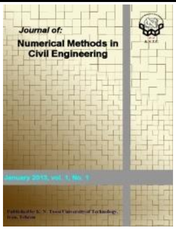

Numerical Methods in Civil Engineering

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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For example, circular openings are required to accommodate service pipes, for plumbing and electrical supply and the rectangular openings are used for the ventilation systems. Behaviour of concrete beam with the circular and the rectangular openings sections under shear, torsion and flexure was studied by Mansur et al. (1984) [2]. Mansur and Tan (1999) [3] proposed that two different sizes of openings are available in beams that are totally dependent on the structural response of the beam. The opening can be considered "small" when the beam is able to maintain the type of behaviour beam and apply theories of the beam. On the other hands, the opening should be classified as "large" when the type of behaviour beam ceases to exist. Fahmy et al. (1996) [4] presented a method for the unreinforced rectangular web openings. This method also explained the effect of eccentricity, height and length of the opening on the strength of the composite beam. The obtained results were far more prominent/more valuable when compared to tests of other researchers. In addition, the effect of the openings on the strength and behaviour of the reinforced concrete (RC) beams are

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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 Ghannadiasl 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 mm, b = 300 mm,

L = 15000 mm, L_1, L_2, L_3 =5000 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 mm, b=300 mm, H=450 mm

L=15000 mm, L_1, L_2, L_3 =5000 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.

$$\begin{aligned} W_{u1} &= 1.25DL + 1.5LL \\ W_{u2} &= DL + 1.2LL + 0.84E \end{aligned} \quad (1)$$

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):

$$\left.\begin{aligned} &d = h + \alpha_1 . x - 60 && \rightarrow 0 \le x \le L_1 \\ &d = H - 60 && \rightarrow L_1 \le x \le L_2 \\ &d = H + \alpha_2 .(x - L_2) - 60 && \rightarrow L_2 \le x \le L_3 \end{aligned}\right\} \quad (2)$$

$$\alpha_1 = \frac{(H - h)}{L_1}, \ \alpha_2 = \frac{(h - H)}{L - L_2}$$

where α_1 and α_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):

$$\left.\begin{aligned} R_r &= \frac{M_u}{b.d^2} \\ m_\phi &= \frac{\phi_s . f_y}{0.85\phi_c . f_c} \end{aligned}\right\} \quad \rho = \frac{1}{m_\phi}\left(1 - \sqrt{1 - \frac{2m_\phi . R_r}{\phi_s . f_y}}\right) \quad (3)$$

where R_r and M_u are a term used in required percentage of steel expression for flexural members and factored moment at a section (N.mm), respectively, and ϕ_s , ϕ_c , f_y , f_c and ρ 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.

$$\left.\rho_b = 0.85\beta_1 \frac{\phi_c . f_c}{\phi_s . f_y} . \frac{700}{700 + f_y}\right\} \quad (4)$$

$$if \rightarrow f_c \le 30MPa \rightarrow \beta_1 = 0.85$$

Also, ρ_b and β_1 are the ratio of tensile reinforcing producing balanced strain condition and the factor for obtaining depth of compression block in concrete, respectively:

$$\rho_{\min} = \max\left\{\frac{1.4}{f_y}, \frac{0.25\sqrt{f_c}}{f_y}\right\} \quad (5)$$

And, ρ_{min} is the minimum ratio of non-pre stressed reinforcement in a section.

If,

$$\rho = \rho_b \rightarrow A_{s1} = \rho.b.d$$

$$x = \frac{\phi_s . A_{S1} . f_y}{0.85.\beta_1 . \phi_c . f_c . b} \rightarrow f_s' = 700 \times \frac{x - d'}{x} \le f_y' \quad (6)$$

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 (mm^2), 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).

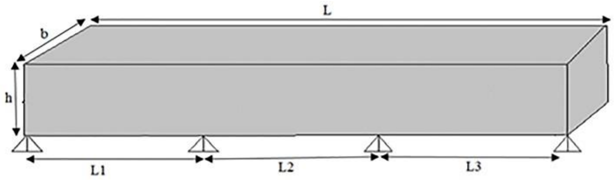

Fig. 1: Uniform reinforced concrete beam with different height of opening in the length of beam

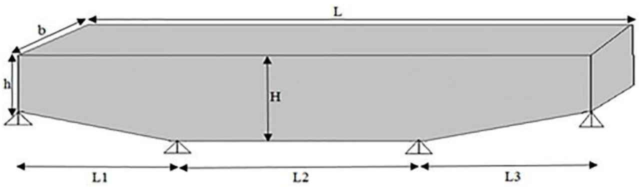

Fig. 2: Non-uniform reinforced concrete beam with different height of opening in the length of beam

