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OPTIMIZATION OF BUILDING STRUCTURES

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Abstract. In the field of the theory of calculation of building structures, there is a constant refinement of the actual operation of these structures, i.e. design schemes are created that most accurately correspond to actual operating conditions. Creating optimal structures is a very urgent task facing designers. Therefore, it is quite natural to try to solve this problem using mathematical programming methods, which involve: selecting dependent and independent variables, constructing mathematical models and establishing criteria for the effectiveness of the selected model. In this case, the model should be a function that fairly accurately describes the research being carried out using mathematical apparatus (various types of functions, equations, systems of equations and inequalities, etc.). In mathematical programming, any set of independent (controlled) variables is called a solution. Optimal solutions are those that, for one reason or another, are preferable to others. The preference (effectiveness) of the study is quantified by the numerical value of the objective function. “Solution Search” is an add-in for Microsoft Excel that is used to solve optimization problems. Simply put, with the Solver add-in, you can determine the maximum or minimum value of one cell by changing other cells. Most often, this add-in is used to find optimal solutions to problems economically. There are not enough results of using this approach for calculating building structures in the public domain. Therefore, it is quite logical to try to use this add-on in problems of optimization of building structures. In this work, an attempt was made to use mathematical programming methods and this add-on to optimize the geometric dimensions of the structure, when the numerical value of the bending moment in a specific section was chosen as an optimization criterion.

Keywords: calculation scheme, line of influence, search for solutions.

ОПТИМІЗАЦІЯ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ

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Анотація. У теорії розрахунку будівельних конструкцій відбувається постійне уточнення фактичної роботи цих конструкцій, тобто створюються такі розрахункові схеми, які найточніше відповідають реальним умовам експлуатації. Створення оптимальних конструкцій є дуже актуальним завданням перед конструкторами. Тому цілком закономірно спробувати вирішити це завдання методами математичного програмування, які передбачають: вибір залежних і незалежних змінних, побудова математичних моделей та встановлення критеріїв ефективності обраної моделі. У цьому випадку модель повинна являти собою функцію, що досить точно описується проведені дослідження з використанням математичного апарату (різного роду функцій, рівнянь, систем рівнянь і нерівностей і т. д.). У математичному програмуванні будь-який набір незалежних (керованих) змінних називається рішенням. Оптимальними рішеннями вважаються ті, які з тих чи інших причин краще інших. Перевага (ефективність) дослідження кількісно оцінюється величиною чисельного значення цільової функції. "Пошук рішення" - надбудова для Microsoft Excel, яка використовується для вирішення задач оптимізації. За допомогою надбудови "Пошук рішення" можна визначити максимальне або мінімальне значення одного осередку, змінюючи інші осередки. Найчастіше ця надбудова використовується для пошуку оптимальних розв'язків задач економічно. У відкритому доступі недостатньо результатів використання цього підходу до розрахунку будівельних конструкцій.

Тому цілком логічно спробувати використати цю надбудову в задачах оптимізації будівельних конструкцій. У цій роботі зроблено спробу використовувати методи математичного програмування і цю надбудову для оптимізації геометричних розмірів конструкції, коли критерієм оптимізації було обрано чисельне значення згинального моменту в конкретному перерізі.

Ключові слова: розрахункова схема, лінія впливу, пошук рішень.

1 INTRODUCTION

In the field of the theory of calculation of building structures, there is a constant refinement of the actual operation of these structures, i.e. design schemes are created that most accurately correspond to actual operating conditions. Creating optimal structures is a very urgent task facing designers. Therefore, it is quite natural to try to solve this problem using mathematical programming methods, which involve: selecting dependent and independent variables, constructing mathematical models and establishing criteria for the effectiveness of the selected model. In this case, the model should be a function that fairly accurately describes the research being carried out using mathematical apparatus (various types of functions, equations, systems of equations and inequalities, etc.). Drawing up a mathematical research model requires the researcher to have a deep understanding of the essence of the phenomenon being described and knowledge of the mathematical apparatus [1].

Among the existing models, first of all, a large class of optimization models should be noted. In this case, the optimization problem can be formulated as follows: find values of the controlled variables that satisfy the system of inequalities (constraints) and turn the objective function into a maximum (or minimum). If the objective function is linear, and the variables in the constraint system are also linear, then such a problem is a linear programming problem. Of all the known methods of mathematical programming, the most widespread and developed is linear programming [2, 3].In addition, nonlinear objective functions can be successfully used.

