Optimization of consumed steel, opening height and location in RC beams by genetic algorithms

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Abstract:
In the construction of modern buildings, many pipes and ducts are necessary to accommodate essential services like water supply, sewage, etc. These pipes and ducts are usually placed underneath the concrete beams. However, for aesthetic reasons, they are covered by a suspended ceiling. Thus, to avoid increasing the height of the ceiling and dead load floor, it is more productive to pass the pipes and ducts through the beams of the ceiling. For this purpose, beams should be designed with openings. In this paper, beams with three spans and two types of uniform and non-uniform cross sections are modeled in SAP. Then beams are subjected to gravity and lateral loads and then analyzed. The results of SAP (flexural moment and shear force) are substituted in MATLAB code. Most appropriate opening positions are identified at different parts of the spans in the code and it is observed that the weight of the consumed steel in uniform beam is more than the others in greater gravity load and a large hole. Finally, steel weight is optimized once for a specified cross-section of the beam with different heights of the hole and once again for a specified height of the hole with different cross-sections of the beam by Genetic algorithm (GA). The results show that the amount of steel weight in optimal state is less than its normal value. Therefore, by decreasing the height of the hole, the width, and height of cross-section, it will be reduced to the least amount.

1. Introduction
In modern buildings, it is typical to place the pipes and ducts under the beams. Nevertheless, to avoid the lack of beauty and to avoid increasing the dead load of the roof in stories, it is better if they are passed through the beam. In this case, initially, the impact of its position and height of the hole should be considered on the shear force and flexural moment, for which complex analysis and design is required. Therefore, a large number of experiments were performed and analysed by investigators who mainly focused on the behaviour, the shape, the opening location, and the load location along the length of beam. Prentza (1968) [1] considered the openings of circular, rectangular, diamond, triangular and even irregular shapes in the experimental study. Although numerous shapes of openings are possible, circular and rectangular openings are the most common ones.

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investigated by other researchers (Mansur, 1998 [5]; Chin et al., 2015 [6]). FRP sheets are used to strengthen the opening region (Abdalla et al. (2003) [7]). A literature review of the FRP strengthening methods for flat slabs against punching shear is introduced by Saleh et al. (2018) [8]. Zhang et al. (2016) [9] presented the numerical mechanics approach for the shear failure of the reinforced concrete beams with any type of concrete and reinforcement. Han and Liu (2014) [10] simulated a RC beam with circle openings through the finite element software. The results have shown that the influence of the hole could be decreased by adding reinforcements around it. Aykac et al. (2013) [11] studied the influence of multiple web openings along the length of a RC beam on its flexural behaviour. The performance of RC beams with the web openings are also investigated by researchers (Ahmeda et al., 2012 [12]; Lee, 2013 [13]). Mohamed et al. (2014) [14] presented the behaviour of the deep RC beams with and without the web openings. The results show that web openings should be avoided if they cross over the expected compression struts. Also, the opening depth should not exceed 20% of the overall depth of the beam. The crack patterns, strain progress and energy absorption of the RC beams under static loads and failure loads are analysed by Hassan et al. (2015) [15]. Nikoo et al. (2015) [16] studied plurality of parameters that influenced the compressive strength of concrete, the nonlinear relationship of parameters and concrete properties according to the Self Organization Feature Map (SOFM) systems. They used several concrete samples with different characteristics and optimized the structures of all SOFM systems by genetic algorithms. The SOFM systems, which were optimized using genetic algorithm, have more accuracy than other models in predicting the compressive strength of the concrete.

Sarıdemir (2011) [17] presented gene expression programming (GEP) as a new tool for the formulations of splitting tensile strength from compressive strength of concrete in which the GEP formulations are developed for splitting tensile strength of concrete as a function of age of specimen and cylinder compressive strength. Govindaraj et al. (2005) [18] presented the application of the Genetic Algorithm (GA) for the RC continuous beams based on the Indian standard specifications. The cross-sectional dimensions and the steel reinforcement of the RC beam are considered as the variables in the present optimum design model.

