

OPTIMIZATION OF THE FORMWORK RENTAL COST USING THE NIF METHOD TAKING INTO ACCOUNT THE VARIATION OF THE CROSS-SECTION OF THE MONOLITHIC ELEMENT

Daniel PRZYWARA

Opole University of Technology, Faculty of Civil Engineering and Architecture; d.przywara@po.edu.pl,
ORCID: 0000-0002-1722-6140

Purpose: The aim of the work is to determine the optimal value of the cost of renting formwork for monolithic works, assuming a variable cross-section of the formwork elements.

Design/methodology/approach: The article attempts to analyze the optimization costs of leasing system formworks using the author's research method NIF (no idle formwork).

It is an extension of the classic parallel-stream methods - with continuous use of production means (no idle) and with uninterrupted work on the work front (no wait).

For the purposes of empirical research, selected structural elements of a sports hall building with a monolithic "foot-column" structure were used.

Findings: The implementation of the proposed NIF method proved that it allows for the selection of the numerical composition of the work team and the division of the work front into elementary plots, finding the optimal team work plan and implementation scenario in the set of admissible solutions, limited by the implementation deadline or cost budget.

Research limitations/implications: The essence of calculating the rental of system forms is to determine the required time of their stay on the work front, during assembly, technological standstill (the process of binding the concrete mix) and dismantling. The calculation of the costs of traditional forms, apart from the time of their assembly and dismantling, during which the costs of human work (labour) are incurred, treats the above principle in a different way: wood formwork material, purchased as a non-renewable resource, is treated in it at the purchase price - with standard recovery, and not at the cost of labour.

Practical implications: Construction formwork for monolithic works, due to its technological specificity, is divided into traditional – made of sawn wood, and system – supplied in the form of unified elements.

Social implications: System formwork forms for monolithic works, as their price-determining component, are cost-intensive equipment units, hence the appropriate selection of their quantity and determination of the lease period on the construction site is a very important issue, affecting the profitability of these works.

Originality/value: The innovative element of the work is the use of the proprietary NIF method, which determines the optimal level of construction formwork lease costs.

Keywords: formwork, cost optimization, schedule coupling.

Category of the paper: Research paper.

1. Introduction

Resource allocation management is one of the main planning problems (Przywara, 2022, 2025). Modeling involves modeling resources that, as a result of a detailed analysis, can be used to carry out the works covered by the schedule.

The issue of time and cost optimization of the rental of system formwork on the construction site was addressed mainly in relation to the search for methods to shorten the duration of works, which also results in a reduction of costs. The paper (Biruk, Jaśkowski, 2017) presents factors influencing the selection of various formwork systems for the construction of high-rise buildings, of which a total of forty were identified.

The analysis revealed that the main ones include the duration of the project, rental costs and the layout of the structure. The research was based on regression analysis to quantify the impact of factors on work efficiency. To determine the interdependencies between the studied factors, the Spearman correlation test was performed, which was intended to identify the independent variable having a significant influence on the selection of the formwork system.

Heuristics are also a popular tool in optimizing the time and cost of formwork. In the work (Kaveh, Behnam, 2012) heuristic algorithms were used for cost optimization in the implementation of ceiling systems, including their formwork. In order to optimally select the formwork, floor slabs with variable thicknesses and spans were considered. The proposed method has been described on three levels. The first is initialization, where elements are randomly selected for analysis. The second step is to search for the optimum that minimizes costs and provides a solution to the problem. The third level is the termination stage. The algorithm checks whether the criteria set by the operator meet the obtained results.

In the paper (Lee et al., 2014), the selection of formwork systems was analyzed by developing criteria for assessing their applicability by decision-makers implementing construction projects in Turkey, at various planning stages. The research results indicate a high level of agreement among participants in investment processes regarding the selection of a system based on criteria such as the degree of repeatability, speed of implementation, rental cost, and the possibility of reuse in subsequent projects. The paper draws attention to the continuous increase in formwork rental costs. A model of formwork arrangement using a genetic algorithm was presented in order to minimize the rental time and obtain the cost level as a solution close to the optimal one. The proposed model searches for the optimal formwork layout to maximize the proportions of modular forms by adopting twelve types of solutions for which positions and sizes are variable. The layout of the formwork forms and the positioning of the columns are determined according to the gene sequences. Based on the case study, the model showed a decrease in the share of formwork covering the surface by approximately 11.9%, while the cost of formwork rental decreased by 10.4%. This concept can also be used at the work planning stage to increase the efficiency of work teams.

Genetic algorithms were also the subject of the analysis of formwork rental costs in (Bhingarde, Bhusari, 2021), where their use was presented to determine the optimal solution for the design of ceiling and beam formwork while maintaining the minimum cost. In this case, the algorithm is activated after determining the gene structure and fitness function, and the gene population is subjected to evolutionary optimization. The first stage is the selection phase, where individuals are selected and reunited to produce new offspring. The aim of the selection is to provide the best adapted solutions. One-point and two-point crossover were used. Then, the normalized efficiency value of the obtained solution was calculated. During each iteration, the adopted reproduction operators determined the means to generate new, better solutions. In addition to crossover, mutation was also used, which is a method of introducing new variables into the gene pool.