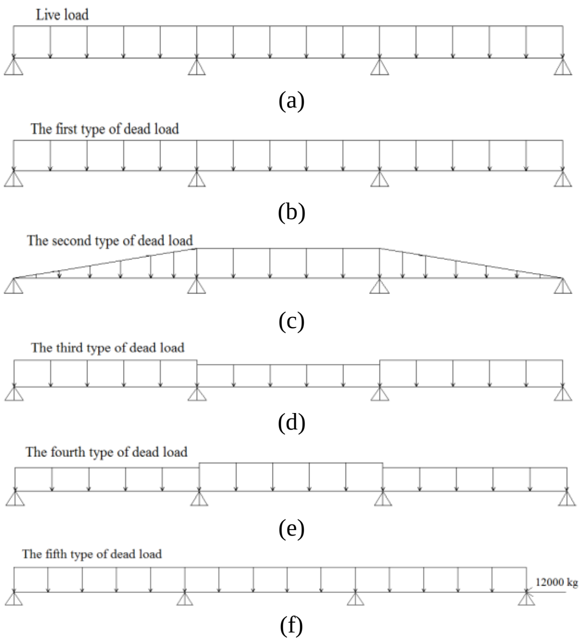

Fig. 3: The types of loads are identified as: a) Live load used in first combination load with value of 1000 Kg/m, b) Uniform dead load with value of 5000 Kg/m, c) Non-uniform dead load with value of 5000 Kg/m, d) Dead load with value of 5000 Kg/m in the middle of span and 5200 Kg/m in first and third 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

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$$M_{r1} = \rho\phi_s f_y bd^2 (1 - 0.59 \frac{\rho\phi_s f_y}{\phi_c f_c}) \quad (7)$$

$$M_{r2} = M_u - M_{r1} \rightarrow A_{s2} = \frac{M_{r2}}{f_y.\phi_s (d - d')}$$
$$\rightarrow A'_s = \frac{A_{s2} \cdot f_y}{f'_s} \quad (8)$$

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).

$$V_c = 0.2 f_c \sqrt{f_c}.b.d, \; V_s = V_u - V_c$$
$$V_s = \frac{\phi_s A_v f_{yv}}{S}(d) \quad (9)$$

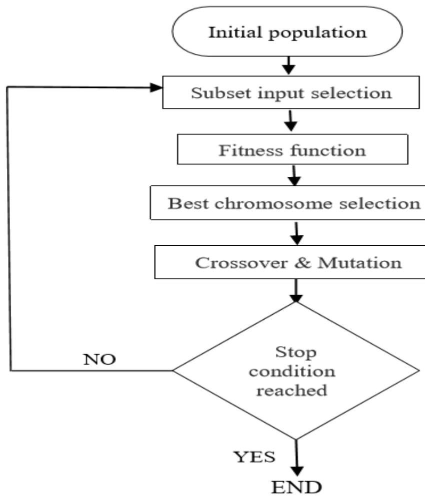
where V_c, V_s and V_u are the shear force resisted by concrete (N), shear force to bear by shear steel (N) and the factored shear force at a section (N), respectively, and A_v, f_{yv} and S are the area of shear reinforcement (mm[2]), specified yield strength of shear reinforcement (Mpa) and the distance 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.



Flowchart. 1: Optimization process

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

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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.

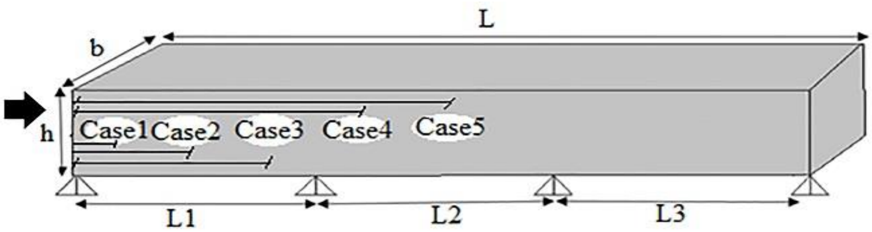

Fig. 4: The position of the hole in the length of beam

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

	The position of holes in uniform and non-uniform beams				
Case	1	2	3	4	5
Distance	d	$L_1/2$	L_1-d	L_1+d	$L_2/2$

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
H5	H6	H7	H8
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.