Also, an application of the GA for the optimization of consumed steel in non-uniform concrete beam by Genetic Algorithm is explored by Ghanadiasl and Gharibi Asl (2016) [19]. Islam and Rokonuzzaman (2018) [20] presented an optimised design process of the spread footing foundation using the GAs. In this study, the objective function was the construction cost. On the other hand, the optimisation variables include the design parameters and the design requirements as constraints.

This paper investigates the weight of the consumed steel for uniform and non-uniform concrete beams with three spans and different heights of opening. The analysis of beams with various loadings is investigated by SAP software and then the results (flexural moment and shear force) are embedded in codes that are written by MATLAB software. Finally, optimal weight of consumed steel, height of openings, and cross-section of beams are obtained by genetic algorithms in MATLAB.

2. Basic Structural Model

In the analysis of the beam with various loadings by SAP software, the cross-section of uniform beam and details of material are presented as (Figure 1):

\[
h = 400 \text{ mm}, b = 300 \text{ mm}, \\
L = 15000 \text{ mm}, L_1, L_2, L_3 = 5000 \text{ mm}
\]

where \( h \) and \( b \) are the height and width of uniform beam, respectively, and \( L \) and \( L_1, L_2, L_3 \) are the total length and the span of uniform beam, respectively.

Also, the concrete compressive strength, the compressive strength steel and the modulus of elasticity are 25, 400 and 2.1E5 MPa. On the other hand, in non-uniform beam, cross section is in accordance with Figure 2.

\[
h=400 \text{ mm}, b=300 \text{ mm}, H=450 \text{ mm}, \\
L=15000 \text{ mm}, L_1, L_2, L_3 = 5000 \text{ mm}
\]

where \( h \), \( H \) and \( b \) are the heights and width of non-uniform beam, respectively, and \( L \) and \( L_1, L_2, L_3 \) are the total length and the span of non-uniform beam, correspondingly.

The combining load in SAP software is based on Eq. (1). So, the first load combination is for the live load and dead loads defined in types (a) to (f) in accordance with Figure 3. But the second load combination is for the live load, the dead and lateral loads with type (f) in Figure 3. Finally, according to this combination of loads, the shear force and the flexural moment are extracted from the analysis in SAP model.

\[
W_{u1} = 1.25DL + 1.5LL \\
W_{u2} = DL + 1.2LL + 0.84E
\]

where DL, LL and E are dead load, live load and earthquake load, respectively.

Beams are designed according to Iran Concrete Regulation (Section ninth national regulations). The concrete cover amount is assumed to be 60 mm and effective height of cross-section for uniform cross-section
Concrete beam is \( d = h - 60 \), but the effective height of cross-section for non-uniform cross-section concrete beam is based on Eq. (2):

\[
d = h + \alpha_1 x - 60 \quad \rightarrow 0 \leq x \leq L_1 \\
d = H - 60 \quad \rightarrow L_1 \leq x \leq L_2 \\
d = H + \alpha_2 (x - L_1) - 60 \quad \rightarrow L_2 \leq x \leq L_3
\]

\[\alpha_1 = \frac{(H - h)}{L_1}, \quad \alpha_2 = \frac{(h - H)}{L_2 - L_1}\]

where \( \alpha_1 \) and \( \alpha_2 \) refer to the slopes in the first and third spans of non-uniform beam, respectively. Also, the tensile steel and compressive steel are calculated based on Eq. (3-5) and Eq. (6-8):

\[
R_y = \frac{M_y}{b.d^2} \quad \rho = \frac{1}{m_y} \left( 1 - \sqrt{\frac{2m_yR_y}{\phi_yf_y}} \right)
\]

\[
m_y = \frac{\phi_yf_y}{0.85\phi_yf_y}
\]

where \( R_y \) and \( M_y \) are a term used in required percentage of steel expression for flexural members and factored moment at a section (N.mm), respectively, and \( \phi_y \), \( f_y \), \( f_y \), \( f_y \), and \( \rho \) are the strength reduction factors of steel, strength reduction factors of concrete, Specified yield strength of flexural reinforcement (MPa), Specified compressive strength of concrete (MPa) and the ratio of non-pre stressed reinforcement in a section, respectively.

