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A GENETIC SEARCH BASED ARRANGEMENT OF LOAD COMBINATIONS IN STRUCTURAL FRAMES

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Abstract

The existing codes of practice propose the live load arrangements in such a way that they result the maximum internal forces in structural analysis. When this rule is utilized for high-rise buildings, a high number of load combinations is required to be applied. Since the use of computers in structural analysis is wide-spread in recent years, an automatic load combination arrangements needs to be developed within a computer environment. Such high number of load combinations and solutions are time consuming and difficult in manual calculations. However, insufficient investigations on this subject have been published, recently.

The primary purpose of this study is faster and more precise calculation of the section forces due to the live load arrangements. For this purpose a genetic algorithm based load arrangement program was developed. The results obtained from the genetic search based method give more precise and rapid results compared to the existing methods.

1 Introduction

Considering the complexity of many practical building frames and the requirement of possible alternative loading, there is evidently a need to simplify. Some approximations can be considered to allow the determinations of moments with reasonable accuracy. This reduces the amount of computation substantially. However, due to the widespread use of computers in structural analysis there is no need to make simplifications.

The effect of live loads which can be placed at different positions on a structure can be conveniently analyzed in graphical form by the use of influence lines. An influence line shows the value of any action due to a unit point load moving across the structure. This is a most commonly used method for determining the worst loading combinations at any considered section.

1.1 Placement of Loads

Loads that act on structures can be divided into three broad categories as dead loads, live loads and environmental

loads. Dead loads are those that are constant in magnitude and fixed in location throughout the lifetime of the structure. Usually the major part of the dead load is the weight of the structure itself.

Live loads consist chiefly of occupancy loads in buildings are traffic loads on bridges. They may be either fully or partially in place or not present at all, and may also change in location. Their magnitude and distribution at given time are uncertain, and even their maximum intensities throughout the lifetime of the structure are not known with precision. The maximum live loads for which the floors and roof of a building should be designed are usually specified in the building code that governs at the site of constructions.

Environmental loads consist mainly of snow loads, wind pressure and suction, earthquake loads (i.e., inertia forces caused by earthquake motions), soil pressures on subsurface portions of structures, loads from possible ponding of rainwater on flat surfaces, and forces caused by temperature differentials. The structural elements are generally constructed continuously. Therefore, behaviour of each element is effected by the others. The effect of continuity is most simply illustrated by a continuous beam, such as shown in Fig.1a.

With simple spans, such as provided in many types of steel construction, only the loaded member CD would deform, and all the other members of the structure would remain straight. But with continuity from one member to the next one through the support regions, as in reinforced concrete structure, the distortion caused by a load on one single span is seen to spread to all other spans, although the magnitude of deformation decreases with increasing distance from the loaded member. All members of the six span structure are to curvature, and thus also to bending moment, as a result of loading span CD.

Similarly, for the rigid-jointed frame of Fig.1b, the distortion caused by a load on the single member GH spreads to all beams and all columns, although, as before, the effect decreases with increasing distance from the load. All members are subjected to bending moment, even though they may carry no transverse load.

The individual member of a structural frame must be designed for the worst combination of loads that can reasonably be expected to occur during its useful life. Internal moments, shears, and thrusts are brought about by

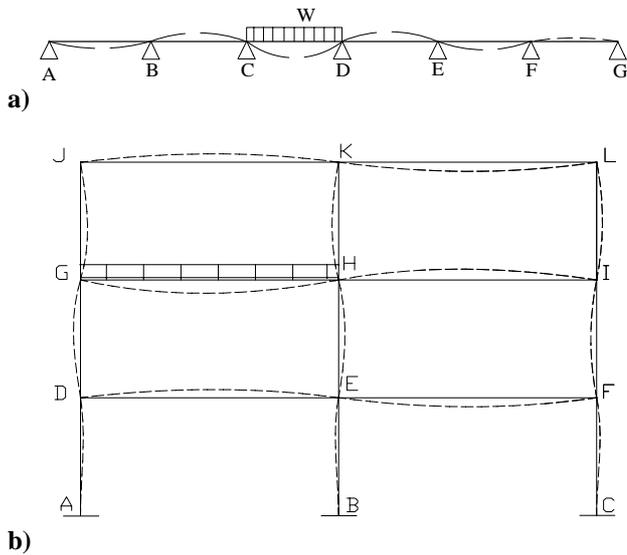


Figure 1. The effect of continuity on continuous structures.

the combined effect of dead and live loads. While the former are constant, live loads such as floor loads from human occupancy can be placed in various ways, some of which will result in larger effect than others.