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Table. 3: Minimum total weight of the consumed steel in the whole length of uniform beams (Kg)

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

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

Heights of holes	Type of dead load and lateral load used in load combination: 1st load	2nd load	3rd load	4th load	5th load
H1	98.8748 Case 5	67.8762 Case 1	101.7905 Case 5	98.8483 Case 5	81.3673 Case 5
H2	98.8732 Case 5	67.8745 Case 1	101.7889 Case 5	98.8467 Case 5	81.3657 Case 5
H3	98.8722 Case 5	67.8736 Case 1	101.7880 Case 5	98.8457 Case 5	81.3647 Case 5
H4	98.8715 Case 5	67.8729 Case 1	101.7873 Case 5	98.8452 Case 5	81.3641 Case 5
H5	98.8701 Case 5	67.8712 Case 1	101.7856 Case 5	98.8470 Case 5	81.3624 Case 5
H6	98.8713 Case 5	67.8702 Case 1	101.7845 Case 5	98.8483 Case 5	81.3613 Case 5
H7	98.8718 Case 5	67.8697 Case 1	101.7850 Case 5	98.8489 Case 5	81.3608 Case 5
H8	98.8741 Case 5	67.8679 Case 1	101.7871 Case 5	98.8516 Case 5	81.3596 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)**		**The optimum weight of the consumed steel (g): 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)		The optimum weight of the consumed steel (g)				
			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	66.72
		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

Uniform beam section b=300 mm , h=400 mm			
Height of hole (mm)		**Weight (g)**	**Percentage difference weight with optimum weight**
0	**Case1**	38.886 3rd load	2.32%
	Case5	55.17 2nd 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, 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.

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Table. 8: Percentage difference maximum non-optimal weight and optimum weight of steel at position of opening in non-uniform beam

Non-uniform beam section b=300 mm , h=400 mm, H=450			
Height of hole (mm)		**Weight (g)**	**Percentage difference weight with optimum weight**
0	**Case1**	39.007 3rd load	3.33%
	Case5	47.19 2nd load	0
56	**Case1**	41.907 3rd load	10.02%
	Case5	54.475 2nd load	13.37%
75	**Case1**	44.298 3rd load	14.87%
	Case5	57.542 2nd load	17.99%
95	**Case1**	47.208 3rd load	20.12%
	Case5	61.300 2nd load	23.02%
135	**Case1**	54.470 3rd load	30.77%
	Case5	70.690 2nd load	33.24%
Optimal hole	**Case1**	37.71 3rd load	-
	Case5	47.19 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)**		**The optimum weight of the consumed steel (g)**				
			1st load	**2nd load**	**3rd load**	**4th load**	**5th load**
b=[350 500], h=550	60	Case1	49.76	49.75	49.91	49.76	49.76
		b (mm)	350	350	350	350	350
		Case2	78.32	49.76	81.62	77.49	62.32
		b (mm)	406.574	350	419.135	403.418	350
		Case3	67.06	55.49	67.97	68.14	54.19
		b (mm)	447.032	388.481	450.362	457.481	357.625
		Case4	70.99	55.23	72.61	71.63	56.49
		b (mm)	427.503	365.698	427.503	438.37	354.553
		Case5	49.76	49.76	49.76	49.76	49.76
		b (mm)	350	350	350	350	350

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)**		**The optimum weight of the consumed steel (g)**				
			1st load	**2nd load**	**3rd load**	**4th load**	**5th load**
b=[350 500], h=500, H=550	60	Case1	45.71	45.08	46.18	45.65	45.08
		b (mm)	350	350	350	350	350
		Case2	80.92	47.25	84.32	80.1	64.37
		b (mm)	428.336	350	441.41	425.08	362.007
		Case3	70.17	57.56	71.19	71.24	56.58
		b (mm)	480.308	394.956	484.825	490.53	384.246
		Case4	75.07	56.51	76.87	75.64	59.73
		b (mm)	429.468	378.343	429.468	440.318	356.223
		Case5	49.76	49.76	49.76	49.76	49.76
		b (mm)	350	350	350	350	350

On the other hand (Table 11), according to the maximum optimum width 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).

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)		The optimum weight of the consumed steel (g)				
			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=450 , 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)		The optimum weight of the consumed steel (g)				
			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

Therefore, for a height of hole equal to 60 mm in uniform beam, height of 400 mm and width of 350 mm in position 1 are optimally suitable. Also in non-uniform beam, height of 500 mm in side spans of beam, height of 550 mm in middle span of beam and width of 350 mm in positions 1, 5 are optimally suitable.

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. Finally, the optimal weight of the consumed steel, height of the openings, 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 and width of beams with height of hole equal to 60 mm it is better to be b=350, h=400 mm for uniform beam in position 1 and b=350, h=500 and H=550 for non-uniform beam in positions 1and 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.

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