The paper (Tierzoglu, Polat, Turkoglu, 2022) presents the results of research on the influence of the choice of formwork system on the time, cost and quality of monolithic works. The research drew attention to the contradiction of some criteria (e.g. time-cost), and the aim was to identify their different groups and analyze the relationships between them. The conclusion was drawn that many previous works ignored the quantitative interdependencies between the identified groups, which had a significant impact on the efficiency of works.

In the publication (Al-Ashwal, Abdullah, Zakaria, 2017), the authors analyzed the durability of traditional formwork and the possibility of its repeated use. Attention was drawn to the economic value of this solution and its simultaneous negative impact on the natural environment. The use of conventional formwork systems in carpentry work has been assessed as incompatible with sustainable economic development, encompassing not only economic but also social and environmental issues.

In the work (Ko, Kuo, 2012) it was indicated that formwork engineering is a key factor influencing the time-cost result of monolithic works. The research was conducted using the Kanban system (Lean Manufacturing method), and the optimization consisted in minimizing the costs of transporting formwork to the work front while simultaneously increasing the degree of their multiple use, through the repeatability of assembled forms.

The work (Baskova, Krajnak, 2013) concerns the influence of the factor of formwork lease time on its costs. The authors showed that the costs of construction formwork in Slovakia constitute 25–30% of the total costs of works, depending on regional differences in the prices of labor and materials. The proposed cost optimization consists in analyzing the number of working plots in the formwork of elements, with gradual shifting of formwork. The method focuses on minimizing the number of individual types of forms.

In (Li et al., 2022) a technique based on genetic algorithms for determining the optimal solution for the formwork design was presented. The formulated objective function takes into account the rental cost of formwork and estimated labour corresponding to the assembly of the forms. The principles of structural design of reinforced concrete elements were adopted as

constraints for the optimization problem. The developed method can be used to design ceiling formwork and high concrete elements.

Time Coupling Methods (TCM), which are sometimes referred to as Linear Scheduling Methods (LSM), were developed by Professor Viktor A. Afanasyev (Afanasyev, 2000, 2008). Using them, he analyzed the schedules of work implementation, assuming the division of the front into work plots of different sizes and the resulting different times of their implementation. Professor Afanasyev scientifically described the LSM (TCM) methodology, providing a workshop of their research tools. The most commonly used parallel-stream methods include: the method with continuous use of production means (no idle) and the method with continuous work on work fronts (no wait) (Hejducki, Mrozowicz, 1994; Przywara, Rak, Chyliński, 2015). The method with continuous use of production resources (no idle) combines subsequent works of one type, determining the degree of their continuity within each type of work (or the degree of continuity of resource use) – resources perform work without unnecessary interruptions. This method assumes zero coupling between the means of production:

$$T = \sum_{j=2}^m t_{rj} + \sum_{i=1}^n t_{im} \quad (1)$$

where:

t_{rj} – time interval between the start of the predecessor and the successor (assuming critical proximity, eliminating overlap of the work of the brigades) [r-h],

t_{im} – duration of the m-th type of work on the i-th construction work front [r-h].

The value of t_{rj} can be expressed by the formula [4]:

$$t_{rj} = \max_k \left(\sum_{i=1}^k t_{i,j-1} - \sum_{i=1}^{k-1} t_{ij} \right) \quad (2)$$

with: $k = 1, 2, \dots, n$, $t_{0j} = 0$.

Changing the order of carrying out works on individual fronts does not affect the change in the duration of the last (mth) type of works, hence:

$$\sum_{i=1}^n t_{im} = \text{const} \quad (3)$$

Therefore, achieving the minimum development time of each type of work is achieved by reducing the development periods of the second and subsequent types of work:

$$T^{\min} = \sum_{j=2}^m t_{rj(\min)} + \sum_{i=1}^n t_{im} \quad (4)$$

In turn, the method with continuous work on work fronts (no wait) combines subsequent works of different types, within each partial complex, defining the degree of continuity of occupation of partial fronts - there are zero couplings between work fronts. In this method, individual tasks are performed without breaks (Hejducki, Mrozowicz, 1994):

$$T = \sum_{j=1}^m t_{1j} + \sum_{i=2}^n t_{zi} \quad (5)$$

where:

t_{1j} – duration of the first partial set of works in the facility [r-h],

t_{zi} – time interval between the completion of the predecessor and successor on plot [r-h].

The value of t_{zi} can be expressed as:

$$t_{zi} = \max_k \left(\sum_{j=k}^m t_{ij} - \sum_{j=k+1}^m t_{i-1,j} \right) \quad (6)$$

with: $k = 1, 2, \dots, m$.

The minimum duration of a set of works is obtained after determining the order in which they are to be carried out, in which the sum of the completion times of the first set and the winding times of the remaining ones is the smallest. The middle block of partial complexes has no influence on the time of completion of the complex of works (the complexes overlap each other). The classical methods of organizing construction projects described above and their popular extensions show a wide spectrum of planning possibilities in the design of various implementation solutions for production systems. In the search for optimization solutions that minimize the time spent by equipment units on the construction site, the most effective results are provided by the parallel-stream method no idle. In special cases, such as excess resources, it may, however, ignore the influence of the degree of occupation of work fronts.

2. The proprietary approach method (NIF) in optimizing the cost of formwork lease

2.1. Model of streamlined execution of works assuming parallel-stream method with continuous use of formwork (no idle formwork)

The proposed method essentially assumes the absence of organizational downtime in the formwork operation, classifying the cost-effectiveness of the process implementation by searching for the optimal division of its working front into plots (Figure 1).

