Optimum design of metal structures by Backtrack-programming

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VII

Optimum Design of Metal Structures by Backtrack Programming

Dimensionnement optimal de constructions métalliques au moyen de la méthode de programmation ,,backtrack''

Optimalbemessung von Metallkonstruktionen mittels der Backtrack-Programmierungsmethode

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SUMMARY

The backtrack method solves the nonlinear constrained function minimization problems by a systematical search procedure. This combinatorial discrete programming method can be successfully applied to optimization problems if the number of unknowns is not too large. In the optimum design of welded beams a substantial search reduction may be achieved. A simple numerical example shows that this method is also advantageous for educational purposes.

RESUME

La méthode ,,backtrack'' donne la solution des problèmes de minimisation de fonctions nonlinéaires conditionnelles par procédé de recherche systématique. Cette méthode combinatoire de la programmation discrète est bien applicable aux problèmes d'optimisation, si le nombre des inconnues n'est pas trop grand. Dans le cas de poutres soudées, il est possible de réduire considérablement les pas de la recherche. Un simple exemple numérique illustre les avantages que cette méthode offre pour l'enseignement.

ZUSAMMENFASSUNG

Die Backtrack-Methode löst die nichtlinearen bedingten Funktionsminimierungsprobleme mit Hilfe eines systematischen Suchverfahrens. Diese kombinatorische diskrete Programmierungsmethode ist auf Optimierungsprobleme gut anwendbar, wenn die Anzahl der Unbekannten nicht sehr gross ist. Im Falle von Schweissträgern kann man die Suchschritte wesentlich reduzieren. Ein einfaches Zahlenbeispiel zeigt, dass diese Methode auch für Unterrichtszwecke vorteilhaft ist.

1. THE BACKTRACK PROGRAMMING METHOD

The general exposition of backtrack was given among others by GOLOMB and BAUMERT [4]. This method was applied to welded girder design e.g. by ANNAMALAI, LEWIS and GOLDBERG [1]. SZABÓ [5] has used it for the minimum cost design of hybrid I-beams. The backtrack method solves the constrained function minimization problems by a systematical search procedure. A partial search is carried out for each variable and, if the possibilities are exhausted, then a backtrack and a new partial search is performed. In the optimum design of welded beams a substantial search reduction may be achieved by utilizing the fact that, in most cases, the cost function becomes maximum if the variables take their maximum values. Thus, the optimum solution can be found by decreasing the variables.

We should search for a vector of variables $\underline{x}$ $(x_1, x_2, \ldots, x_n)$ for which the cost function will be minimal: $C(\underline{x}) \rightarrow \min$ and which satisfies the design constraints: $g_j(\underline{x}) \geq 0$ $(j=1\ldots p)$. The series of discrete values of variables are determined by x_{imin}, x_{imax} and by the constant steps Δx_i between them. The flow diagram of backtrack for three variables is given in Fig.1. The main phases of the calculation are described as follows.

1/ With constant values of x_{2max} and x_{3max} the minimum x_{1m} value is searched which still satisfies the design constraints. For the sake of simplicity we use further on the notation $x_{1m}=x_1$. The search may be more efficient by using the interval halving procedure. First, x_{1min} value is proved. If x_{1min} dissatisfies the requirements, the interval $x_{1max}-x_{1min}$ is halved. For the halving method it should be $x_{imax}-x_{imin} = \Delta x_i \cdot 2^q$ where q is an integer.

2/ Similarly to the first phase, the minimum $x_{2m}=x_2$ value is determined by means of halving process, which satisfies the design constraints.

3/ In order to obtain the next x_3-value, we do not use the interval halving method. In general, x_3 may be easily expressed from the equation $C(x_1,x_2,x_3) = C_0$, so this will be the next x_3-value. Thus, for the series of x_3-values it is not necessary to prescribe the condition $x_{3max}-x_{3min} = \Delta x_3 \cdot 2^q$. Regarding the next x_3-value three cases may occur as follows.

3a/ If $x_3 > x_{3max}$, we take $x_3 = x_{3max}$ and decrease it step-by-step till x_{3m} which satisfies the constraints or till x_{3min}. Then the first partial search region is exhausted and we must backtrack to x_2. If $x_2 < x_{2max}$, we continue the calculation with $x_2 + \Delta x_2$; if $x_2 = x_{2max}$, we backtrack to x_1.

3b/ If $x_3 < x_{3min}$, we backtrack to x_1.

3c/ If $x_{3min} < x_3 < x_{3max}$ and x_3 dissatisfies the constraints, we backtrack to x_2. If the constraints are satisfied, we continue the calculation according to 3a.

The simplicity of the method enables us to apply it in the education as well. The following numerical example shows that the steps of the calculation can be easily followed by a pocket calculator.

