International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 3 Issue 5, August 2019 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

A Review on Civil Structural Optimization

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How to cite this paper: Dinesh Kumar Suryavanshi | Dr. Saleem Akhtar "A Review on Civil Structural Optimization" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-5, August 2019, pp.59-64, **https://doi.org/10.31142/ijtsrd25232**

IJTSRD25232

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ABSTRACT

Reinforced Concrete (RC) slab is the key structural component and is used in houses to provide flat surfaces (floors and ceilings). Concrete slabs are effective systems where putting columns interrupts the structure's (Audiences, parking lots, hotels, airports, etc.) serviceability to cover the lengthy spans. From the economic point of view the total cost optimization of RC slabs is very important issue and must be the prime concern of structural optimization in near future. In recent past, metaheuristic optimization algorithms have been applied to many structural problems, and RC slabs are no exception as a result a number of articles on RC slabs optimization have been published. This paper presents firstly presents a brief overview of four type of slabs (Simply Supported, One-end Continuous, Both-end Continuous, and Cantilever), then describes the optimization algorithms and finally presents a review of some of the recent literatures related to the RC slab optimization.

KEYWORDS: *Reinforced Concrete Slab, Metaheuristic Algorithms, Cost Optimization*

1. INTRODUCTION

RC slab is a structural element that is smaller in thickness than the other two dimensions. Slabs are generally classified as one-way or two-way. When loads are distributed in one direction in RC slabs, they are called one-way slabs. Two-way slabs in two perpendicular directions distribute loads. Two-way slabs can be reinforced by placing beams between the columns, densifying the slabs around the columns (drop panels) and flaring the columns under the slabs (column capitals).

Flat plates (Fig. 1) are solid RC concrete slabs of uniform depths that directly transfer loads to the supporting columns, as shown in the figure, without the aid of beams or capitals or drop panels. Due to their simple formwork and reinforcing bar arrangements, flat plates can be quickly constructed. Flat plate systems are now popular for use in slab systems for hotels, motels, apartment buildings, hospitals, and dormitories. Safety and cost are the most important part of structural design. Structural optimization algorithms must therefore be used to optimize costs and applied to realistic structures that are subject to the real constraints of commonly used design codes such as the American Concrete Institute Code.

Slabs are generally classified into one-way slab and two-way slab based on the reinforcement provided, beam support, and span ratio. On two sides, the former is supported and the long to short span ratio is greater than two (Fig. 2). On four sides, however, the latter is supported and the long to short span ratio is lower than two.

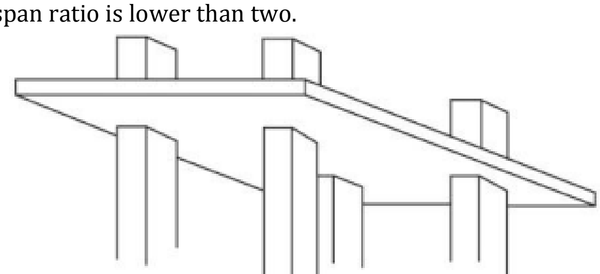

Figure1: RC Flat Slab System.

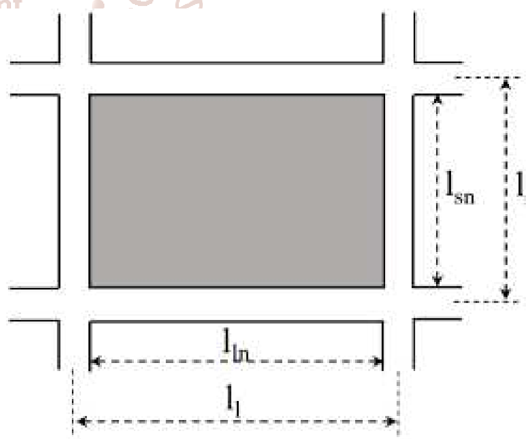

Figure2: one-way and two-way slab.

$$m = \frac{l_l}{l_s}$$

$if\ m < 2, Two\ way\ slab.$

$if\ m > 2, One\ way\ slab$

Simply supported slabs are supported on columns or stanchions. Simply supported slabs are classified as One-way slabs and Two-way slabs. One-way slabs bend in one direction only and transfer their loads to the two support beams in opposite directions.