Time values are expressed in machine hours [m-h], because they refer to the work of formworks as construction equipment, and not to work crews [r-g], the lack of downtime of which is assumed by the no idle method.

The implementation cycle of the analyzed j -th construction process in all its working plots ($i = 1, 2, \dots, n$), taking into account the working operations that create it ($k = 1, 2, \dots, p$) in the NIF method is calculated from the relationship:

$$T_{nj}^{PW(NIF)} = \sum_{i=1}^{n-1} \sum_{k=1}^p t_{ik} + t_{nj} \quad (7)$$

where:

t_{ik} – duration of the k -th work operation on the i -th work plot in the formwork operation,

t_n – duration of works on the last (n) working plot, for all work operations.

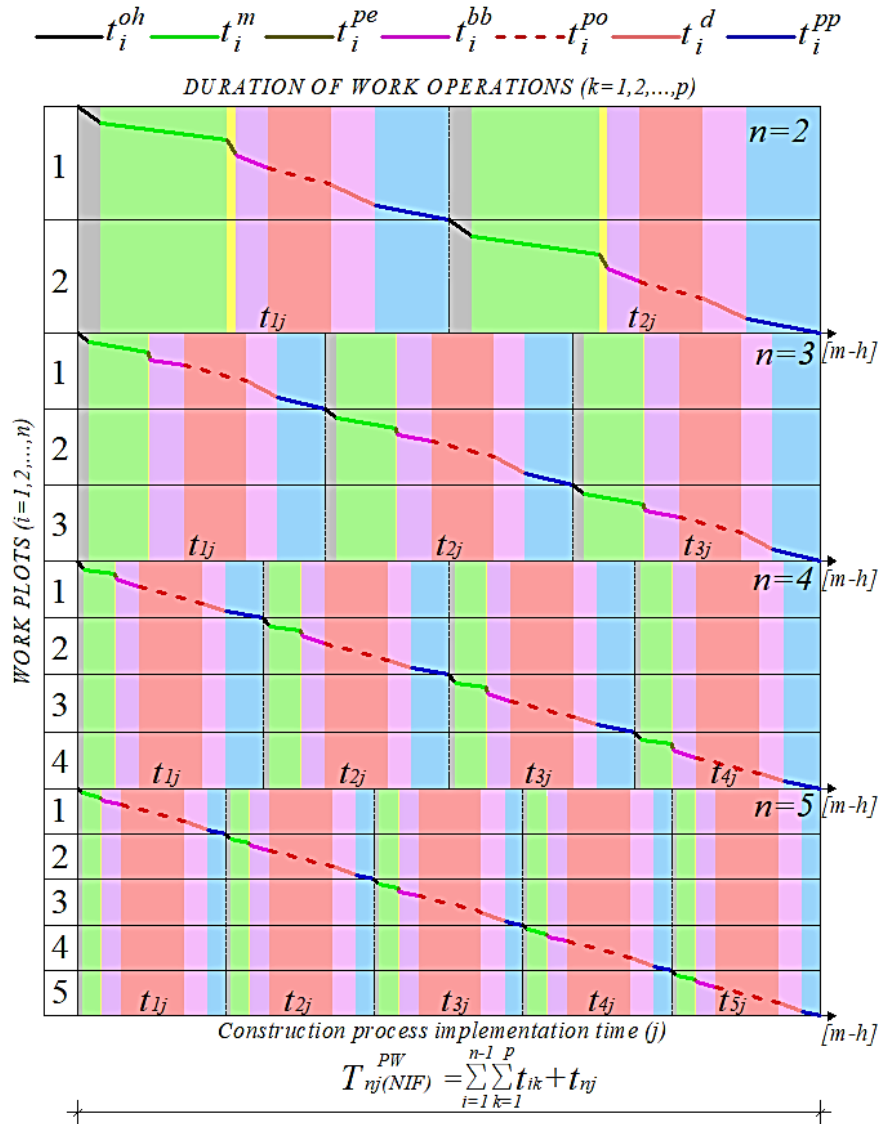


Figure 1. Generalized cyclogram of work operations ($p = 7$) of the construction process ($j = 1$) in the parallel-flow method with continuous use of formwork (no idle formwork) in four scenarios of division into working plots ($i = 2, 3, 4, 5$).

Source: Own study.

The value of t_{ik} can be expressed by the formula (with: $v = 1, 2, \dots, n$, $t_{0i} = 0$):

$$t_{ik} = \min_v (t_{C(j)}^{(sp)} + t_{B(j)}^{(sp)}) = \min_v \sum_{i=1}^n (t_i^{oh} + t_i^m + t_i^d + t_i^{pp}) + n * p_{ij}^d \quad (8)$$

The technological downtime of formwork (p_{ij}^d) is a value independent of the number of working sections, but correlates with the number of repetitions (waiting for concreting: t_{ij}^{pe} , concreting of the element: t_{ij}^{bb} , binding of the mixture (technological downtime of formwork: t_{ij}^{po}).