\[
\rho_b = 0.85\beta_1 \frac{\phi_yf_y}{\phi_yf_y + 700} = \frac{700}{700 + f_y}
\]

\[
\text{if} \quad f_y \leq 30 \text{MPa} \quad \rightarrow \beta_1 = 0.85
\]

Also, \( \rho_b \) and \( \beta_1 \) are the ratio of tensile reinforcing produced balancing strain condition and the factor for obtaining depth of compression block in concrete, respectively:

\[
\rho_{\text{min}} = \max \left\{ \frac{1.4}{f_y}, \frac{0.25\sqrt{f_y}}{f_y} \right\}
\]

And, \( \rho_{\text{min}} \) is the minimum ratio of non-pre stressed reinforcement in a section.

If,

\[
\rho = \rho_b \rightarrow A_{s1} = \rho_b b d \quad \phi_s A_{s1} f_y \rightarrow f'_s = 700 \times \frac{x - d'}{x} \leq f'_y
\]

where \( x \), \( A_{s1} \), \( d' \), \( f'_s \) and \( f'_y \) are the distances of the neutral axis from the farthest tensile section (mm), area of steel consumption (mm²), concrete cover to center of reinforcing (mm), computed flexural stress in compression steel (MPa) and specified yield strength of compression reinforcement (MPa), respectively. The factored moment to be used in design are calculated by Eq. (7-8).

Fig. 1: Uniform reinforced concrete beam with different height of opening in the length of beam

Fig. 2: Non-uniform reinforced concrete beam with different height of opening in the length of beam

Fig. 3: The types of loads are identified as: a) Live load used in first combination load with value of 1000 Kg/m, b) Uniform dead load with value of 5000 Kg/m, c) Non-uniform dead load with value of 5000 Kg/m, d) Dead load with value of 5000 Kg/m in the middle of span and 5200 Kg/m in first and third spans, e) Dead load with value of 5200 Kg/m in the middle of span and 5000 Kg/m in first and third spans, f) Uniform dead load with value of 5000 Kg/m and earthquake load of 12000 Kg
where \( M_{r1} \), \( M_{r2} \), \( A_{s2} \) and \( A_{s}' \) are the factored moment to be used in design (N.mm), area of steel, area of steel consumption (mm\(^2\)) and area of compression reinforcement (mm\(^2\)), respectively. Also, the shear reinforcement around the opening is equal to Eq. (9).

\[
V_{c} = 0.2 f_{c} \sqrt{f_{r} \cdot b \cdot d}, \quad V_{s} = V_{u} - V_{c}
\]

\[
V_{s} = \frac{\phi_{s} A_{s} f_{y}}{S} (d)
\]

where \( V_{c} \), \( V_{s} \) and \( V_{u} \) are the shear force resisted by concrete (N), shear force to be by shear steel (N) and the factored shear force at a section (N), respectively, and \( A_{s} \), \( f_{y} \) and \( S \) are the area of shear reinforcement (mm\(^2\)), specified yield strength of shear reinforcement (Mpa) and the distance between shear steel (mm), respectively.

3. Optimization of weight of the consumed steel and height of openings

Due to a significant increase in the price of land and materials, the increasing population in Iran is in urgent need of housing. Therefore, to avoid additional costs in construction, building engineers need a comprehensive approach that can reduce time to optimality. The Optimization theory includes optimization studies and methods to achieve them. The "optimal" as a technical term implies quantitative measurements and mathematical analysis while the best is less precise and mostly used in daily routines. In this paper, an appropriate algorithm for the design of concrete beam with non-uniform and uniform cross section is provided. Also, the aim is to get the best rate of steel consumption by optimizing the genetic algorithm.