In Fig.2 only span CD is loaded by live load. The distortions of the various frame members are seen to be largest in, and immediately adjacent to, the loaded span and to decrease rapidly with increasing distance from the load. Since bending moments are proportional to curvatures, the moments in more remote members are correspondingly smaller than those in, or close to, the loaded span. However, the loading of Fig. 2 does not produce the maximum possible positive moment in CD. In fact, if additional live load were placed on span AB, this span would bend down, BC would bend up, and CD itself would bend down in same manner, although to a lesser degree, as it is bent by its own load. Hence, the positive moment in CD is increased if AB, and by the same reasoning EF, are loaded simultaneously. Maximum negative moments at the supports of the girders are obtained, on the other hand, if loads are placed on the two spans adjacent to the particular support and in a corresponding pattern on the more remote girders. A separate loading scheme of this type is then required for each support for which maximum negative moments are to be computed [1].

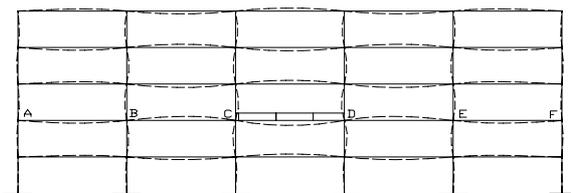


Figure 2. The distortion degrees of elements depending on the locations.

1.2 Genetic Algorithms

Genetic Algorithms were originally by John Holland at the University of Michigan[2] The aim of his research has been to rigorously explain the adaptive process of artificial systems that retain the important mechanisms of natural systems and to design artificial systems that retain the important mechanisms of natural systems. There is a form of evolution, called a Genetic Algorithm, that takes place in a computer. In Genetic Algorithms, selection operates on strings of binary digits stored in the computer's memory, and overtime, the functionality of this strings evolves in much the same way that natural populations of individuals evolve. Although the computational setting is highly simplified compared with the natural world, Genetic Algorithms are capable of evolving surprisingly complex and interesting structures.

Many papers and dissertations have established the validity of the technique for function optimization. Genetic Algorithms are computationally simple, but powerful in their search for improvement. In addition, they are not limited by restrictive assumptions about search space, such as continuity or existence of derivatives. Goldberg[2], describes the nature of Genetic Algorithms of choice by combining a Darwinian survival of the fittest procedure with a structured, but randomized, in formation exchange to form a canonical search procedure that is capable of addressing a broad spectrum of problems. Genetic Algorithms are search procedure based on the mechanism of natural genetics and natural selection. They combine the concept of artificial survival of the fittest with genetic operators abstracted from nature to form a robots search mechanism. Genetic Algorithms differ from traditional optimization algorithms in many ways. A few are listed by Lieppings and Hillard [3].

- Genetic Algorithms do not require problem- specific knowledge to carry out a search. For instance, calculus-based search algorithms use derivative information to carry out a search.
- Genetic Algorithms work on coded design variables, this are finite length strings. These strings represent artificial chromosomes. Every character in the string is an artificial gene. Genetic Algorithms process successive populations of these artificial chromosomes in successive generations.
- Genetic Algorithms use randomized operators in place of the usual deterministic ones. The random operators improve the search process in an adaptive manner.

These three properties separation of domain knowledge from search, working on coded design variables, population processing and randomized operators, give the Genetic Algorithms their relative merit. It has already been mentioned that Genetic Algorithms get their power from the genetic operators. The various genetic operators can be

identified as Reproduction, Crossover, Mutation, Dominance, Inversion, Deletion, Segregation and Sharing.

Depending on the nature of the problem and on the requirements for performance, Genetic Algorithms can be improved by applying more and more of these operators. The present study concentrates an simple Genetic Algorithm with reproduction and crossover operators. The reproduction operator emphasizes the survival of the fittest in Genetic Algorithms. There are many ways of achieving effective reproduction. One simple scheme selects individual strings in the population on the proportionate basis for reproduction according to the their fitness. Fitness is defined as a figure of merit, which is either maximized or minimized. In an effective reproduction, individuals with higher fitness values have a higher probability of being selected for mating and subsequent genetic action.

Crossover is a recombination operator, which proceeds in three steps. First, the reproduction operator makes a match of two individual strings for mating. Then a cross site is selected at random along the string length and position values are swapped between the two strings following the cross site. For instance, let two selected strings in the matching pair be A= 11111 and B= 00000. If random selection of a cross site is two, then the new strings following the crossover would be A'=11000 and B'= 00111. This is a single-site crossover. Strings A' and B' are the offspring of A and B are then placed in the new population of the next generation.