In the case of the NIF method, the duration of works on the last (n) working plot, related to all its working operations, is a constant value, being the last "link" of the implementation flow:

$$\sum_{k=1}^p t_{nj} = \text{const} \quad (9)$$

Determination of the minimum development time of work operations on each work plot (except the last one) is achieved by minimizing them on the first and subsequent ones:

$$T_{(NIF)}^{min} = \sum_{i=1}^{n-1} \sum_{k=1}^p t_{ik}^{min} + t_{nj} \quad (10)$$

2.2. Description of the research model

In the implementation of the proposed NIF method, a research model was used in the form of a structural system consisting of eight reinforced concrete monolithic columns with variable cross-section (elements S-2/S-2'/S-2'' – figure 2-3). The construction project of a school sports hall was carried out with the author's participation in 2009 in Przystajń (Silesian Voivodeship, Poland).



Figure 2. Research model: reinforced concrete columns S-2/S-2'/S-2''.

Source: author's photographs.

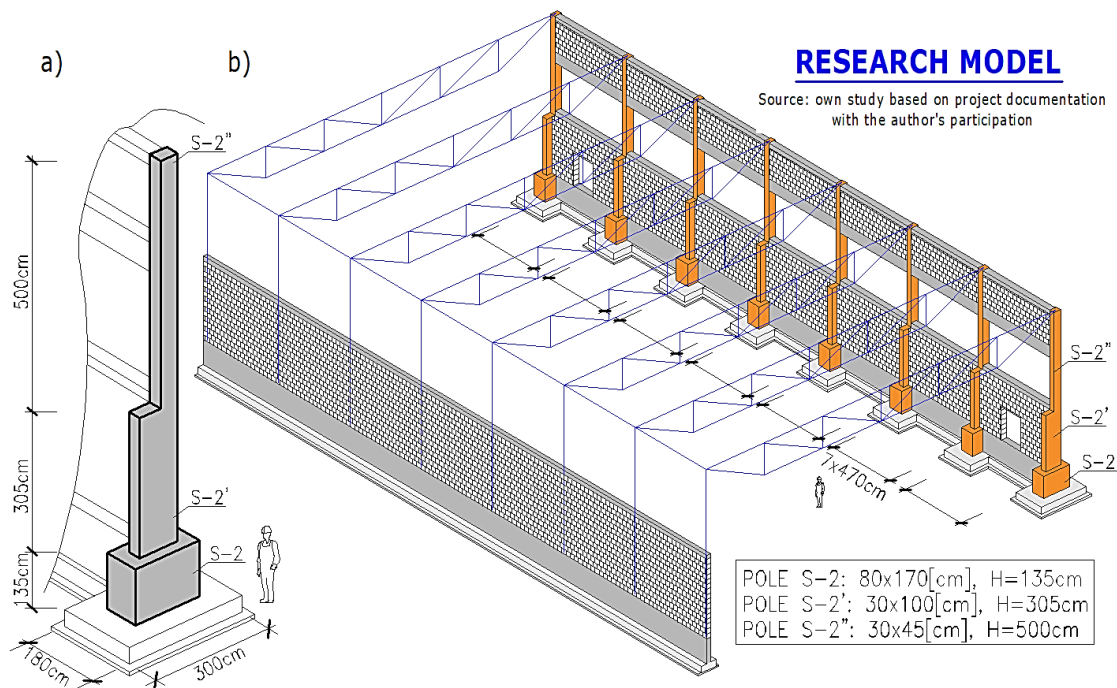


Figure 3. Research model for analysis: structural system of the sports hall: a) dimensions of the analyzed elements, b) axonometric view of the object (Przystajń/Kłobuck district/Silesian Voivodeship/Poland, description in the text).

Source: own study based on the design documentation of the object.

In the optimization analysis, a catalogue classification of the group of material outlays of individual column parts was made, making their implementation workload dependent on the ratio of the length of the formwork perimeter to the surface area of their cross-section. According to the table of standards 0269 of the KNR 0-20 catalogue ("Monolithic concrete and reinforced concrete structures in Peri formwork"), the following groups of outlays were categorised for the analysed element: "up to 6 m/m²" (S-2), "up to 9 m/m²" (S-2') and "up to 12 m/m²" (S-2'').

2.3. Application of the proprietary NIF method (no idle formwork)

Table 1 presents calculations of basic time and cost parameters of the analyzed monolithic element. Based on the standard formwork area per unit of structure measurement (P_{desk}^{jm}), the area of its complete set and the corresponding rental and labor costs of the work crew were determined.

Table 1.*Characteristics of the tested monolithic element: reinforced concrete column S-2 / S-2' / S-2''*