In fact, the genetic algorithms use the basic principles of Darwin's natural selection to find the optimal formula for predicting or pattern matching. GA is often a great option for the forecasting techniques based on regression. In artificial intelligence, GA is the programming technique that makes use of genetic evolution as the problem-solving pattern. The problem must be solved. Then, solutions are evaluated as candidates by the evaluation function and if the exit condition is provided, the algorithm will be finished.

Generally, the genetic algorithm is an iterative algorithm that will be selected for random processes. First, various solutions to this problem are produced accidentally or algorithmically. This solution set is called the initial population and each answer is called a chromosome. Then, it will create a leap in them using a genetic algorithm operators and select the better chromosomes and combine them. Finally, the current population is combined with a new population that comes from the combination and mutations in chromosomes. Also, the use of genetic algorithms, which are generally carried out in a step by step process in MATLAB is given in the form of flowcharts, as in Flowchart 1.

4. Numerical results

In this paper, the RC beam models with different loading, various positions (Figure 4) and heights of the hole in beams are analysed and designed (Tables 1 and 2). These models are analysed by SAP software and then designed according to the latest code [21]. Tables 3 and 4 present the minimum total weight of the consumed steel in the whole length of uniform and non-uniform beams for all combination loads, respectively. It is observed that the total weight of the consumed steel in the whole length of beams is increased in dead loads No. 3, 1, 4, 5 and 2 (Figure 3), respectively. This is due to the effect of increase of the dead loads, on the first load combination (Eq. 1). Also, according to Table 3, total weight of the consumed steel increases at all positions, with the increment in the height of the hole at all dead loads, except in the second dead load. But in Table 4, the total weight of the consumed steel increases at positions 2, 3 and 4, with the increment in the height of the hole at all dead loads except in the second dead load. In the second load, only in position 1 the total weight of the consumed steel increases.
weight of the consumed steel decreases with increasing hole height.

According to the position of the hole, minimum total weight of the consumed steel in the whole length of uniform and non-uniform beams in Tables 3 and 4 occurs only in positions 1 and 5, which is optimally positioned to place the hole.

In optimizing the height of hole by genetic algorithm for uniform and non-uniform beams the section of RC beam is constant. It is shown in Tables 5 and 6, that only positions 1 and 5 can be suitable for opening, but positions 2, 3, and 4 are not suitable for opening because more weight of the consumed steel is used in these positions which is due to more flexural moment and shear force in these positions.

Also, weight of the consumed steel used in a uniform beam is more than a non-uniform beam, due to the fact that the height of the non-uniform beam is larger than the uniform beam. By increasing the height of beam in positions 1 and 5, the optimal opening height in the uniform beam becomes greater than the non-uniform beam which is especially noticeable in the middle span.

According to the variable height for opening from 0 to 200, the optimum opening height at position 1 is about 12 to 60 mm for uniform beam and about 17 to 160 mm for non-uniform beam. For position 5, it is approximately 0 to 60 for uniform beam and about 0 to 131 mm for non-uniform beam.

The position of the hole in the length of beam

![Fig. 4: The position of the hole in the length of beam](image)

Table 1: The position of the hole in the length of beam

| Case | 1 | 2 | 3 | 4 | 5 |
|------|---|---|---|---|---|
| Distance | d | L1/2 | L1-d | L1+d | L2/2 |

Table 2: The hole height for RC beams with uniform and non-uniform cross section

| The height of hole | H1 | H2 | H3 | H4 |
|-------------------|----|----|----|----|
| 38 | 56 | 67 | 75 |
| 95 | 105 | 110 | 135 |

The weight of the consumed steel used in positions 2, 3, and 4 is also greater than positions 1 and 5 in optimum opening height. This is due to the fact that at position 2, 3 and 4, the flexural moment and shear force is greater than positions 1 and 5. So the hole in these places is not suitable and is not economically feasible in steel consumption.