2. NUMERICAL EXAMPLE

The cross section arear of a welded I-section subjected to bending and compression should be minimized. The objective function is

$$C = A = ht_w + 2A_f \tag{1}$$

$h = x_1$ web height, $t_w = x_2$ web thickness, $A_f = x_3$ area of a flange. The constraint of maximum stress (g_1) is

$$\sigma_M + \sigma_N \le R_u \tag{2}$$

where $\sigma_M = M/W_x$; the section modulus $W_x \cong h(A_f + ht_w/6)$ (3)

and $\sigma_N = N/A$ (4)

M and N are the factored bending moment and compressive force, respectively, R_u is the limit stress /ultimate resistance/.

The constraint of web buckling (g_2) for steels of tensile strength 370 MPa may be expressed as [3]

$$\frac{h}{t_w} \le 145 \sqrt[4]{\frac{(1 + \sigma_N/\sigma_M)^2}{1+173(\sigma_N/\sigma_M)^2}} \tag{5}$$

Take M = 320 kNm, N = 128 kN, R_u = 200 MPa. The lists of discrete values are as follows (cm, cm^2): h_{min} = 66; h_{max} = 74; Δh = 2; t_{wmin} =0,5; t_{wmax}=0,9; Δt_w=0,1; A_{fmin} =14; A_{fmax} =22; ΔA_f=1. Thus, the total number of combinations is 5.5.9 = 225. The steps of the calculations are shown in Table 1. It can be seen that the backtrack method requires only 37 tests to obtain the following optimal values: h = 70 cm; t_w = 0,6 cm; A_f = 18 cm^2.

Note that a significant search reduction can be achieved by using first a coarse scale of discrete values (larger Δx_i) and then continuing with smaller Δx_i values in a smaller region near the optimum found in first phase.

3. APPLICATIONS

We have carried out calculations with a Fortran program of backtrack method for the following optimization problems.

1/ Optimum design of compressed columns of constant welded square box cross section by using the author's calculation method published in [2] (2 unknowns).

2/ Minimization of cross section area of welded I-sections subjected to bending and compression (4 unknowns). The application of these suboptimized I-sections to the elastic minimum weight design of frames was demonstrated by a numerical example in [3]. This numerical example was calculated as a problem with 8 unknowns as well.

3/ Minimum cost design of welded homogeneous and hybrid I-beams, simply supported and uniformly loaded (4 unknowns). In the objective function the costs of materials, welding and painting were taken into account. The lowering of flange thickness with a welded splice was also considered [3], [5].

REFERENCES

1. ANNAMALAI,N.,LEWIS,A.D.M.,GOLDBERG,J.E.: Cost optimization of welded plate girders.- J.Struct.Div.Proc.ASCE 98 (1972) No.ST10, p.2235-2246

2. FARKAS,J.: Optimum design of compressed columns of constant welded square box cross section... Acta Techn.Hung. 84(1977) No.3-4. p.335-348

3. FARKAS,J.,SZABÓ.L.: Optimum design of beams and frames of welded I-section by means of backtrack programming.- Acta Techn.Hung. 91 (1981) (to be published)