Number of working plots	Standard surface area of a complete formwork set	Assembly and disassembly time: FORMWORKING	Formwork working time: FORMWORKING	Formwork rental cost: (NIF)	Brigade working time standards	The numerical composition of the work brigade	Assembly and disassembly time BRIGADE	Cost of hiring a brigade: (NI)
X [szt]	$P_{desk}^{kpl(X)}$ [m²]	$T_{desk}^{M,D(X)}$ [m-g]	$T_{desk}^P(X)$ [m-g]	$K_N(X)^{desk}$ [pln]	$T_{rob}^{M,D(X) / JW=1}$ [r-g]	JW [os]	$T_{rob}^{M,D(X)}$ [r-g]	$K_N(X)^{rob}$ [pln]
POLE - Hi S-2: (formwork area per unit of measurement $P_{desk}^{jm}=7,02 \text{ m}^2/\text{m}^3$)								
1	103,12	14,60	80,00	3 642,78	124,08	12	90,34	36 316,54
2	51,56		160,00	3 361,65	204,08	6	194,01	38 996,54
4	25,78		320,00	3 221,08	364,08	3	441,36	44 356,54
POLE - Hi S-2': (formwork area per unit of measurement $P_{desk}^{jm}=13,61 \text{ m}^2/\text{m}^3$)								
1	99,63	14,26	80,00	3 506,45	121,01	12	90,08	36 213,97
2	49,81		160,00	3 241,23	201,01	6	193,50	38 893,97
4	24,91		320,00	3 108,62	361,01	3	440,34	44 253,97
POLE - Hi S-2'': (formwork area per unit of measurement $P_{desk}^{jm}=28,78 \text{ m}^2/\text{m}^3$)								
1	155,41	17,64	80,00	5 666,05	141,79	12	91,82	36 909,80
2	77,71		160,00	5 154,26	221,79	6	196,96	39 589,80
4	38,85		320,00	4 898,36	381,79	3	447,26	44 949,80

Standard technological downtime of formwork $t_d = 10$ days. Working day regime: $t_R = 8$ m-h/day. Labor rate: $C_{jrob} = 33.50$ PLN/r-h, formwork: $C_{jn} = 37.34$ PLN/m-h/100 m² (according to Q3 2024). Implementation variant: II (use of a concrete pump). P_{desk}^{jm} value according to table 9906 (KNR 0-20).

Source: own study based on the design documentation of the object.

The column was divided into parts (S-2/S-2'/S-2'') resulting from the variable dimensions of its cross-section. The optimization analysis assumed three scenarios of dividing the front into work plots ($X=1/2/4$) and the corresponding work plans, assuming a variable numerical composition of the work brigade ($JW=12/6/3$).

Figure 4 compares the unit cost of formwork rental and crew labor corresponding to the adopted scenario (X) and work plan (JW). The rental of formwork forms was related to their surface area (PLN/m²), while the labor cost was related to the formwork quantity per volume of the formed element (PLN/m²/m³). The obtained values indicate that the increase in the number of working plots (X) is accompanied by higher unit labor costs of the work team – despite its decreasing numerical composition (JW), and decreasing formwork rental costs.

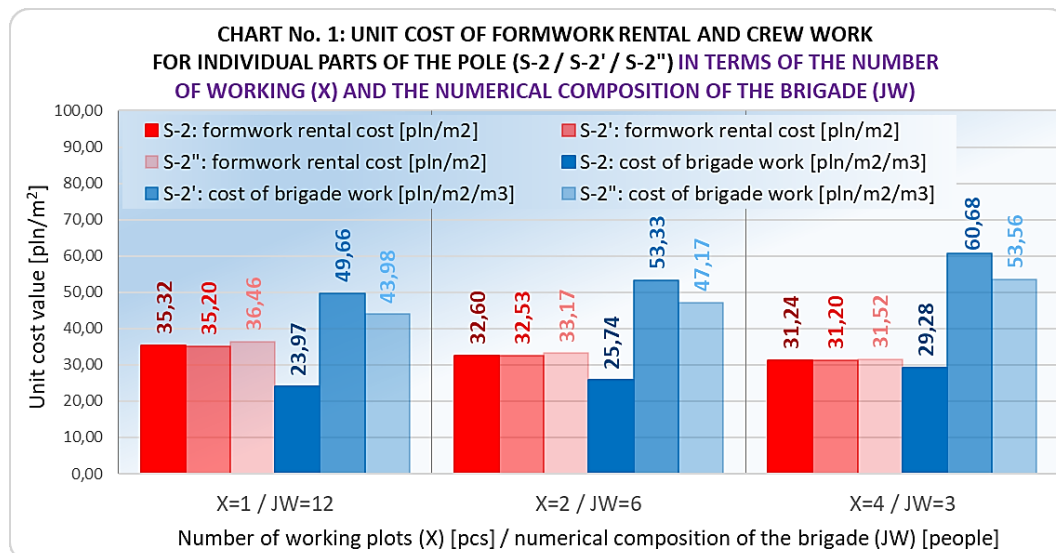


Figure 4. Unit cost of formwork rental and crew work for individual parts of the pole (S-2/S-2'/S-2'').

In this case, the analysis showed an increase in production labour costs by 7.20-7.40%, with a decrease in the share of formwork forms by 7.70-9.00% (for X=1/JW=12, X=2/JW=6). This trend is also maintained by the second change of the scenario and work plan (X=2/JW=6, X=4/JW=3), although the greater dynamics of changes in the crew costs (13.60-13.80%) is accompanied by a smaller amplitude of the formwork lease costs (4.20-4.98%). Moreover, the growing value of the column perimeter-cross-section ratio (m/m^2) is accompanied by a slight decrease in the formwork rental costs (S-2/S-2': 0.10-0.30%) – with dynamically increasing team labour costs (by 107.20%). The second change in the column dimensions (S-2'/S-2'') generates an inverse relationship – a decrease in the labor costs of the work crew (11.44-11.73%), with an incomparably smaller increase in the cost of renting formwork (1.03-3.60%). The study therefore leads to the conclusion that wide analysis ranges containing groups of column implementation costs (perimeter-cross-section ratio) may include in their extreme values various monotonicity of cost increase, depending on its dimensions, which result from static and strength calculations.

