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The effect of the consideration of slab dimensions on optimum design of reinforced concrete beams

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Abstract

In the design of reinforced concrete (RC) beams, the slab can be also considered as a part of the beam and a t-shaped cross section is considered. In the presented study, the optimum design of RC beams are investigated for different slab thickness values. Thus, the effect of the consideration of slab dimensions for the optimum design is investigated. In the optimization methodology, an iterative cost optimization process is proposed. The process contains the optimization of design variables such as the cross-section dimensions and amount of rebar of RC beams subjected to flexural moments. In order to find a precise optimum solution without trapping local optimums, a metaheuristic based method called harmony search is employed. The optimum values are chosen according to user selected range and the design constraints. The design constraints are generated according to ACI318- Building code requirements for structural concrete. By the increase of compressive force in the compressive section of the beam, the amount of the rebar shows a decreasing manner and this situation is effective on the optimum design and cost.

Key words

Metaheuristic algorithm, Frames, Optimization, Teaching learning based optimization

1. INTRODUCTION

In the design of reinforced concrete (RC) beams, the slab can be included in the compressive section of the beam in order to increase the force carried by the concrete. Thus, a T-shaped cross section is used and the flange width is calculated according to effective width by considering zero moment measures while the thickness of the flange is equal to the thickness of the slab. The consideration of a T-shaped section is effective on the economy in order to reduce the amount of rebar, especially in the compressive section.

In this paper, the optimum design of RC beams under flexural moments are presented for different thickness values of slab and the results are also compared with a rectangular section. The optimum design employs harmony search algorithm (HS) [1] and considers the rules of ACI318: Building code requirements for structural concrete [2] in the analyses.

Harmony search (HS) is a music inspired metaheuristic algorithm. Like genetic algorithm inspired form the evaluation theory [3] or ant colony optimization [4] inspired from the food search process of ants, HS inspired from musical performance in which a musician tries to find the best harmony in order to gain attention of the listeners. In this process, a well-known popular note can be played or it can be modified a little in order to adjust the level of admiration. Metaheuristic based methodologies are effective on the engineering problems and several good examples can be also found for optimization of RC members like beams [5-8], columns [9-10], frames [11-12] and retaining walls [13-14].

2. METHODOLOGY

The methodology of the optimization process can be explained in five steps. These steps are summarized in the flowchart given as Fig. 1.