In the other condition, the height of the opening is equal to 60 mm, which is often suitable for opening with a common pipe section with height of 50 mm. Also, 10 mm is proper for placement and preventing damage to the pipe in the opening and the sections of uniform and non-uniform beams are optimized (the width and height of the beams) by the genetic algorithm. In this case, the width of the beam is variable from 350 to 500 mm, and the height of the hole with the height of the beam is constant. According to these preliminary assumptions, for the dimensions of the beam and the height of the hole, the optimum dimensions of the uniform and non-uniform beams are obtained under the applied loads by genetic algorithm.
Table. 3: Minimum total weight of the consumed steel in the whole length of uniform beams (Kg)

| Type of dead load and lateral load used in load combination | Heights of holes | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|-----------------------------------------------------------|------------------|---------|---------|---------|---------|---------|
| H1                                                        | Cases 1, 5       | 103.3655 | 69.9748 | 106.6469 | 103.322 | 83.7770 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H2                                                        | Case 5          | 103.3675 | 69.9732 | 106.6487 | 103.3241 | 83.7754 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H3                                                        | Case 5          | 103.3688 | 69.9723 | 106.6499 | 103.3254 | 83.7762 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H4                                                        | Case 5          | 103.3698 | 69.972  | 106.6508 | 103.326  | 83.7770 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H5                                                        | Case 5          | 103.3726 | 69.9699 | 106.6534 | 103.329  | 83.7791 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H6                                                        | Case 5          | 103.3746 | 69.9689 | 106.6552 | 103.3313 | 83.7806 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H7                                                        | Case 5          | 103.3755 | 69.9684 | 106.6561 | 103.3323 | 83.7813 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |
| H8                                                        | Case 5          | 103.3799 | 69.9665 | 106.6601 | 103.3366 | 83.7845 |
|                                                           | Case 1          | Case 5  | Case 1  | Case 5  | Case 1  | Case 5  |

Table. 4: Minimum total weight of the consumed steel in the whole length of non-uniform beams (Kg)

| Type of dead load and lateral load used in load combination | Heights of holes | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|-----------------------------------------------------------|------------------|---------|---------|---------|---------|---------|
| H1                                                        | Case 5          | 98.8748 | 67.8762 | 101.7905 | 98.8483 | 81.3673 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H2                                                        | Case 5          | 98.8732 | 67.8745 | 101.7889 | 98.8467 | 81.3657 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H3                                                        | Case 5          | 98.8722 | 67.8736 | 101.7880 | 98.8457 | 81.3647 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H4                                                        | Case 5          | 98.8715 | 67.8729 | 101.7873 | 98.8452 | 81.3641 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H5                                                        | Case 5          | 98.8701 | 67.8712 | 101.7856 | 98.8470 | 81.3624 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H6                                                        | Case 5          | 98.8713 | 67.8702 | 101.7845 | 98.8483 | 81.3613 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H7                                                        | Case 5          | 98.8718 | 67.8697 | 101.7850 | 98.8489 | 81.3608 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |
| H8                                                        | Case 5          | 98.8741 | 67.8679 | 101.7871 | 98.8516 | 81.3596 |
|                                                           | Case 5          | Case 1  | Case 5  | Case 1  | Case 5  | Case 5  |

Table. 5: The optimum weight of the consumed steel and height of hole at position of opening in uniform beam