Solver is a Microsoft Excel add-in that can be used to solve optimization problems. Simply put, with this add-in you can determine the maximum or minimum value in one of the cells by changing the numerical values of other cells. Most often, this add-on is used to optimize economic problems. There are not enough results of using this approach for calculating building structures in the public domain. Therefore, it is quite logical to try to use this add-on in problems of optimization of building structures. In this work, an attempt was made to use mathematical programming methods and this add-on to optimize the geometric dimensions of the structure, when the numerical value of the bending moment in a specific section was chosen as an optimization criterion.

2 ANALYSIS OF PUBLICATIONS

In the open access, there are not enough results of using mathematical programming at individual stages of calculations for strength, rigidity and stability. Therefore, it is quite logical to try to use the “Search for Solutions” add-on in the problems of optimizing the calculations of building structures. [4, 5, 6, 7].

3 MATERIALS AND METHODS

This article attempts to show the feasibility of using the methods of mathematical programming and the "Search for Solutions" add-on at the stage of choosing the optimal parameters of the design scheme of a structure.

4 RESEARCH RESULTS

Based on the results obtained in [6], we will show how else it is possible to optimize the main geometric parameters of the design scheme. In contrast to the previously considered problem [7], the geometric dimensions are set by the controlled variables l_1, ..., l_6:

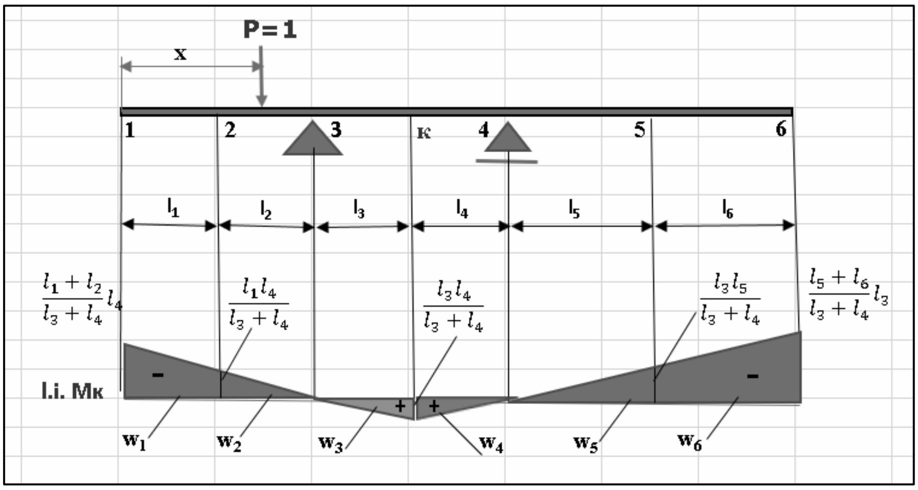


Fig. 1. Calculation scheme and the line of influence of the bending moment

To illustrate the idea of the proposed approach, a simple statically determinate beam on two supports was deliberately chosen (Fig. 1). This is done so that the idea of the proposed approach is not lost due to the complexity and cumbersomeness of the calculations.

From the proposed loading options, we choose, for example, the one that corresponds to the smallest bending moment in the “k” section [6]:

q1	q2	q3	q4	q5	P1	P2	P3	P4
30	20	0	0	30	100	50	150	0

Fig. 2. Numerical values of the external load corresponding to $M_{k\ min}$

In the course of structural mechanics, a formula is known for determining the numerical value of the generalized internal force factor F along the corresponding line of influence [8, 9, 10]:

$$F = \sum q_i w_i + \sum P_i y_i + \sum M_i \tan \alpha_i \qquad (1)$$

In our case, formula (1) will look like:

$$M_k = q_1(w_1 + w_2 + w_3 + w_4 + w_5 + w_6) + q_2(w_1 + w_2) +$$

$$+q_5 w_5 + P_1 y_1 + P_2 y_2 + P_3 y_3 \qquad (2)$$

Let us determine the areas of the corresponding sections and the ordinates of the line of influence:

$$w_1 = -\frac{1}{2} \cdot \left(\frac{(l_1 + l_2)}{(l_3 + l_4)} \cdot l_4 + \frac{l_1 \cdot l_4}{(l_3 + l_4)}\right) \cdot l_1 \qquad w_2 = -\frac{1}{2} \cdot \frac{l_1 \cdot l_4 \cdot l_2}{(l_3 + l_4)}$$

