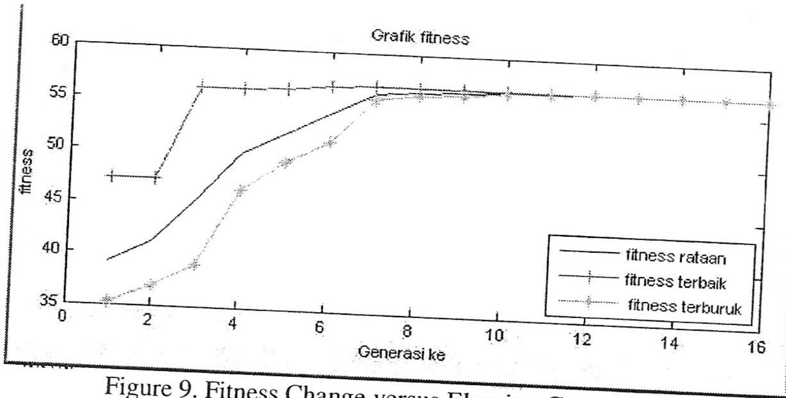


Figure 9. Fitness Change versus Elapsing Generations.

5.1. Carrying Capacity of Cellular Beams

A computer program for Genetic Algorithm was written for the purpose of simulation studies of various castellated optimum beams, utilizing MATLAB programming language. A subroutine for stress analysis using triangular plane elements was also produced from the above software. The validity of this particular program was achieved by comparing test results against those acquired from simulation analyses.

To arrive at a ligitimate best solution the weight constants C_1 and C_2 of the penalty function above still need to be determined. This is achieved by running simulation analyses applying varying combinations of C_1 and C_2. For this purpose castellated beams with spans of 1500 mm and 1750 mm were considered, each with even and odd number of openings. The beams were subjected to three different loading conditions. The castellated beams were assumed to be produced from original 150x75x5x7 I-beam of Gunung Garuda steelworks. There are in total 108 cases. The results show that maximum percentage of opening area is achieved when $C_1 = 0.8$ (or $C_2 = 0.2$). This 0.8-0.2 combination of C_1-C_2 was then accepted as the best combination valid for any beam condition. It was then applied to the optimization of castellated beams with lengths between and included 1000 mm – 2500 mm, varying with 250 mm intervals. These beams were then subjected to the same three loading conditions. There are in total 42 cases. Table 1. Recapitulates the resulting carrying capacity ratios of the above analysis. It shows that cellular beams with even number of holes have larger carrying capacity than the those with odd number of holes. More specifically

1. The increase in elastic strength is around 10%, if the even number of holes is larger than the odd one,
2. The increase in strength is around 26%, if the even number of holes is less then the odd one.

Bear in mind that the above results are strongly dependent on the pattern of loading conditions.

It is interesting to note how the bearing capacity of elastic castellated beams increased over that of the beam from which it originated. Table 2. summarizes the various conditions and strength ratios of the beams. The strength increase of castellated beams may reach almost three times of that of the original beam.

5.2. Parametric Studies

Table 1. Carrying Capacity Ratio of Beams with Even Numbered Holes over That with Odd Numbered Ones.