| Uniform beam section(mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|--------------------------|---------------------|---------|---------|---------|---------|---------|
| b=300, h=400             | D=[0,200]           |         |         |         |         |         |
| Case1                    | 37.01               | 21.52   | 37.96   | 36.89   | 31.58   |
| D (mm)                   | 18.872              | 153.769 | 12.285  | 19.683  | 59.137  |
| Case2                    | 101.56              | 45.60   | 106.47  | 100.353 | 78.83   |
| D (mm)                   | 0                   | 0       | 0       | 0       | 0       |
| Case3                    | 92.35               | 75.03   | 93.61   | 94.52   | 70.67   |
| D (mm)                   | 0                   | 0       | 0       | 0       | 0       |
| Case4                    | 98.46               | 72.46   | 108.1   | 99.85   | 75.01   |
| D (mm)                   | 0                   | 0       | 0       | 0       | 0       |
| Case5                    | 33.29               | 55.17   | 32.28   | 34.82   | 29.82   |
| D (mm)                   | 16.739              | 0       | 28.656  | 0       | 57.202  |
Table 6: The optimum weight of the consumed steel and height of hole at position of opening in non-uniform beam

| Non-uniform beam section (mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|------------------------------|--------------------|----------|----------|----------|----------|----------|
| b=300, h=400, H=450 | D=0,200 | Case1 | 36.77 | 21.45 | 37.71 | 36.65 | 31.38 |
|                         | D (mm) | 23.906 | 157.967 | 17.372 | 24.708 | 63.993 |
| Case2 | 91.49 | 42.06 | 95.74 | 90.46 | 71.55 |
| D (mm) | 0 | 0 | 0 | 0 | 0 |
| Case3 | 87.34 | 68.59 | 88.76 | 89.142 | 67.22 |
| D (mm) | 0 | 0 | 0 | 0 | 0 |
| Case4 | 90.934 | 66.30 | 93.10 | 92.17 | 69.27 |
| D (mm) | 0 | 0 | 0 | 0 | 0 |
| Case5 | 31.02 | 47.19 | 29.80 | 32.65 | 27.79 |
| D (mm) | 93.128 | 0 | 107.335 | 74.269 | 130.804 |

In the event that the maximum weight of the consumed steel is optimally compared to the non-optimal state, according to Tables 7 and 8, it is observed that by increasing the height of the hole, a percentage reduction in the amount of consumed steel in optimal state increases compared to the non-optimal state. And this amount is lower in uniform beam than non-uniform beam, when they have a hole. This is due to the fact that it consumes more steel in both optimal and non-optimal state. For example, in height of hole equal to 131 mm, the reduction percentage for position 1 is 32% and 31%, and for position 5, it is 41% and 33.5% in uniform and non-uniform beams, respectively. Also, this percentage reduction in position 5 is greater than position 1 in both cases.

Table 7: Percentage difference maximum non-optimal weight and optimum weight of steel at position of opening in uniform beam

| Height of hole (mm) | Uniform beam section b=300 mm , h=400 mm | Weight (g) | Percentage difference weight with optimum weight |
|--------------------|-----------------------------------------|-----------|-----------------------------------------------|
| 0                  | Case1 | 38.886 | 3rd load | 2.32% |
|                    | Case5 | 55.17 | 3rd load | 0% |
| 56                 | Case1 | 42.775 | 3rd load | 11.26% |
|                    | Case5 | 65.716 | 2nd load | 16.1% |
| 75                 | Case1 | 45.239 | 3rd load | 16.1% |
|                    | Case5 | 70.418 | 2nd load | 21.65% |
| 95                 | Case1 | 48.250 | 3rd load | 21.33% |
|                    | Case5 | 76.438 | 2nd load | 27.82% |
| 135                | Case1 | 55.815 | 3rd load | 31.99% |
|                    | Case5 | 93.123 | 2nd load | 40.76% |
| Optimal hole       | Case1 | 37.96 | 3rd load | - |
|                    | Case5 | 55.17 | 2nd load | - |