The working of the simple Genetic Algorithm is explained in detail in following section, on an example of the forty-six member of structural frame.

Though these operators look very simple, their combined action is responsible for much of Genetic Algorithms power. From A computer implementation point of view, they involve only random number generation, string copying, and partial string swapping. Goldberg also adds to a mutation operator in a simple GA. But in the present study, only reproduction and crossover operators are used. The mutation operator preserves the diversity among the populations, which is also very important to the search.

A population of three individuals is shown in Fig.3. Each is assigned a fitness value by the function F. On the basis of these fitnesses the selection phase assigns the first individual(00111) zero copies, the second (11100) two, and operators are applied probabilistically, the first individual the third (01010) one copy. After selection, genetic

has its first bit mutated from a 1 to a 0, and crossover combines the second two individuals into two new ones. The resulting population is shown in the box labeled Tn+1 [4].

2 Application to the Load Arrangements

The main purpose of the study was to generate an automatic load combinations for the worst conditions in a structure. However, no systematic simplified method was developed like Furlong's suggestions[5]. The load combinations have been generated through a genetic search based computer program and the results were compared to the Large and Furlong's simplified suggestions. The main aim of Furlong's method is the obtaining of maximum bending, shear and thrusts at the structural beams as close as to real results by the least positions of live load arrangements. An example 6 storey structural frame considered in this study requires load combinations for approximate maximum bending moments. However, by increasing the number of spans, the number of load combinations are also increases. The second method suggested in the literature was the study of Large [6]. The method mainly based on conventional influence line method. According to this method, the number of live load combinations to obtain support moments is equal to the number of beam-column joints. Additionally, two load combinations are required to obtain the span bending moments. Therefore, the number of load combinations is higher compared to Furlong's method, and it requires numerous influence line diagrams for the example frame given in this study. It can be clearly seen that Large's method is time consuming compared to the Furlong's method, and it requires much more load arrangements by the increment of number of span and storey.

In this study, a structural frame with 4 spans and 6 storey has been considered. All columns and beams have similar dimensions at 30/50 cm. The moment of inertia of the sections therefore is $I=0.003125 \text{ m}^4$, the area $A=0.15 \text{ m}^2$, the modulus of elasticity $E=20 \times 10^6 \text{ kN/m}^2$ and Poisson's ratio $\nu=0.20$. The total loads (live and dead) per