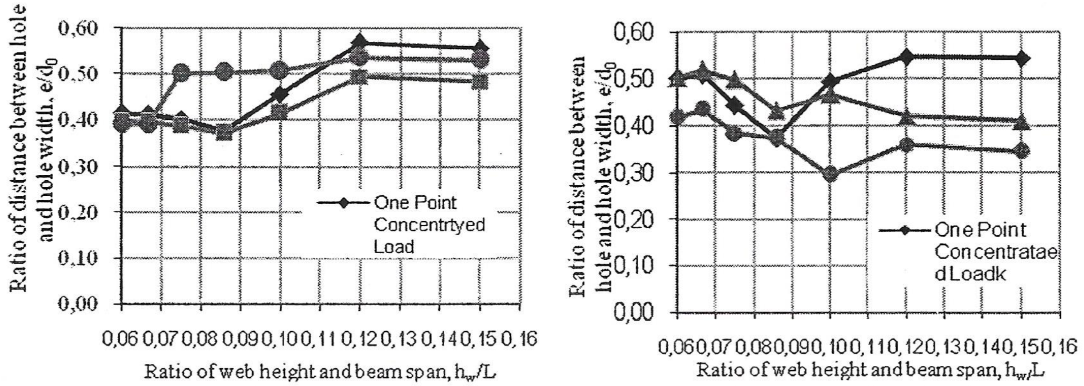
Span mm	Number of holes						Ratio Carrying Capacity Even to Odd		
	One Point Loading		Two Point Loading		Uniform Loading		One Point Loading	Two Point Loading	Uniform Loading
	Even	Odd	Even	Odd	Even	Odd			
1000	6	5	4	5	4	5	1.048	1.253	1.176
1250	6	5	6	5	6	5	1.038	1.104	1.030
1500	8	9	6	7	6	7	1.131	1.263	1.196
1750	8	9	8	9	6	7	1.125	1.200	1.183
2000	8	9	10	11	8	9	1.214	1.223	1.137
2250	10	9	12	13	12	11	1.083	1.016	1.088
2500	12	11	12	11	12	13	1.200	1.072	1.177

A study was also made to investigate the relation between the width of the web post and the height of the web and that between the hole height and web height. Those relations are plotted in nondimensinal mode in figures 10. and

11. respectively. The first figure shows that the widths of the web post are $0{,}25.d_0 \leq e \leq 0{,}60.d_0$, well within previously defined limits (Macsteel), for all web heights considered in this research. While the latter figures shows that the optimum size and shape of the openings varies from circles and upright ellipses with ratios of hole height and width between 1.0 – 1.4 depending on the span lengths of the cellular beam, or $1{,}0a \leq b \leq 1{,}40a$.

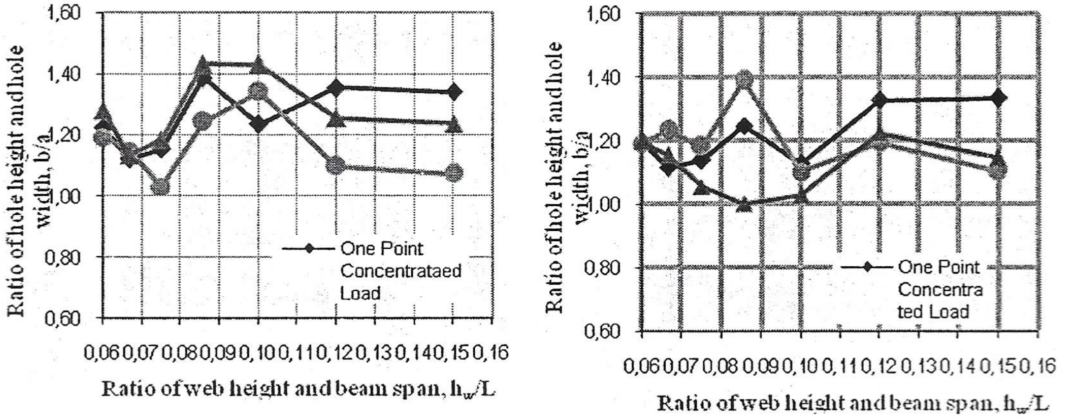
Table 2. Carrying Capacity Ratios of Cellular Beams to Those of the Original Beam