The following figures (No. 5-7) present the results of cost optimization of carpentry works of the tested monolithic element – in the aspect of selecting the numerical composition of the brigade (JW) carrying them out and the degree of division of the front into plots (X): in the case of limiting the set of permissible solutions in the form of an imposed directive deadline. The optimization analysis using the proposed NIF (no idle formwork) method indicates its logical response to the given organizational conditions regarding the staffing of the work front (JW) and the adopted set of formwork forms for one-time formwork (X). The results of empirical studies were compared for the value of total costs of carpentry work (team work and formwork rental).

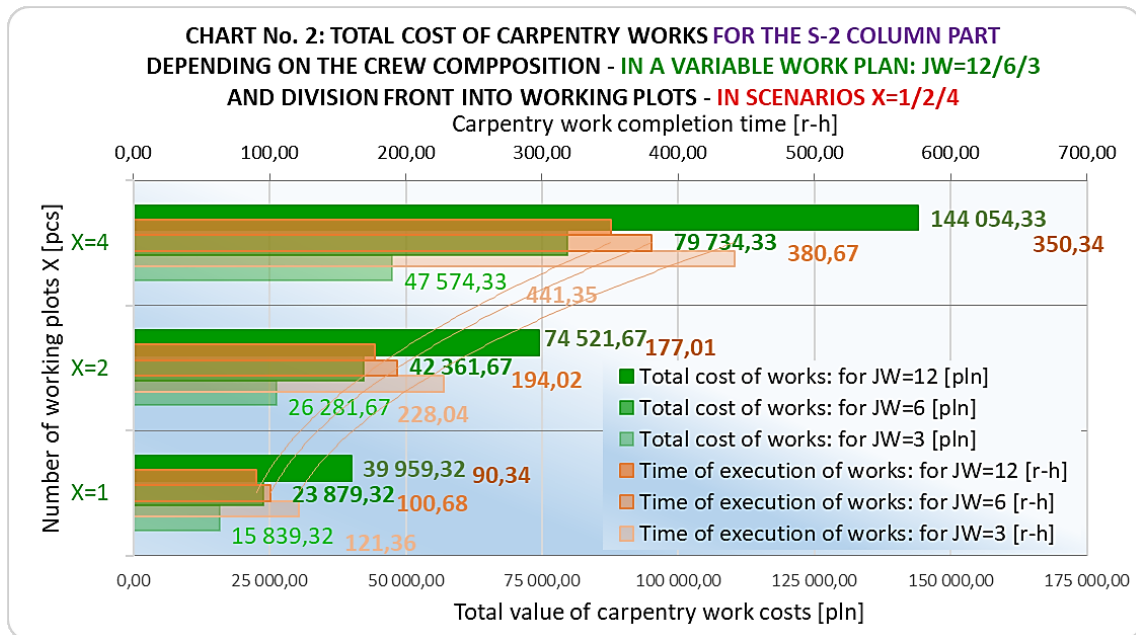


Figure 5. Total cost of carpentry works for the S-2 column part.

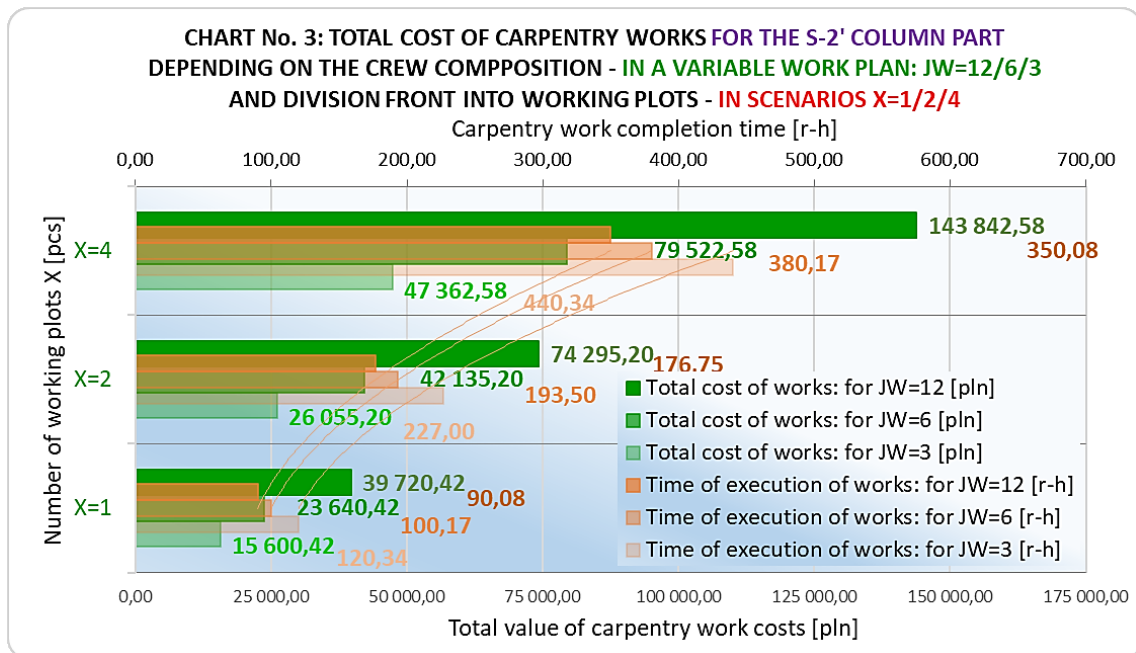


Figure 6. Total cost of carpentry works for the S-2' column part.