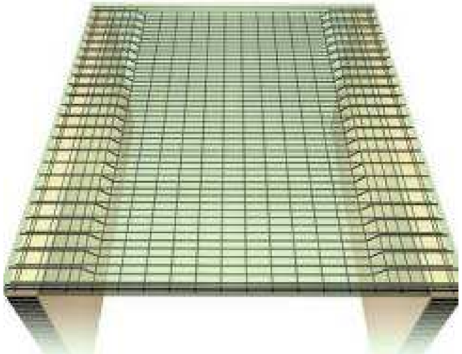

Figure3: One-Way Simply Supported Slab.

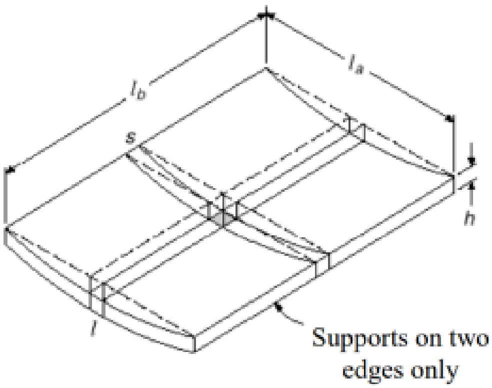

Figure4: Load Transfer in One-Way Simply Supported Slab.

As shown in Fig. 3, the one-way slabs bend in one direction only and transfer their loads to the two support beams in opposite directions. Their main steel in on shorter span length. L/B ratio is generally less than 2.

Figure5: Two-Way Simply Supported Slab.

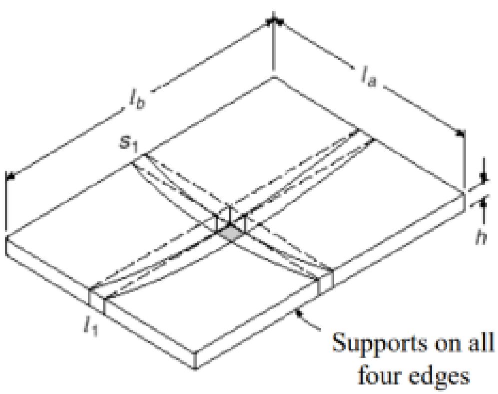

Figure6: Load Transfer in Two-Way Simply Supported Slab.

1.2 Continuous Slabs

1.2.1 One-End Continuous Slabs

The slabs spanning in one direction and continuous over supports are called one-way continuous slabs. These are idealized as continuous beam of unit width.

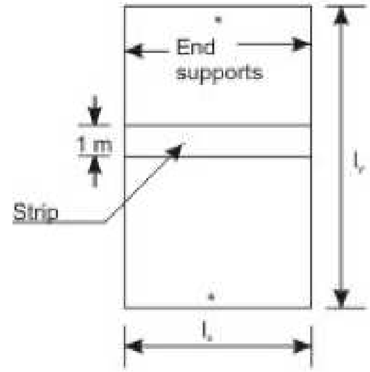

Figure7: One Span of Slab.

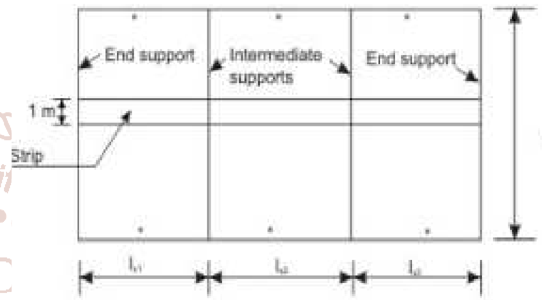

Figure8: Continuous in One Direction.