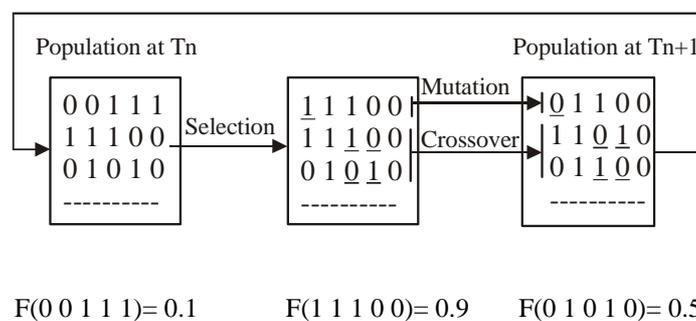


Figure 3. An example of population for three individuals

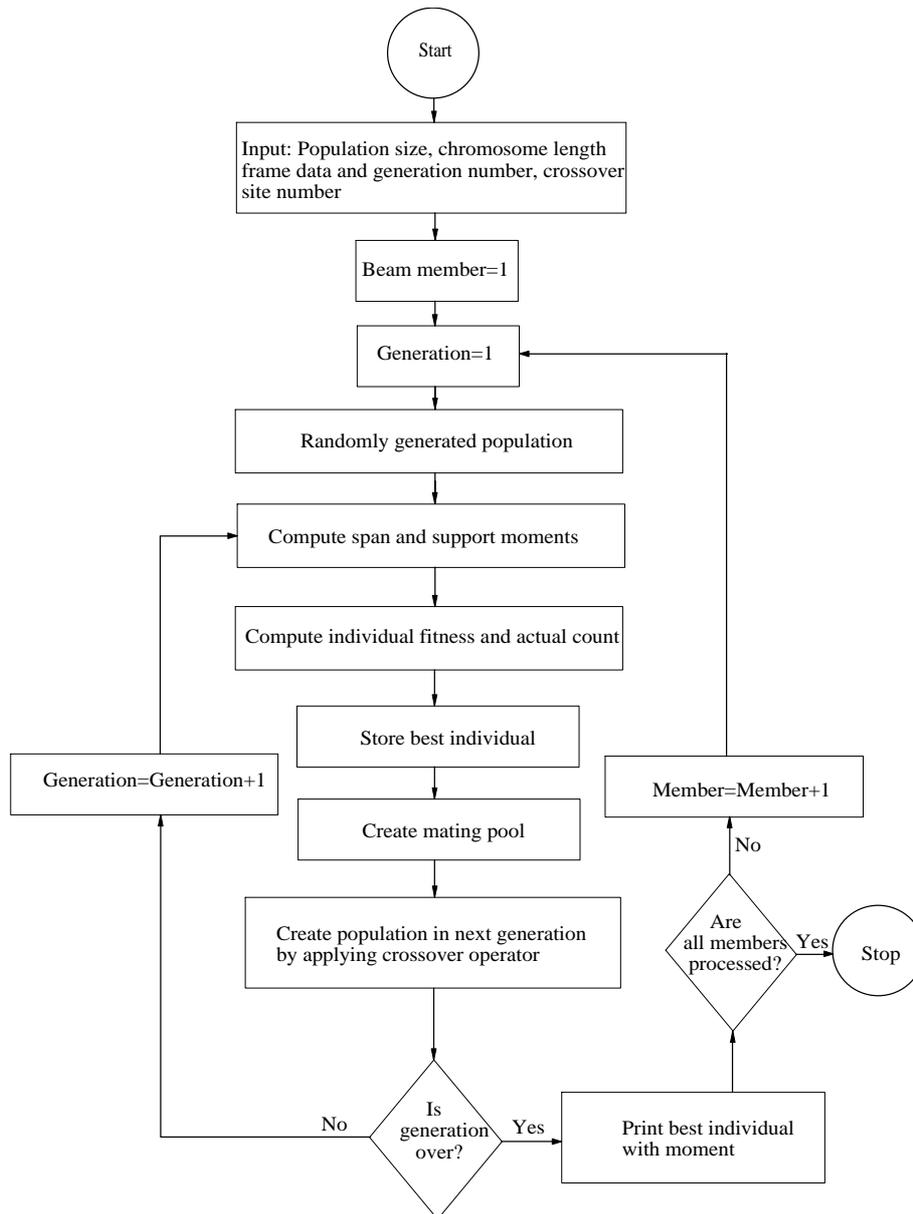


Figure 4. A typical flow-chart diagram for the Genetic search process.

unit length were taken as 15 kN/m and the ratio of dead load to total load was $\lambda=0.5$. A matrix-displacement method was implemented to the program as subroutine for analysis of structure.

The most important stage of the study was the implementing of the chromosome map. The number of chromosome was taken equal to the number of beams. Each beam is represented by a single chromosome and a single gen. The genes for each beam can take 0 or 1 value, 1 corresponds to the existing of live+dead load and 0 only dead load.

A typical flow chart diagram for the genetic search process is given in Fig.4. At the first stage, the properties of the considered system are given to the computer as data. The population size were selected as 20 in this study. It is well known that the population size affects the performance

of the G.A. substantially. The number of crossover were given to the computer as variable, and the number of cross site were taken as 6. Evolution stage or generation is taken as 40. As can be seen in Fig.5, after the 6th generation a similarity among the individuals clearly appears. This clearly shows that G.A. based load arrangement procedure gives a well result even for 6 generation.

At the first generation, the first population were created randomly. Then, the compatibility values (moments) of the created population were calculated and the individuals set up in order from lower to the higher. The objective function of the study were the maximization of the moments. Following the storage of valid individuals, the gen pool were created. Two gens from the pool were selected randomly and the mating process were operated. All these procedures go on up to the pre-selected generation number.