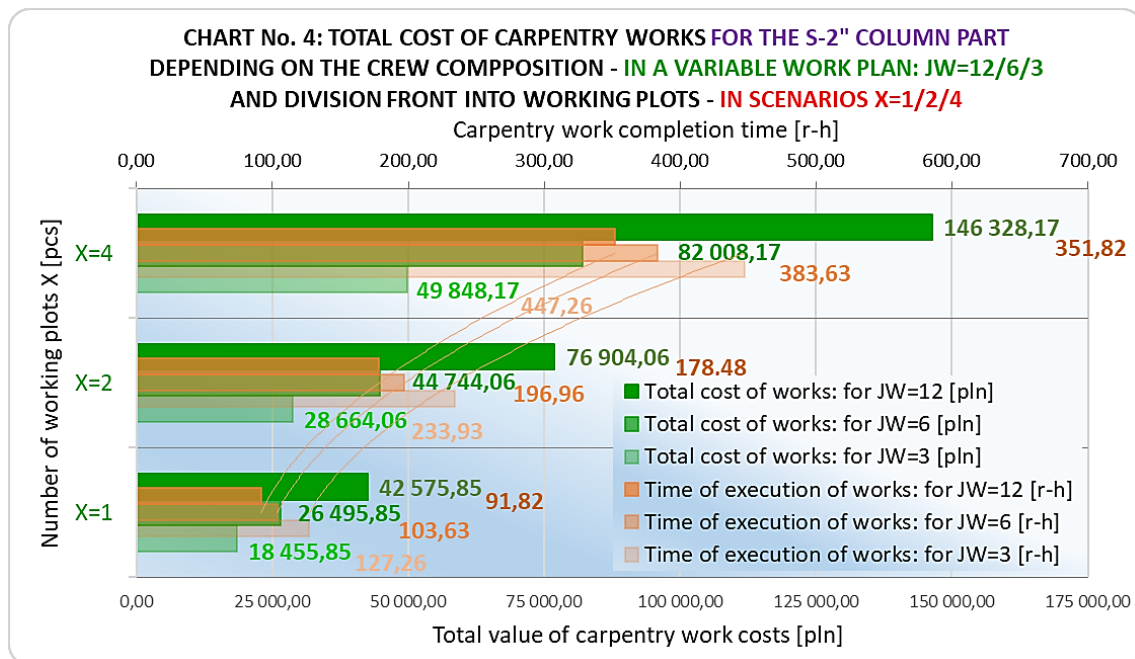


Figure 7. Total cost of carpentry works for the S-2" column part.

For each of the analyzed parts of the column (S-2/S-2'/S-2'') – in all implementation scenarios (X=1/2/4) – the reduction of the duration of works, consisting in supplying the brigade with an additional stream of production means (JW=3/6/12), resulted in an increase in costs. In the case of the S-2 column part (figure 5), which falls within the group of costs meeting the value range of "up to 6 m/m²", the largest dispersion of the values of time and cost of works was obtained for the implementation scenario X=4: doubling the composition of the brigade (JW=6/12) results in a shortening of the implementation time by 8.00%, with an increase in costs by 80.7%. The next scenarios – X=2, X=4 – correspond to increasing, in absolute value, time reductions (by 8.80%, 10.30%, respectively) with lower cost increases (75.90% (X=2), 67.30% (X=4)).

The analysis of the values obtained using the NIF method for the S-2' column section (figure 6 outlay group "up to 9 m/m²") shows similar relationships. The most effective, from the point of view of the time of carpentry work, is the simultaneous formwork of the entire work front (X=1) – with maximum team power (JW=12). The reduction of the brigade to JW=6 corresponds to a 59.75% decrease in work costs and a simultaneous extension of their duration by 11.45%. The third work plan (JW=3) reduces implementation costs by 34.00% - with its time extension by 20.14%. The subsequent work implementation scenarios (X=2, X=4) are characterized by lower formwork rental costs and higher team labor costs, which ultimately translates into an increase in their total values. However, such optimization does not take into account the issue of limited access to production resources (workers and formwork molds), which translates into the need to select the best solution from the set of acceptable solutions, constituting the essence of the proposed NIF method.

Figure 7 presents the results of the optimization analysis for the S-2 column section". The determined time and cost values are characterized by the analogy of the obtained dependencies in this case, in comparison with the S-2 and S-2' column sections. In the case of a work organization scenario covering the entire front simultaneously ($X=1$), reducing the number of working teams by half ($JW=12/6$) generates an extension of their duration by 12.86%, with a simultaneous increase in costs by 37.77%. Further reduction of the team composition ($JW=6/3$) causes their implementation in a longer time by 22.80%, thus reducing the total costs of the works by 30.34%. The comparison of the values obtained for the three parts of the column (S-2/S-2'/S-2'') shows a constant trend: decreasing the dispersion of the percentage values of the time and cost of carpentry work, along with the increasing value of the perimeter-to-cross-section ratio ("up to 6/9/12 m/m²") assigning the element to different catalogue groups of material outlays. This dependence results from the increasing labour intensity of making the column formwork, related to the production unit (m³) – along with the increasing slenderness of the element. It is also worth noting that in each of the assumed implementation scenarios (X) both time and cost values do not show linear dependencies. The total cost of leasing the formwork for the examined column, in each of the analysed scenarios (X), shows an upward trend, regardless of the accompanying systematic reduction in the number of the crew (figure 8).