$$w_3 = \frac{1}{2} \cdot \frac{l_3 \cdot l_4 \cdot l_3}{(l_3 + l_4)} \qquad w_4 = \frac{1}{2} \cdot \frac{l_3 \cdot l_4 \cdot l_4}{(l_3 + l_4)}$$

$$w_5 = -\frac{1}{2} \cdot \frac{l_3 \cdot l_5 \cdot l_5}{(l_3 + l_4)} \qquad w_6 = -\frac{1}{2} \cdot \left(\frac{l_3 \cdot l_5}{(l_3 + l_4)} + \frac{(l_5 + l_6) \cdot l_3}{(l_3 + l_4)}\right) \cdot l_6$$

$$y_1 = -\frac{l_3 \cdot l_5}{(l_3 + l_4)} \qquad y_2 = -\frac{l_1 \cdot l_4}{(l_3 + l_4)} \qquad y_3 = \frac{l_3 \cdot l_4}{(l_3 + l_4)}$$

In further calculations, we will assume that the bending moment is positive if it stretches the lower fibers.

Now let's introduce restrictions on the controlled variables l_1, ,…., l_6. Constraints define the conditions that these variables must satisfy. The type of restrictions is determined by the conditions of a particular task and the goal to be achieved.

Let us introduce, for example, the following restrictions:

$$\begin{cases} l_1, \dots, l_6 \geq 1 \\ l_1 + \dots + l_6 = 7 \\ l_3 = l_4 \end{cases}$$

In this case, the solution search parameters table will have the form shown in Fig. 3.

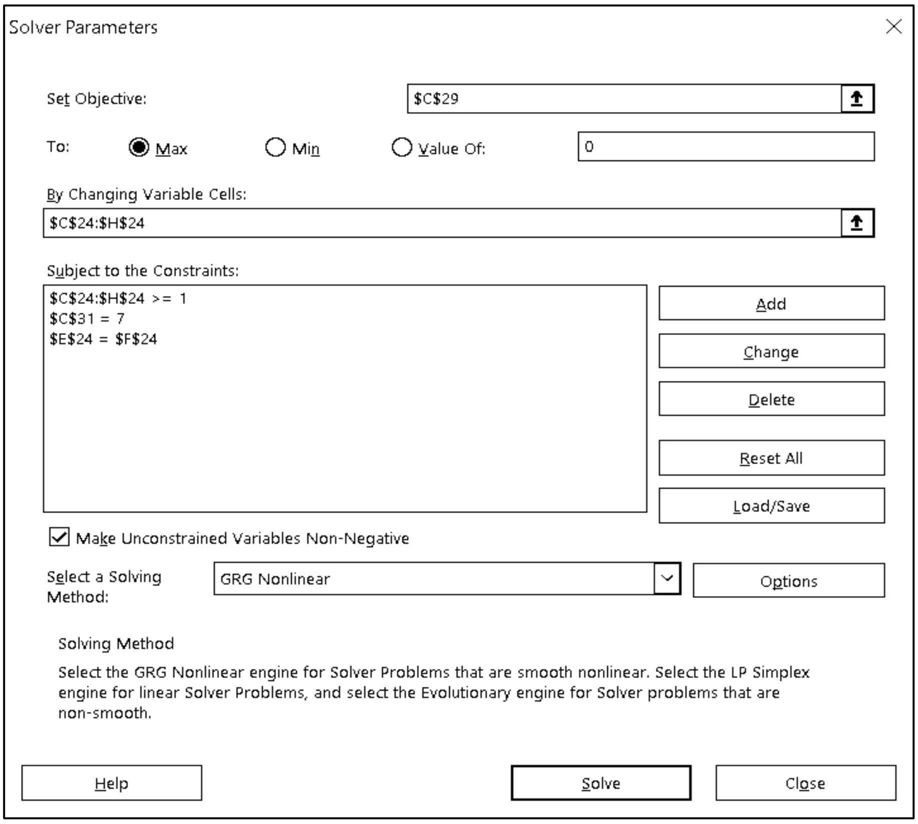
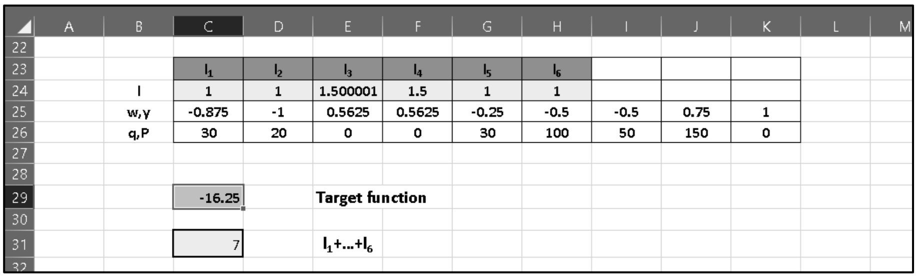