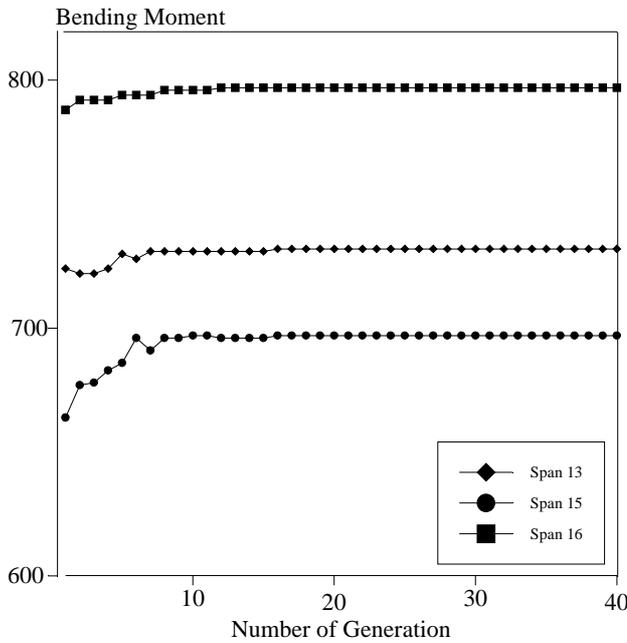


Figure 5. Evolution stage of the system.

3 Discussions

The maximum span bending moments and the corresponding chromosome values obtained from G.A. analysis are given in Table 1 for some beam elements. Each chromosome value represents the loading condition of the corresponding beams. The 0 value represents only the dead loading, 1 value represents the total loading condition. The maximum moments, obtained from the solution according to the loading are also given in the same table with Large (Influence line method) and Furlong solutions. It is interesting that G.A. solution gives different loading combinations for various span moments. However, Large solution gives two different loading arrangement for maximum span moments. Some differences between Furlong

and G.A. solutions were expected at the beginning due to the approximation of Furlong method. However, the difference between the Large and G.A. solutions is quite small, and in most cases it is equal to each other. The moment ratios are also given in the table for easy comparison. Although there is no difference between the moment values those obtained from Large and G.A. solutions, the loading types are slightly different. Accordingly loaded example frames are given in Fig.6a and 6b. The first frame is loaded based on results of Large solution and the second frame is from the G.A. solution for maximum moment for span no.4. The main differences between these two loadings are at the spans, no.9 and 18. While span no.9 is occupied only with the dead load in Large solution, the same span is occupied with the total load in G.A. solution. A contrary load arrangement is valid for span no.18.

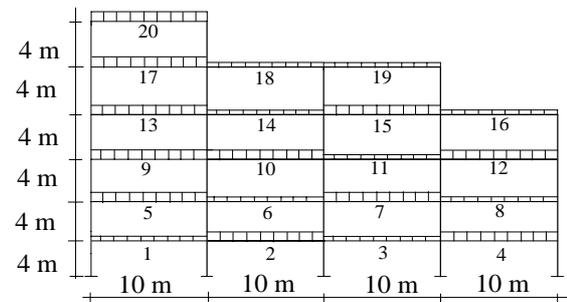
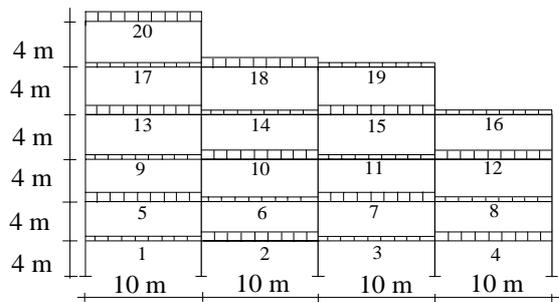
The maximum support bending moments and the corresponding chromosome values obtained from G.A. analysis are given Table 2 for selected elements. The value in the parenthesis beside the span number represents the support location as 1 for the left hand side joint, and 2 for the right hand side joint. This table also includes Large and Furlong solutions. Surprisingly, the G.A. / Large support moment ratios are higher compared to those for the span moments up to 7 %. The corresponding load distributions in the example frame according to Large method were given Fig. 7a for maximum support bending moments at the support between span no.13 and 14. The resultant load arrangement based on G.A. analysis is also given in Fig.7b for the same support.

The confidence level of the G.A. based results are quite substantial in the comparison with Large method results. The span moments obtained by G.A. analysis are similar to those calculated from Large method. However, the support bending moments are up to 7 % higher in some supports. The proposed method converges much quicker than Large or influence line method.