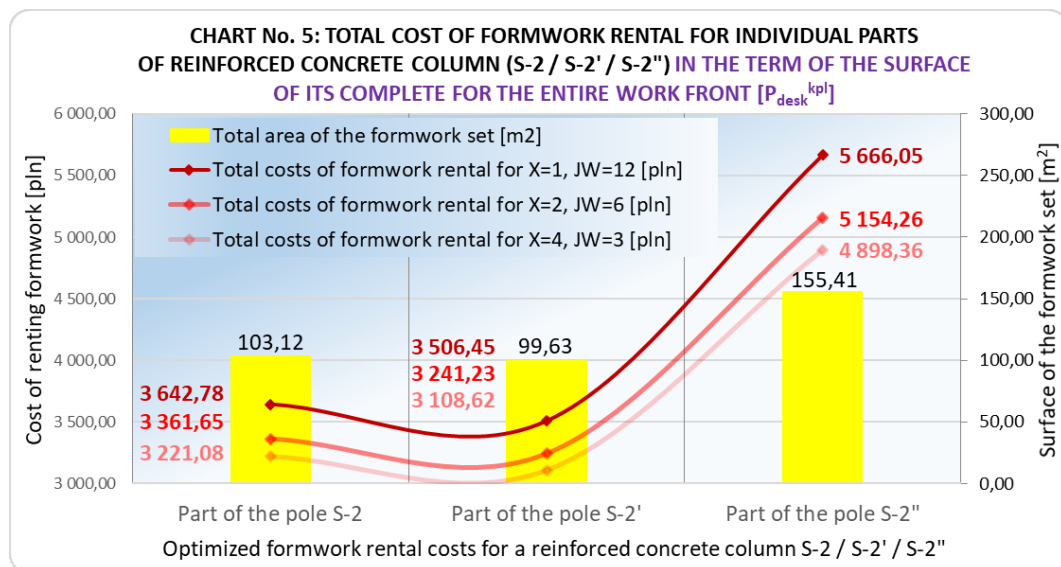


Figure 8. Total cost of formwork rental for individual parts of reinforced concrete column (S-2/S-2'/S-2'').

The highest cost values were obtained for the implementation scenario $X=1$: with the area of the required set $P_{desk}^{kpl}=103.12 \text{ m}^2$, the lease of formwork forms is 8.36% more expensive than the option including the division of the front into two working plots ($X=2$). Increasing the number of plots to four ($X=4$) results in costs being 4.18% lower compared to the second scenario ($X=2$). The second part of the column (S-2': $P_{desk}^{kpl}=99.63 \text{ m}^2$) is characterized by a lower value of the total cost of formwork lease – and slightly lower variability in the transition between subsequent scenarios. For $X=1/2$, a 7.56% decrease in their value was obtained, while

for $X=2/4$: 4.09%. The largest area of the formwork set ($P_{\text{desk}}^{\text{kp}}=155.41 \text{ m}^2$), relating to the column part with the greatest slenderness ($S-2''$: the ratio of the perimeter to the cross-section of the element "up to 12 m/m^2 ") is characterized by the highest value of the amplitude of the increase in total costs. For the transition between the implementation scenarios $X=1/2$, a jump of 9.03% was recorded, and by 4.97%, respectively – with their change $X=2/4$. The optimization analysis of the formwork rental cost, taking into account the time of carpentry work and the variability of the cross-sectional dimensions of the monolithic element, shows a tendency for the costs to increase with its increasing slenderness.

As shown in Table 1, the categorization of individual parts of the tested column into one of the catalog effort groups ("up to $6/9/12 \text{ m/m}^2$ ") - with a decreasing value of the formwork assembly and disassembly time standards (m-h/m^3) generates an increase in the formwork area per unit of structure measurement ($P_{\text{desk}}^{\text{jm}}: \text{m}^2/\text{m}^3$). The adopted research model (Figure 2) contains elements of different, increasing heights ($S-2$: 1.35 m, $S-2'$: 3.05 m, $S-2''$: 5.00 m). Assuming in the analysis the average height of the column over its height ($S-2 = S-2' = S-2'' = 3.13 \text{ m}$) would give a linear relationship of decreasing – with increasing slenderness – total formwork rental costs with their increasing values, related to the volume of the formed element (pln/m^3).

3. Conclusions from the conducted analyses

The optimization of the rental cost of formwork for carpentry work is justified when a directive implementation deadline is imposed on them. The proposed NIF method takes into account both the duration of the works and their cost. It also allows for the selection of the numerical composition of the work team and the division of the work front into elementary sections, finding the optimal team work plan (JW) and implementation scenario (X) in the set of admissible solutions, limited by the implementation deadline or cost budget.

The optimization analysis carried out, taking into account the variability of the cross-section of the monolithic formwork element, shows the correct dependencies of the increasing costs of formwork forms - with the increasing massiveness of the element (decreasing slenderness), and a simultaneous decrease in the value of unit costs. Similarly in the case of the analysis of time variables – the increasing numerical composition of the work team and the decreasing number of work sections are accompanied by their shortening.

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