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Optimizing the cost of a school building using the Rao algorithm

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Abstract: In this study, cost optimization of a 4-storey school building is carried out. For the optimization, ACDOS (Automated Cost and Design Optimization of Structures) program – which is a computing platform created by the authors – is used. The Rao-1 algorithm is the optimization method used. As a result, a cost analysis of the RC building was performed and 12% cost savings were achieved.

Keywords: metaheuristic, optimization, ETABS-OAPI, Rao-1 algorithm

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Introduction

In the last decade, as in all other disciplines, technological developments have opened new dimensions in the field of civil engineering. Building design is one of them. It is possible to offer the most ideal solutions with fast data transfers in building designs. The fast processing of data facilitates the processing steps of new metaheuristic optimization algorithms. One of these processes is the optimization of the element cross-section sizes of reinforced concrete structures. It is possible to come across studies on the optimization of RC structures in the existing literature. However, these studies are focused on specific areas. It does not consider RC structures as a whole and there are few studies under real loads (Oliva, 2014). Baghdadi et al. (2020) applied optimization by moving columns and walls in a structure. Afzal

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et al. (2020) worked-on material-cost optimization efficiency. Kayabekir (2018) optimized costs on retaining walls. Rakıcı et al. (2021) performed optimization using the JAYA algorithm by creating constraints according to the ACI 318-05 design code for reinforced concrete frames. Baghdadi et al. (2020) proposed a method for the optimum design of shell-form elements using a semi-supervised meta-heuristic algorithm. Aslay and Dede (2022) performed a real-world public building 3D (three dimension) optimization.

There is a need for more autonomous processes in studies in the field of optimization of reinforced concrete structures. For this, real loads can be used even for RC frame solutions in a specific area. And the constraints can be set according to practical applications. In this study, a 4-storey RC school building was optimized with automatic data transfers. All building loads entered the system in real time. The RC structure cost was obtained as minimum.

1. The Rao algorithm

This algorithm, also known as Rao series or Rao algorithms (Rao, 2020), focuses on developing simple optimization techniques that can provide effective solutions to complex problems. In each iteration, all candidate solutions are allowed to take the best value of $f(x)$ for the best candidate and the worst value of $f(x)$ for the worst candidate. All candidate solutions $X_{j,k,i}$, during the i iteration, the relation between the k candidate and the j variable are given in equation (1).

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}(X_{j,best,i} - X_{j,worst,i}) \tag{1}$$