According to the results for uniform beam (Table 9), weight of the consumed steel and the maximum optimal width in positions 2, 3 and 4 is greater than positions 1 and 5, which is approximately equal to 350, 400, 450, and 350 mm for positions 1, 2, 3, 4 and 5, respectively. Also, for non-uniform beam in Table 10, weight of the consumed steel and the maximum optimal width in positions 2, 3 and 4 is greater than positions 1 and 5, which is approximately equal to 350, 450, 500, 450, and 350 mm for positions 1, 2, 3, 4 and 5, respectively. So, the non-uniform beam has a maximum optimal width less than a uniform beam, and the weight of the consumed steel is more or equal in comparison to uniform beam in the positions of 2, 3 and 4.
Table 8: Percentage difference maximum non-optimal weight and optimum weight of steel at position of opening in non-uniform beam

| Height of hole (mm) | Weight (g) | Percentage difference weight with optimum weight |
|--------------------|------------|-----------------------------------------------|
| 0                  | 39.007 3rd load | 3.33% |
| 56                 | 41.907 3rd load | 10.02% |
| 75                 | 44.298 3rd load | 14.87% |
| 95                 | 47.208 3rd load | 20.12% |
| 135                | 49.76 3rd load | 33.24% |

Optimal hole

Case 1: 49.76 3rd load
Case 5: 49.76 2nd load

Table 9: The optimum weight of the consumed steel and width of beam at position of opening in uniform beam

| Uniform beam section (mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|--------------------------|---------------------|----------|----------|----------|----------|----------|
| b=350, h=500             | 60                  |          |          |          |          |          |
| Case 1 b (mm)            | 49.76               | 49.75    | 49.91    | 49.76    | 49.76    |
| Case 2 b (mm)            | 78.32               | 49.76    | 81.62    | 77.49    | 62.32    |
| Case 3 b (mm)            | 67.06               | 55.49    | 67.97    | 68.14    | 54.19    |
| Case 4 b (mm)            | 447.032             | 388.481  | 450.362  | 457.481  | 357.625  |
| Case 5 b (mm)            | 70.99               | 55.23    | 71.63    | 56.49    |

Table 10: The optimum weight of the consumed steel and width of beam at position of opening in non-uniform beam.

| Non-uniform beam section (mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|-------------------------------|---------------------|----------|----------|----------|----------|----------|
| b=350, h=500, H=550          | 60                  |          |          |          |          |          |
| Case 1 b (mm)                | 45.71               | 45.08    | 46.18    | 45.65    | 45.08    |
| Case 2 b (mm)                | 80.92               | 47.25    | 84.32    | 80.1     | 64.37    |
| Case 3 b (mm)                | 67.06               | 55.49    | 67.97    | 68.14    | 54.19    |
| Case 4 b (mm)                | 447.032             | 388.481  | 450.362  | 457.481  | 357.625  |
| Case 5 b (mm)                | 70.99               | 55.23    | 71.63    | 56.49    |

On the other hand (Table 11), according to the maximum optimum weight and height of the hole, the height of beams are optimized. Finally, it is observed that the optimal height for the position 1 is between 350 to 400 mm, in position 2 between 450 and 650 mm, in position 3 between 500 to 550 mm, in position 4 between 500 and 600 mm and in position 5 between 350 and 550 mm for optimal width of uniform beam (350, 400, 450, 450, and 350 mm respectively). But in non-uniform beam (Table 12), the optimal height for the position 1 is equal to 550 mm, in position 2 between 550 and 700 mm, in position 3 it is equal to 550 mm, in position 4 between 550 and 600 mm and in position 5 equal to 550 mm for optimal width of beam (350, 450, 500, 450, and 350 mm respectively).
that the weight of the consumed steel, height of the beam, and position of opening in uniform beam. Also, the side openings with additional height can be used in a non-uniform beam.

In optimization of height of the hole, it is better to be b=350, h=60 mm for non-uniform beam (b=300, h=400 mm) and in the range of 0 to 160 mm for non-uniform beam (b=300, h=400, H=450 mm). But in optimization of height of the hole to be in the range of 0 to 60 mm for uniform beam. Finally, the optimal weight of the consumed steel, height of the opening, and cross-section of beam is obtained by genetic algorithms in MATLAB. By decreasing height of the hole, the width and height of beam will be minimum amount. Also, in optimization of height of the hole, it is better for the height of the hole to be in the range of 0 to 60 mm for uniform beam (b=300, h=400 mm) and in the range of 0 to 160 mm for non-uniform beam (b=300, h=400, H=450 mm). But in optimization of height of beam with height of hole equal to 60 mm it is better to be b=350, h=500, H=5500 for uniform beam in position 1 and b=350, h=500 and H=550 for non-uniform beam in position 1, 5, because they are economically feasible. In non-uniform beam, the height of middle span is 50 mm higher than the side spans, which makes the weight of the consumed steel to be less than the uniform beam. Also, the opening with additional height can be used in a non-uniform beam.