All previously explained results are obtained from the assumption of average cross section values for beam and

Span No	Genetic Chromosomes	Moment [kNm]			Moment Ratio	
		G.A.	Large	Furlong	G.A./Large	G.A./Furlong
2	01011010010110100101	69.2	69.2	66.7	1.00	1.04
4	01011010110110101001	71.6	71.6	69.5	1.00	1.03
5	01011010010110110101	72.0	72.0	68.0	1.00	1.04
7	01011010010110100100	70.6	70.6	65.8	1.00	1.07
9	10100101101001001010	72.3	72.3	68.2	1.00	1.06
12	11011010010110100101	71.6	71.6	66.8	1.00	1.07
13	01011011010110100101	73.2	73.2	68.8	1.00	1.06
15	01011010010110100101	69.7	69.7	63.9	1.00	1.09
16	00101101001001011010	79.6	79.6	75.4	1.00	1.06
18	01001010010110100101	74.6	74.6	69.8	1.00	1.07

Table 1. The span bending moments obtained from G.A. analysis.



a) Large loading for maximum moments in full loaded spans.

b) G.A. Loading for maximum moment in span no.4

Figure 6. Loadings of maximum span bending moments for selected spans of the example frame.

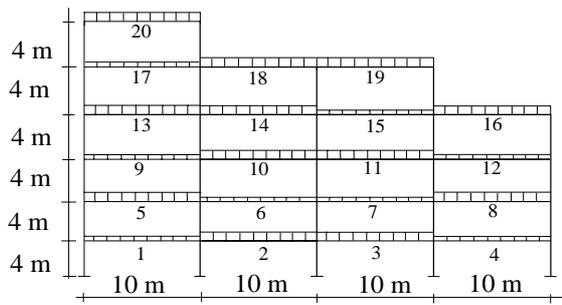
column elements in practice. When larger cross sections were used for columns and beams, the G.A. / Large span moment ratios dramatically increase. For second application, the moment of inertia and cross section of the element were taken larger. Then, a comparison has been carried out between the results of two methods. It has been observed that the Genetic Algorithm based analysis gives up to 14% higher bending moments in some spans. Therefore, It can be concluded that while the element cross sections increase, the result of influence line method are far from the load arrangement to calculate precise moment values. This comparison and load arrangements were given in Table 3. As can be seen from the table the resultant loading arrangements (genetic chromosomes) are different those from the first application.

4 Concluding Remarks

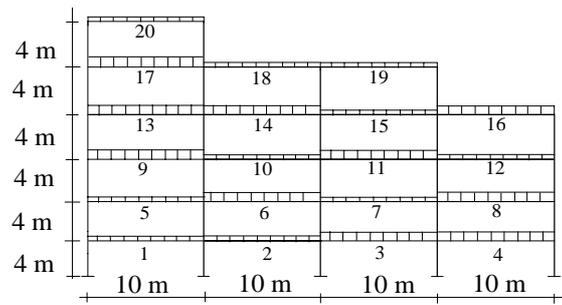
The genetic algorithm is the simulation of natural evolution on computer environment. The basic philosophy of the G.A. is the genetic processes like the generation of populations, mating and the mutations. The presented study is the first stage of a series of study on this subject. An important shortcomings are appeared in investigations on this subject. Therefore, the success of the genetic algorithm methodology for load arrangements in structural frames is important. It can be concluded that the proposed method has been successfully implemented and gives more precise results. It also provides a continuous analysis on the computer.

Span No	Genetic Chromosomes	Moment [kNm]			Moment Ratio	
		G.A.	Large	Furlong	G.A./Large	G.A./Furlong
1 (2)	11001010010100100010	135.2	131.0	132.0	1.03	1.02
2 (1)	11010111101001100010	133.0	132.6	127.8	1.00	1.04
4 (2)	11011011011000110110	113.7	112.8	111.2	1.01	1.02
7 (2)	11101011111001010110	135.6	135.1	126.9	1.00	1.07
8 (1)	01010011010110101101	135.4	128.1	129.5	1.06	1.04
9 (1)	01101101101111010111	121.0	120.3	116.0	1.01	1.04
13 (2)	00110101101011011000	133.2	124.2	125.1	1.07	1.06
14 (1)	01101010011111010111	137.1	136.7	126.3	1.00	1.09
15 (2)	01100101111010111110	142.5	141.9	134.8	1.00	1.06
16 (1)	11001010010100110101	137.0	129.8	128.8	1.06	1.06

Table 2. The support bending moments obtained from G.A. analysis.



a) Large loading



b) G.A. loading

Figure 7. Loadings for maximum support bending moments at the support between span no.13 and 14.

Span No	Genetic Chromosomes	Moment [kNm]		Ratio
		Genetic Algorithm	Large Method	G.A./Large
12	01110110011101100110	89.4	79.4	1.13
13	11101110011011101111	96.0	89.5	1.07
16	01110111011001110110	110.2	97.0	1.14

Table 3. The comparison of the maximum span bending moments for larger moment of inertia.

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