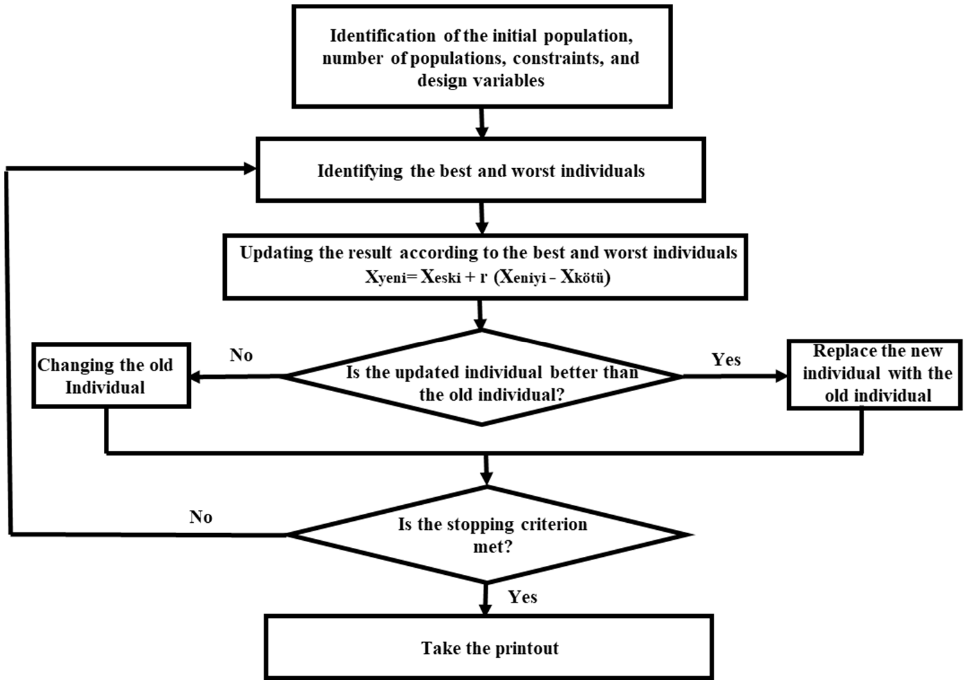

Fig. 1. Flow chart of Rao-1 algorithms (Rao, 2020)

The equation provided above represents the value of variable j for the best candidate, denoted as $X_{j,best,i}$. $X_{j,worst,i}$ represents the value of variable j for the worst candidate during the i-th iteration. $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. $r_{1,j,i}$ and $r_{2,j,i}$ are two random numbers within the range [0, 1] for the j-th variable during the i-th iteration. A Rao-1 algorithm flow chart is given in Figure 1 (Rao, 2020).

2. ETABS-OAPI

The article authors have developed a software called ACDOS (Automated Cost and Design Optimization of Structures), which is integrated into the ETABS (Extended Three-Dimensional Analysis of Building Structure) structural analysis program (Aslay & Dede, 2023). This software performs the optimization processes of the current model through the ETABS program (ETABS, 2017). The OAPI feature of the ETABS program allows data transfer. In this way, autonomous processes are followed and reinforced concrete structures are optimized. In a similar way, a concrete bridge was analyzed using SAP2000's and Open Applicable Programming Interface (OAPI) features (Atmaca et al., 2019).

3. Numerical example

In this study, a school building was used as a numerical example. The school building has 4 floors and consists of 12 classrooms. The construction year is 2012 and the cost values are taken from real field data. The real approximate cost value is 3,149,631.02 Turkish liras (TL). The visual image of the ETABS model of the school building is given in Figure 2.

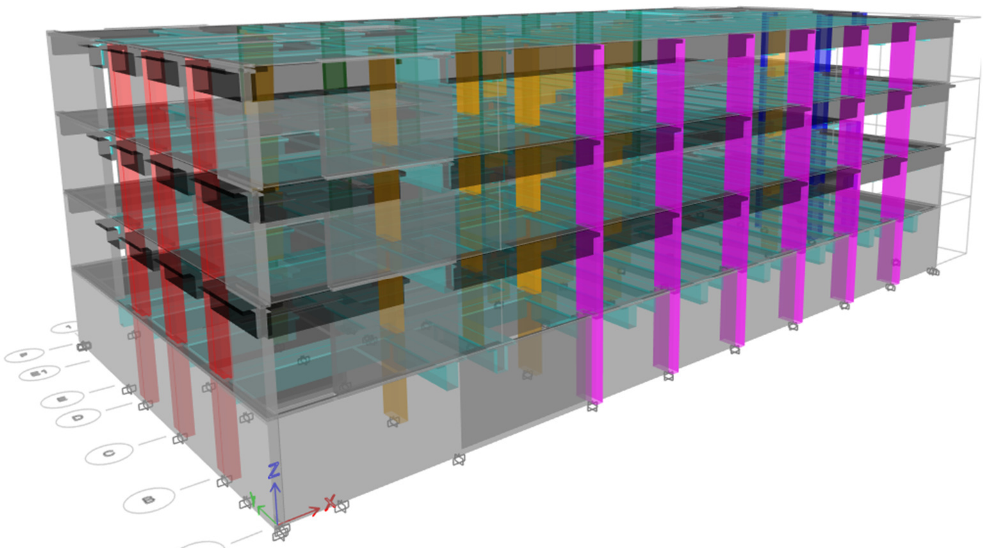

Fig. 2. School building image (*own research*)

The Rao-1 algorithm was used for cost optimization of the building. It was applied with the parameters of 10 runs, 30 populations, and 100 generations. In each iteration loop, the cost values were updated with the approximate cost values that are lower. The initial construction cost, including concrete-formwork-rebar (labor and materials), was 3,149,631.02 TL, which was reduced by 2,745,934.25 TL. The total approximate cost reduction rate was 12%. Necessary checks are being performed to ensure that the constraint values are compatible and that an optimal solution has been found. In Table 1, the results of the Rao-1 algorithm are given in detail.