4. GOLOMB,S.W.,BAUMERT,L.D.: Backtrack programming.- J.Assoc.Comput. Machinery 12 (1965) p.516-524

5. SZABÓ,L.: Optimum design of hybrid I-beams. Ph.D.Dissertation (in Hungarian). Techn.Univ. Miskolc, 1978

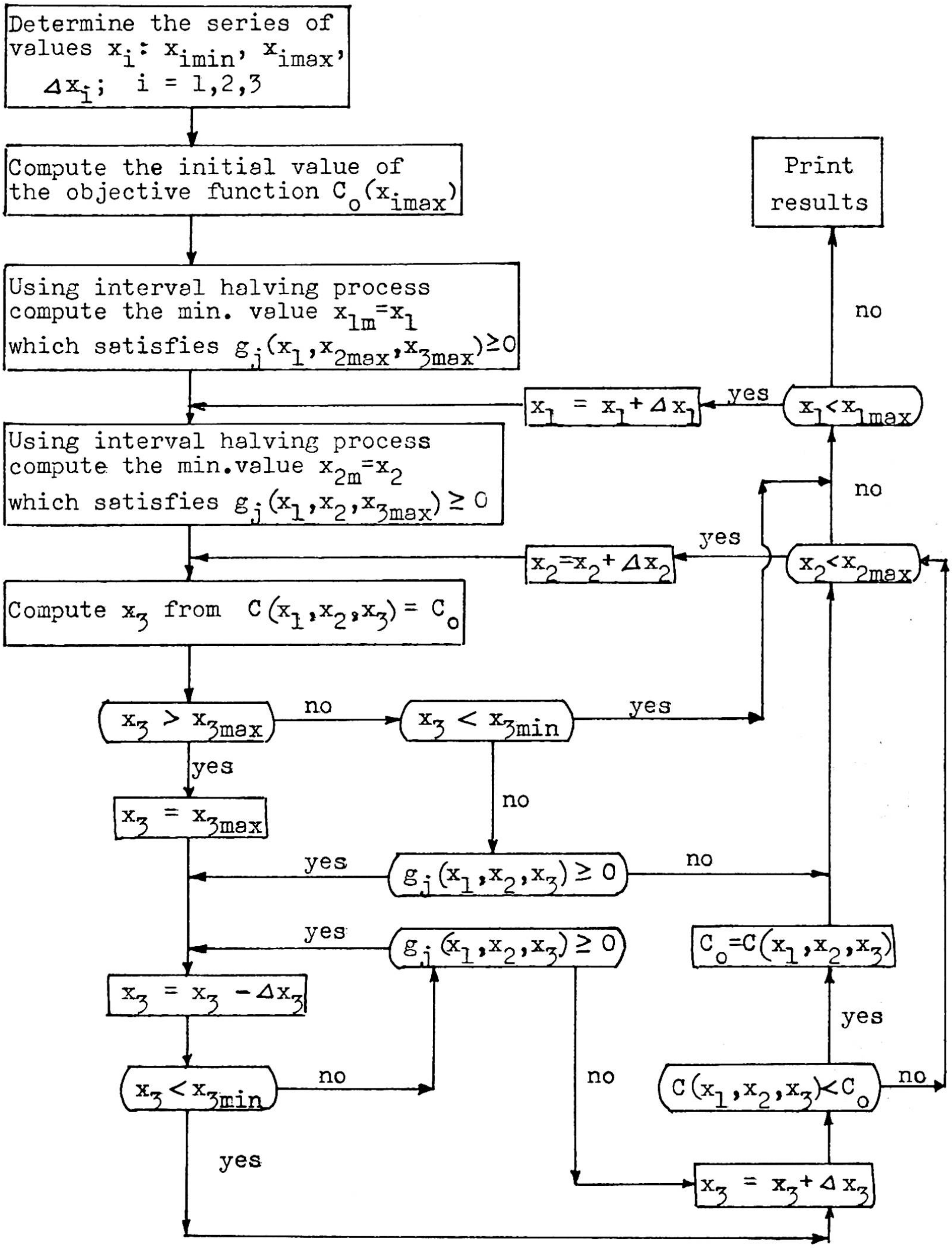

Fig.1 Flow chart for the backtrack programming

Table 1. Numerical example illustrating the steps of backtrack method in the case of three unknowns. Notation: + satisfies, – dissatisfies

x_1 (cm)	x_2 (cm)	x_3 (cm^2)	C (cm^2)	g_1 Eq. (2)	g_2 Eq. (5)	Comments
74	0,9	22	110,6	+	+	C_o = 110,6 cm^2
66	0,9	22	103,4	+	+	x_{1min} satisfies, it is not necessary to use the halving process for x_1, only for x_2
66	0,5	22	77,0	+	–	
66	0,7	22	90,2	+	+	
66	0,6	22	83,6	+	+	
66	0,6	22	83,6	+	+	x_3=(110,6-66.0,6)/2=35,5 > > x_{3max}; C_o = 79,6
66	0,6	21	81,6	+	+	
66	0,6	20	79,6	+	+	
66	0,6	19	77,6	–	+	backtrack with x_2
66	0,7	16	78,2	–	+	x_3=(79,6-66.0,7)/2 = 16,7
66	0,8	13				$x_3 < x_{3min}$, backtrack with x_1
68	0,9	22	105,2	+	+	halving process for x_2
68	0,5	22	78,0	+	–	
68	0,7	22	91,6	+	+	
68	0,6	22	84,8	+	+	
68	0,6	19	78,8	+	+	x_3=(79,6-68.0,6)/2 = 19,4
68	0,6	18	76,8	–	+	C_o = 78,8; backtrack with x_2
68	0,7	15	77,6	–	+	x_3=(78,8-68.0,7)/2 = 15,6
68	0,8	12				$x_3 < x_{3min}$, backtrack with x_1
70	0,9	22	107,0	+	+	halving process for x_2
70	0,5	22	79,0	+	–	
70	0,7	22	93,0	+	+	
70	0,6	22	86,0	+	+	
70	0,6	18	78,0	+	+	x_3=(78,8-70.0,6)/2 = 18,4
70	0,6	17	76,0	–	+	C_o = 78,0; backtrack with x_2
70	0,7	14	77,0	–	+	x_3=(78,0-70.0,7)/2 = 14,5
70	0,8	11				$x_3 < x_{3min}$, backtrack with x_1
72	0,9	22	108,8	+	+	halving process for x_2
72	0,5	22	80,0	+	–	
72	0,7	22	94,4	+	+	
72	0,6	22	87,2	+	–	
72	0,7	13				x_3=(78,0-72.0,7)/2 = 13,8< <x_{3min}, backtrack with x_1
74	0,9	22	110,6	+	+	halving process for x_2
74	0,5	22	81,0	+	–	
74	0,7	22	95,8	+	+	
74	0,6	22	88,4	+	–	
74	0,7	13				x_3= (78,0-74.0,7)/2=13,1<x_{3min} x_1=x_{1max}; results: C_{omin}=78,0 x_1= 70; x_2= 0,6; x_3= 18