Span mm	Number of holes						Ratio of Carrying Capacity Cellular to Original Beams					
	1-Point Loading		2-Point Loading		Uniform Loading							
	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even	Odd	Even
1000	5	6	5	4	5	4	1.950	2.0430	1.205	1.509	1.477	1.737
1250	5	6	5	6	5	6	2.348	2.4364	1.387	1.531	2.156	2.220
1500	9	8	7	6	7	6	2.474	2.7992	1.536	1.940	2.298	2.748
1750	9	8	9	8	7	6	2.289	2.5752	1.633	1.960	1.839	2.176
2000	9	8	11	10	9	8	2.272	2.7583	1.685	2.061	2.566	2.918
2250	9	10	13	12	11	12	2.191	2.3735	1.681	1.709	2.413	2.627
2500	11	12	11	12	13	12	2.028	2.4339	1.640	1.758	2.417	2.845



a. Odd number of holes b. Even number of holes

Figure 10. Relation between h_w/L and e/d_0 for Odd and Even Numbers of Holes



a .Odd number of hole b. Even number of hole

Figure 11. Relation between h_w/L and b/d for Odd and even Number of Holes

5.3. Alternating Three Loading Conditions

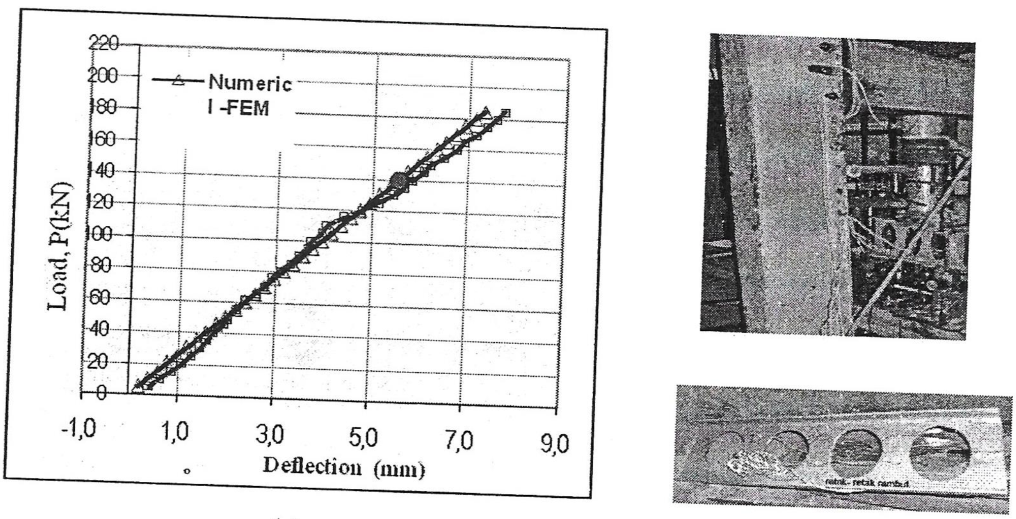
The possibility of a beam being subjected to alternating three loading pattern was also considered in this study. The three loading patterns are one concentrated load P kN at mid span, two concentrated loads ¾ P kN at third points of span, and a uniformly distributed load q = 2P/L. These three loading pattern produce the same amount of moment at mid span of the beam. Beams with lengths of 1000 mm to 2500 mm, with 250 mm intervals, subjected to the three alternating loading conditions, were considered. The beams were given even and odd numbers of web openings. There are in total 14 cases. Table 3. summarizes the results of the above analyses. It shows that uniform loading produces the highest fitness value of the population, meaning that uniform loading produces the best optimum solution.

Table 3. Fitness Values for Beams with Various Configurations and Loading Conditions.

Span mm	Number of holes		Fitness Value at Loading Type						Determined Loading Type
	Odd	Even	Odd number of holes			Even number of holes			
			1-Point	2-Point	Uniform	1-Point	2-Point	Uniform	
1000	5	6	43.9431	47.1628	49.4437	47.4575	50.3442	52.9366	Uniform
1250	5	6	55.0294	55.2112	55.5871	46.6273	47.8591	49.9464	Uniform
1500	7	8	48.4513	50.7791	53.2540	51.9320	52.7323	53.8062	Uniform
1750	9	10	46.8180	49.9832	52.3135	47.7498	48.9463	50.6997	Uniform
2000	11	12	51.2106	52.8059	54.8895	50.5013	51.9456	53.9601	Uniform
2250	13	12	48.0443	50.0608	51.8137	45.6389	48.1421	50.1552	Uniform
2500	13	14	48.9152	51.1308	52.8945	48.4862	50.5550	52.2502	Uniform