Fig. 3. Solution search parameters

The calculation results are shown in Fig. 4:



	B	C	D	E	F	G	H	I	J	K
23		l_1	l_2	l_3	l_4	l_5	l_6			
24	l	1	1	1.500001	1.5	1	1			
25	w,y	-0.875	-1	0.5625	0.5625	-0.25	-0.5	-0.5	0.75	1
26	q,P	30	20	0	0	30	100	50	150	0
29		-16.25		Target function						
31		7		$l_1+\dots+l_6$						

Fig. 4. Numerical values of controlled variables and objective function

The value of the objective function corresponds to the value of the maximum bending moment in the section "k" (Mk = -16.25 kNm). Since the value is negative, the top fibers of the cross section will be stretched. If the results of the calculation are presented graphically, then we obtain the calculation scheme shown in Fig. 5.

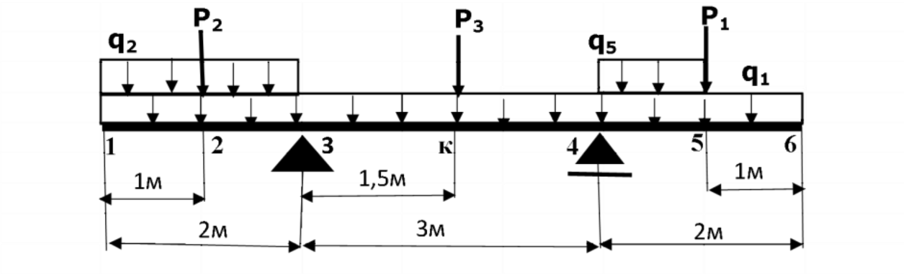


Fig. 5. Calculation scheme corresponding to $M_{k,max}$

Similarly, the geometric parameters of the design scheme are determined, at which the bending moment in the section "k" will be minimal (Fig. 6).

	A	B	C	D	E	F	G	H	I	J	K	L	M
22													
23			l_1	l_2	l_3	l_4	l_5	l_6					
24		l	1.999999	1	1.000001	1	1	1					
25		w,y	-3.5	-3	0.25	0.25	-0.25	-0.5	-1	0.5	1		
26		q,P	30	20	0	0	30	100	50	150	0		
27													
28													
29			-197.5		Target function								
30													
31			7		$l_1+…+l_6$								

Fig. 6. Numerical values of controlled variables and objective function

If the results of the calculation are presented graphically, then we obtain the calculation scheme shown in Fig. 7.

The obtained value differs from $M_{k,min}$ in [6] because the controlled parameters li provide more details of the calculation scheme than the parameters a, b, c.

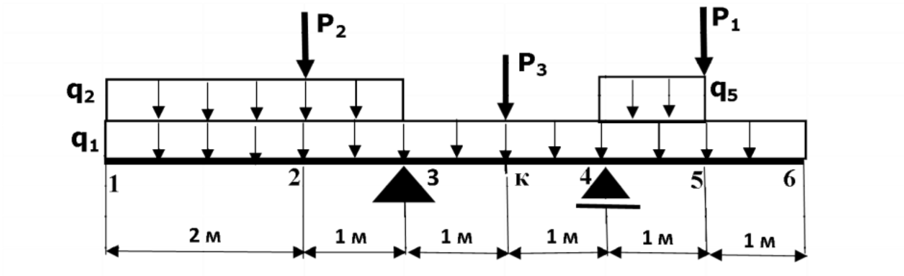


Fig.7. Calculation scheme corresponding to $M_{k,min}$

If restrictions are added to the solution search parameters table

$$\begin{cases} (l_5 + l_6) \geq (l_1 + l_2) \\ l_1 = l_2 \\ l_5 = l_6 \end{cases},$$

then we obtain the same result as in [7].