5. Conclusions

This paper investigated the optimum weight of the consumed steel for the RC beams with the different heights of openings. In addition, this paper also summarized two types of concrete beams, one uniform cross-section, and another non-uniform cross-section, which are all affected by uniform and non-uniform dead loads, uniform live load and lateral load. The analysis of beams with various loadings is presented by SAP software and then the results (flexural moment and shear force) are embedded in codes of MATLAB software to obtain weight of the consumed steel with different heights of openings.

### Table 11: The optimum weight of the consumed steel and height of beam at position of opening in uniform beam.

| Uniform beam section (mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|---------------------------|---------------------|----------|----------|----------|----------|----------|
| b=350, h=[350,700]        | 60                  | Case1    | 38.43    | 29.70    | 39.36    | 38.31    | 33.07    |
|                           | h (mm)              | 412.827  | 350      | 418.953  | 412.085  | 375.578  |
| b=400, h=[350,700]        | 60                  | Case2    | 66.63    | 46.36    | 67.96    | 66.29    | 59.69    |
|                           | h (mm)              | 633.137  | 456.3    | 644.787  | 630.194  | 572.629  |
| b=450, h=[350,700]        | 60                  | Case3    | 67.18    | 60.03    | 67.96    | 67.83    | 57.83    |
|                           | h (mm)              | 548.381  | 515.276  | 550.197  | 554.056  | 496.822  |
| b=500, h=[350,700]        | 60                  | Case4    | 67.69    | 58.57    | 68.43    | 67.96    | 60.68    |
|                           | h (mm)              | 574.693  | 501.724  | 580.472  | 576.81   | 520.355  |
| b=350, h=[350,700]        | 60                  | Case5    | 36.21    | 47.19    | 35.09    | 37.80    | 32.45    |
|                           | h (mm)              | 414.829  | 524.362  | 403.821  | 430.777  | 377.369  |

### Table 12: The optimum weight of the consumed steel and height of beam at position of opening in non-uniform beam.

| Non-uniform beam section (mm) | Height of hole (mm) | 1st load | 2nd load | 3rd load | 4th load | 5th load |
|-------------------------------|---------------------|----------|----------|----------|----------|----------|
| b=350, h=500, H=[550,750]    | 60                  | Case1    | 45.71    | 45.08    | 46.18    | 45.65    | 45.08    |
|                              | h (mm)              | 550      | 550      | 550      | 550      | 550      |
| b=450, h=500, H=[550,750]    | 60                  | Case2    | 70.22    | 61.28    | 71.61    | 69.87    | 62.94    |
|                              | h (mm)              | 688.601  | 550      | 710.223  | 683.187  | 575.786  |
| b=500, h=500, H=[550,750]    | 60                  | Case3    | 72.12    | 71.48    | 72.69    | 72.18    | 71.48    |
|                              | h (mm)              | 550      | 550      | 550      | 550      | 550      |
| b=450, h=500, H=[550,750]    | 60                  | Case4    | 69.55    | 64.50    | 70.35    | 69.78    | 64.50    |
|                              | h (mm)              | 589.098  | 550      | 595.322  | 590.959  | 550      |
| b=350, h=500, H=[550,750]    | 60                  | Case5    | 49.76    | 49.76    | 49.76    | 49.76    | 49.76    |
|                              | h (mm)              | 550      | 550      | 550      | 550      | 550      |
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