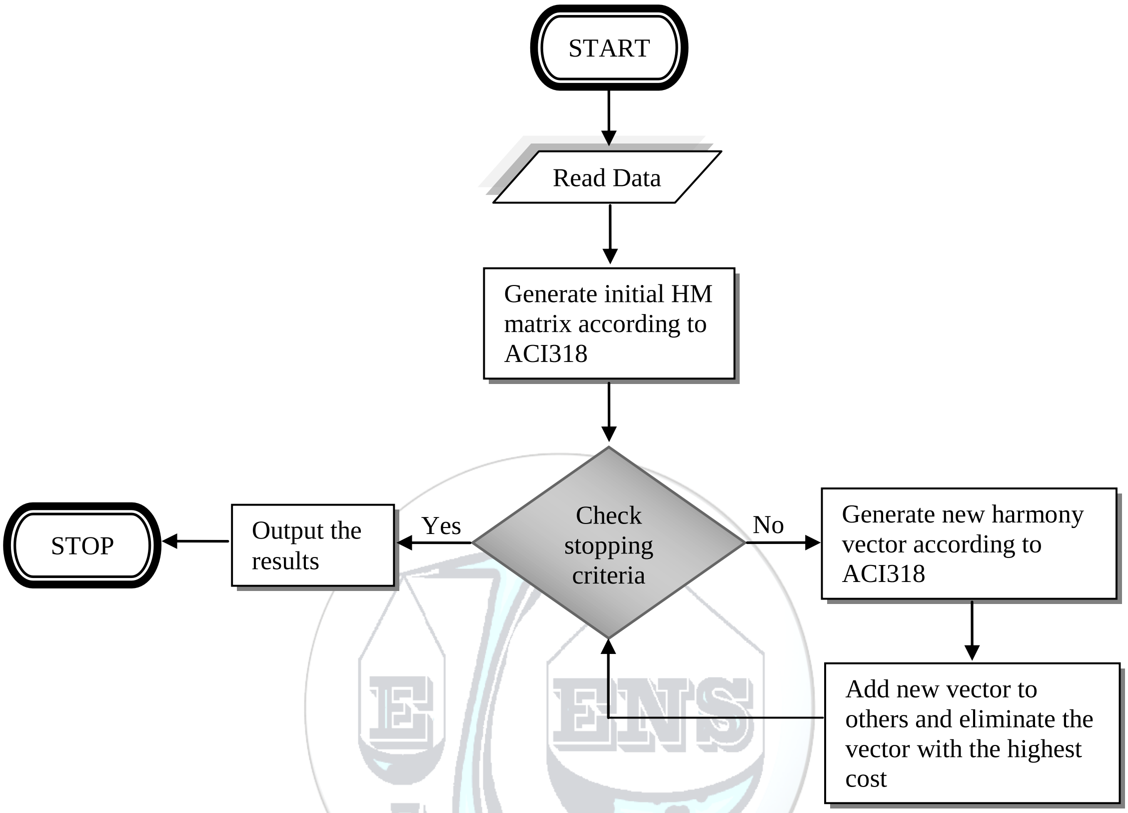

Figure 1. Flowchart of the methodology [7]

Step 1: Read Data

In this step, the design constants (given in Table 2 with the values used in numerical example), the ranges of design variables (values also given in Table 2) such as height (h) and width (b) of the beam, number (n_1, n_2, n_3 and n_4) and size (ϕ_1, ϕ_2, ϕ_3 and ϕ_4) of rebar, the algorithm parameters (HMS: harmony memory size, HMCR: harmony memory considering rate, PAR: pitch adjusting rate, values on Table 2) are defined. A T-shaped cross section which is optimized, is shown in Fig. 2.

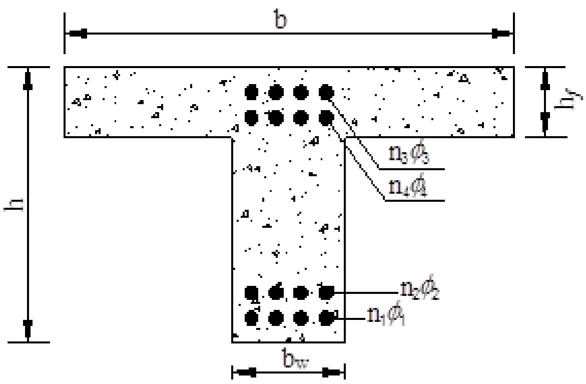

Figure 2. The T-shaped cross section

Step 2: Generate initial harmony memory (HM) matrix

In this step, initial solution vectors for design variables are randomly generated. This generation of vectors is done for HMS and the initial HM matrix is generated. In the generated values must provide the ACI-318 rules in the analyses.

Step 3: Generate a new harmony memory

After the generation of initial HM matrix, a new vector is generated in two ways. These two ways are chosen with possibility called HMCR. With HMCR possibility, a new solution is generated around existing solution by using a narrow range which is PAR times of the length of the initial solution range. The other way is to use the initial solution range in the generation of design variables. All dimension variables are rounded to values which are divisible to 50 mm and the diameters of rebar are even numbers for practical production in a construction yard.

Step 4: Elimination and update

If the newly generated solution is better than the worst existing solution, the solution is keep and the old one is eliminated. This comparison is done according to objective function which is the total material cost of unit meter.

Step 5: Check the stopping criteria

The methodology has various criteria for stopping of the iterative process given as step 3 and 4. The difference of the web width and height for different sets of solution must be smaller than 50 mm. Also, the difference in flexural moment strength and the required flexural moment capacity must be less than 0.5% of required. The required flexural moments are increased by dividing the values by 0.9 according to ACI-318. When these criteria are satisfied, the optimum results are output.

3. NUMERICAL EXAMPLE

The investigation is done for 4 cases of the slab thickness (h_f). In the first case, the section is rectangular (h_f=0). All numerical values used in the optimization are presented in Table 2. The required flexural moments are investigated for different values and the optimum results are given in Table 3.

Table 1. The design constants, ranges and parameters

Definition	Symbol	Unit	Value
Range of width section	b_{wmin}, b_{wmax}	mm	250-350
Range of height section	h_{min}, h_{max}	mm	300-500
Clear cover	cc	mm	35
Range of diameter of rebar	ϕ_{min}, ϕ_{max}	mm	10-30
Size of stirrups	ϕ_v	mm	10
Width of flange	b	mm	1000
Slab thickness	h_f	mm	0 (case 1) 100 (case 2) 120 (case 3) 140 (case 4)
Max. aggregate diameter	D_{max}	mm	16
Yield strength of steel	f_y	MPa	420
Comp. strength of concrete	f_c'	MPa	25
Elasticity modulus of steel	E_s	MPa	200000
Specific gravity of steel	γ_s	t/m^3	7.86
Specific gravity of concrete	γ_c	t/m^3	2.5
Cost of the concrete per m^3	C_c	\$/ m^3	40
Cost of the steel per ton	C_s	\$/ m^3	400
Harmony memory size	HMS	-	5
Harmony memory considering rate	HMCR	-	0.5
Pitch adjusting rate	PAR	-	0.5