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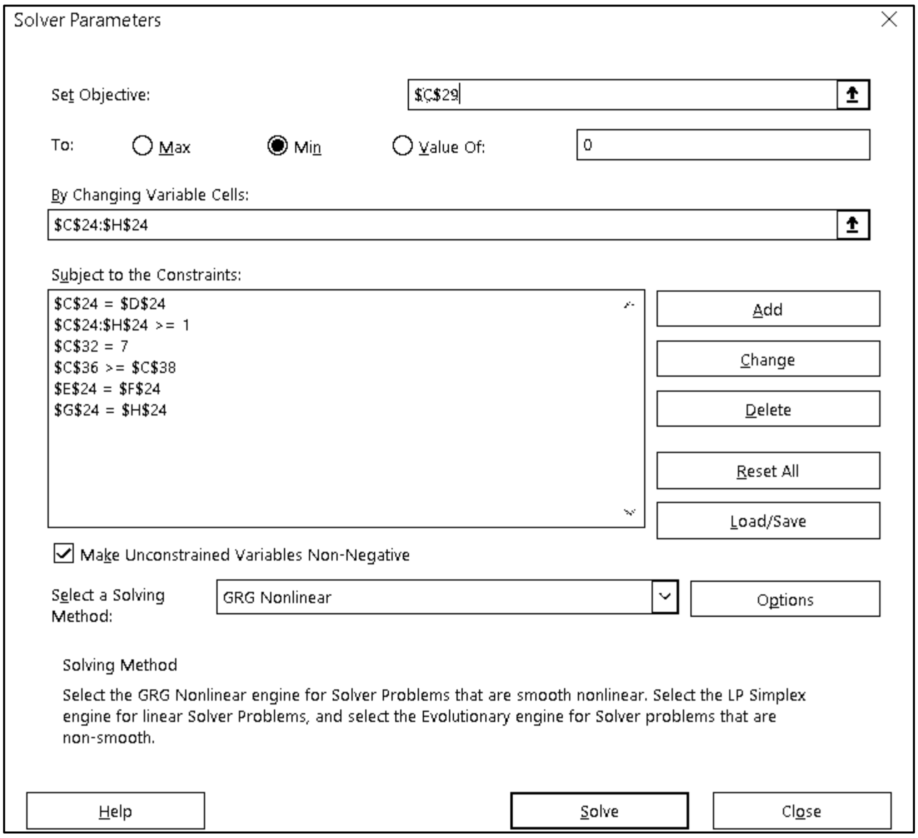
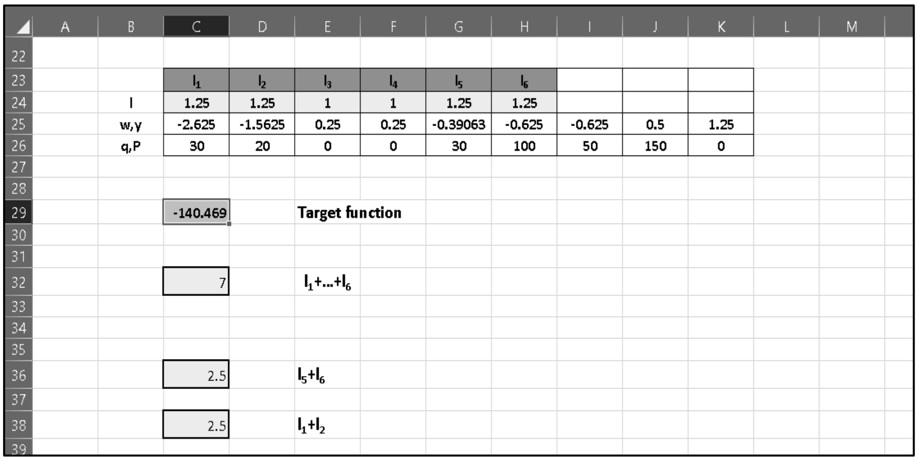


Fig. 8. Solution search parameters



	A	B	C	D	E	F	G	H	I	J	K
23			l_1	l_2	l_3	l_4	l_5	l_6			
24		l	1.25	1.25	1	1	1.25	1.25			
25		w,y	-2.625	-1.5625	0.25	0.25	-0.39063	-0.625	-0.625	0.5	1.25
26		q,P	30	20	0	0	30	100	50	150	0
29			-140.469		Target function						
32			7		$l_1+...+l_6$						
36			2.5		l_5+l_6						
38			2.5		l_1+l_2						

Fig. 9. Numerical values of controlled variables and objective function

5 CONCLUSIONS

Thus, this article shows:

- the possibility and expediency of using the "search for solutions" at the stage of choosing the optimal parameters of the design scheme of the structure;

- sensitivity of calculation results to restrictions on controlled variables.

After the design scheme is defined, for its complete calculation, more powerful conventional means of calculating building structures can be involved.

6 GRATITUDES

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7 ETHICAL DECLARATIONS

The authors have no relevant financial or non-financial interests to report.

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