Table 1. Rao-1 algorithm data for school building (*own research*)

Algorithm	Run	Population	Generation	Initial cost [TL]	Optimum cost [TL]	Rate reduction
Rao-1	10	30	100	3,149,631	2,745,934	12.82%

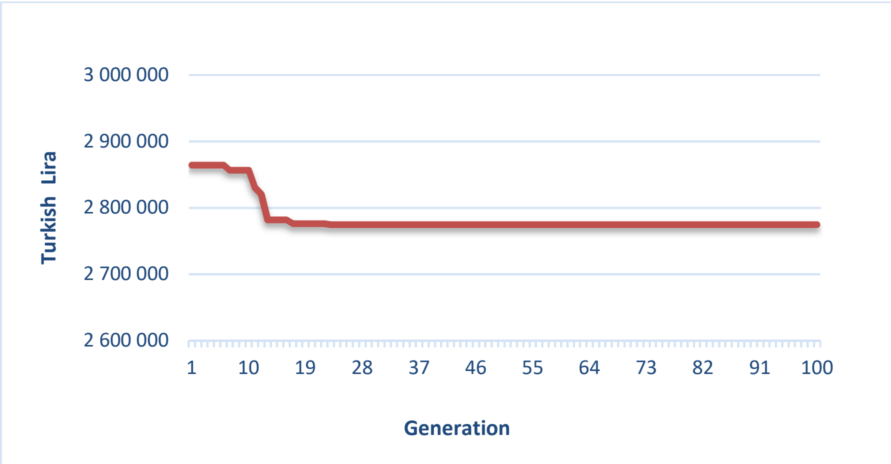

Fig. 3. School building best solution chart (*own research*)

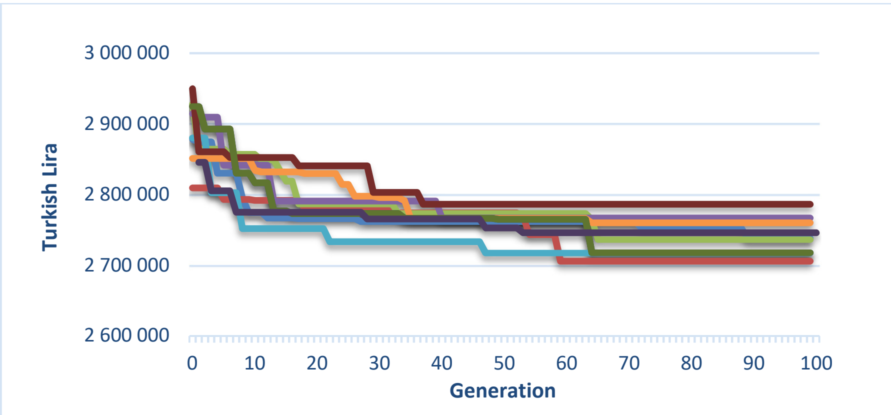

Fig. 4. All 10 run results of the school building (*own research*)

In the analysis, the best solution among 10 run values is given in Figure 3. After obtaining the best value, the iteration values remain constant. All the 10 run values, which are all the results, are given in Figure 4. As seen in this figure, all run values occur close to each other. Algorithm application values, 10 run, 30 population and 100 generation values, are sufficient to form the solution set.

Conclusion

In this study, a reinforced concrete school building is optimized using the computational platform (ACDOS). The school building, which is used as a numerical example, is optimized with the Rao-1 algorithm. With the Rao-1 algorithm, the RC building with an initial construction cost of 3,149,631.02 TL, was optimized to 2,745,934.25 TL. For the cost optimization process, 10% profit was achieved by automatic data transfer with the ETABS-OAPI feature. Profit efficiency was ensured throughout the entire optimization process.

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