Table 2. The optimum results

	Objective Flexural Moment (kNm)	50	100	150	200	250	300	350	400	450	500
CASE 1	h (mm)	300	400	500	500	500	500	500	500	500	500
	b_w (mm)	250	250	250	250	250	250	250	300	350	350
	ϕ_1 (mm)	10	12	16	16	22	30	30	30	26	30
	ϕ_3 (mm)	30	16	12	14	10	10	10	10	20	22
	n_1	5	4	3	4	3	3	3	4	5	4
	n_3	0	0	0	0	0	3	0	4	2	3
	ϕ_2 (mm)	10	12	12	14	18	10	18	10	10	16
	ϕ_4 (mm)	24	14	16	30	16	18	30	18	10	20
	n_2	3	4	4	4	3	2	4	3	8	5
	n_4	0	0	0	0	0	0	0	0	3	0
	M_u (kNm)	55.96	112.00	172.26	222.77	280.42	343.99	393.37	451.50	501.01	572.40
	Cost ($/m)	4.95	6.81	8.28	9.41	10.91	12.80	14.74	16.48	19.87	22.44
CASE 2	h (mm)	350	350	350	400	450	500	500	500	500	500
	b_w (mm)	250	250	250	250	250	250	250	250	250	250
	ϕ_1 (mm)	10	12	16	16	18	24	24	28	20	24
	ϕ_3 (mm)	14	18	28	12	20	22	14	26	28	16
	n_1	2	3	3	4	3	2	2	2	4	3
	n_3	0	0	0	0	0	0	0	0	0	0
	ϕ_2 (mm)	10	10	10	10	14	12	12	14	14	22
	ϕ_4 (mm)	22	30	22	22	18	26	14	20	16	20
	n_2	2	3	4	2	2	2	4	2	3	2
	n_4	0	0	0	0	0	0	0	0	0	0
	M_u (kNm)	36.87	67.26	105.92	133.76	168.11	201.03	236.70	268.95	300.78	360.03
	Cost ($/m)	7.48	8.28	9.35	9.98	10.83	11.51	12.21	12.78	13.33	14.57
CASE 3	h (mm)	350	350	400	400	450	500	500	500	500	500
	b_w (mm)	250	250	250	250	250	250	250	250	250	250
	ϕ_1 (mm)	10	12	10	16	14	24	22	28	20	24
	ϕ_3 (mm)	30	10	16	30	28	14	14	24	12	16
	n_1	3	3	5	3	4	2	3	2	4	3
	n_3	0	0	0	0	0	0	0	0	0	0
	ϕ_2 (mm)	10	10	12	10	14	10	12	12	18	16
	ϕ_4 (mm)	28	14	14	14	10	26	28	22	30	22
	n_2	2	3	3	5	3	3	2	3	2	3
	n_4	0	0	0	0	0	0	0	0	0	0
	M_u (kNm)	46.53	67.26	100.25	134.76	167.74	202.63	243.10	273.86	307.64	337.39
	Cost ($/m)	8.32	8.88	9.87	10.69	11.44	12.14	12.84	13.48	14.08	14.68
CASE 4	h (mm)	350	350	350	400	450	500	500	500	500	500
	b_w (mm)	250	250	250	250	250	250	250	250	250	250
	ϕ_1 (mm)	12	12	12	14	18	16	18	24	24	26
	ϕ_3 (mm)	30	26	30	24	28	28	12	30	24	28
	n_1	2	3	4	4	3	4	4	3	3	3
	n_3	0	0	0	0	0	0	0	0	0	0
	ϕ_2 (mm)	10	10	12	16	12	12	14	10	16	16
	ϕ_4 (mm)	24	28	20	12	20	24	26	22	22	28
	n_2	2	3	4	2	3	3	2	2	2	2
	n_4	0	0	0	0	0	0	0	0	0	0
	M_u (kNm)	45.15	67.26	103.19	137.72	172.65	203.70	235.74	269.45	306.89	345.88
	Cost ($/m)	8.89	9.48	10.51	11.36	12.12	12.75	13.32	13.90	14.66	15.39

4. CONCLUSIONS

Generally, the rectangular design is economical for low flexural moment values as seen in the optimum results, but it must be noted that the optimum cost is only calculated by using h_f=0. In that case, the slab concrete cost is not taken in the consideration. Although the slab is not considered in case 1, the cost is more than other cases, if the required flexural moment is more than 250 kNm. The significant effect on the increase of the cost is because of the need for rebar in compressive section. According to the results, the thickness of the slab has no significant effect on the optimum cost, but the consideration of a T shaped design is important in optimization.

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