5.4. Validation of the FEM Program

The written FEM program applied in the structural analyses of this study needs to be validated for the legitimacy of the results. This validation is carried out by comparing the computer outcome of the program with data acquired from testing. For this purpose, the load-deflection curve of a castellated beam specimen subjected to a varying single load at mid span is plotted against that acquired from FEM analysis. Figure 12. (a) shows that both curves closely coincide with each other, and hence providing proof of the correctness of the FEM program. Figure 12.(b) shows the testing set up and the tested specimen.



(a) (b)

Figure 12. (a) Load-Deflection Curves of Test Data Against that of FEM Output
(b)The Test Setup and the Tested Specimen

6. CONCLUDING REMARKS

This study reveals that

a. Optimized cellular beams with even number of web openings subjected to load patterns considered in this study has greater elastic carrying capacity then those with odd number of web openings.
b. Optimization results show that the elastic carrying capacity of cellular beams of equal lengths increase sharply if the even number of openings is smaller than that of the odd one.
c. Cellular openings produced by optimization have forms close to circles for short span beams and produced upright ellipses for longer span ones.
d. Optimum elastic carrying capacity of cellular beams with one point concentrated load is controlled by allowable stresses for short span beams and it is controlled by allowable deflection for long span ones.
e. Elliptical or circular cellular holes with smooth sides eliminate stress concentrations taking place in the corners of hexagonal openings. This may easily be observed from the figure showing the stress contours.

REFERENCES

Aglan, A.A., and Redwood, R. G., 1974, Web buckling in castellated beams, Proceeding Institution Civil Engineers, London U.K., 57, Part 2, 304-320

Anon, 2006, Partial Differential Equation Toolbox for Use with MATLAB – User's Guide, The MathWorks, Inc, 3 Apple Hill Drive, Natick, MA 01760-2098

Besari M.S. and F.X.N Wibowo.,1994, Genetics Algorithms in Plane Truss Shape Optimization, 3rd Regional Conference on Computer Applications in Civil Engineering, Kuala Lumpur, Malaysia, p.10.1 -10.12.

Chipperfield A., Fleming P.,Pohlheim H. and Fonseca C., 2004, Genetic Algorithm Toolbox – For Use with MATLAB, users,s Guide, Department of Automatic Control and Systems Engineering, University of Sheffield.

Delesquez R., 1968, Stability of web posts of castellated beams, Const. Metallique, Paris, France, 3: 26 -33.

Gen, M. and R. Cheng, 1997, Genetic Algorithm and Engineering Design, A Willey-Interscience Publication, John Willey and Sons, Inc

Hamit Saruhan, 2004, Design Optimization of a Three-Lobe Journal Bearing Using a Genetic Algorithm, Journal of Naval Science and Engineering 2(2).

Holland, J.H., 1992,Genetic Algorithms, Scientifics America, p.44-50.

Kerdall D. and D.A. Netherchots 1968, Failure modes for castellated beams, Journal Construction Steel Research, 4:295-315

Redwood R. and Demirdjian S., Castellated Beam Web Buckling in Shear, Journal of Structural Engineering, 1998: 1202-1207

Silva S., 2004, A Genetic Programming Toolbox for MATLAB, Evolutionary and Complex system Group, University of Coimbra, Portugal.

Wibowo F.X.N. and M.S Besari., 1998, Genetic Algorithms in Shape Optimization of Oval Axially Symmetrical Shells, ASCO '98 Proceeding, University of Sidney Australia.

Wibowo F.X.N.,1996, Optimasi Bentuk Oval Cangkang Simetri Sumbu, Disertasi S-3, Jurusan Teknik Sipil, Institut Teknologi Bandung.