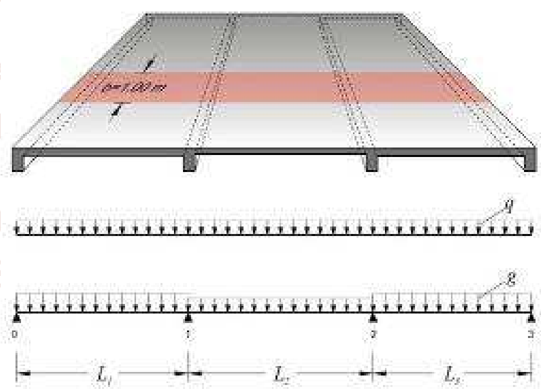

Figure9: One-End Continuous Slab.

1.2.2 Both-End Continuous Slab

The slabs spanning in both direction and continuous over supports are called two-way continuous slabs.

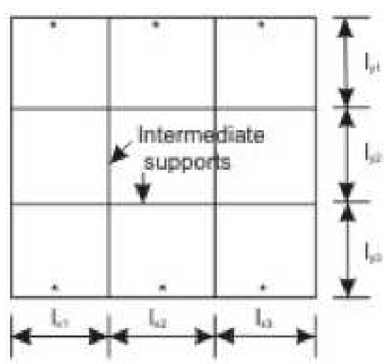

Figure10: Continuous in Both Directions.

1.3 Cantilever Slab
A cantilever is a rigid structural element, such as a beam or a plate, anchored at one end to a (usually vertical) support from which it protrudes; this connection could also be perpendicular to a flat, vertical surface such as a wall. Cantilevers can also be constructed with trusses or slabs.

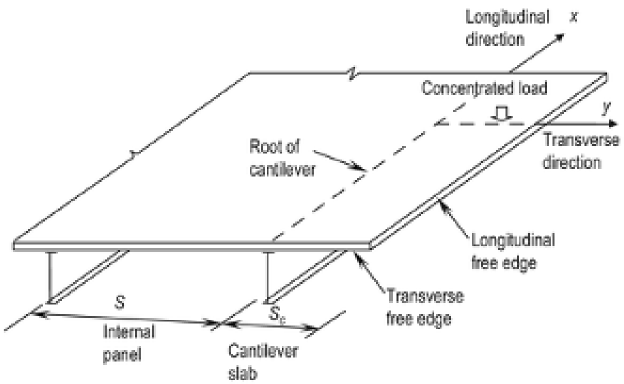

Figure11: Cantilever Slab.

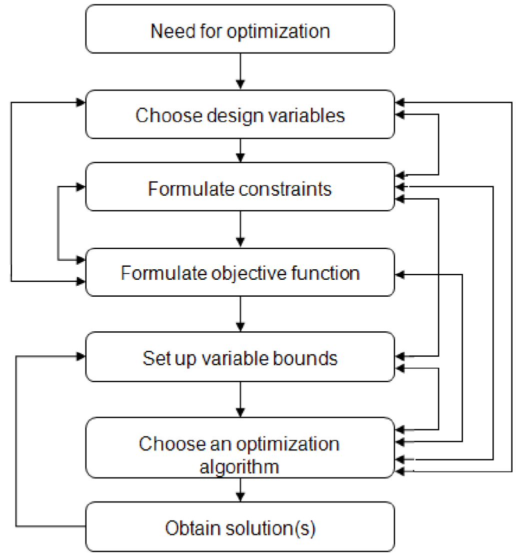

Figure12: Flowchart of the optimal design procedure.

2. Optimization Algorithms
The design objective in optimizing a design could be simply to minimize production costs or maximize production efficiency. An optimization algorithm is a procedure that is carried out iteratively by comparing different solutions until an optimal or satisfactory solution is found. Optimization has become part of computer-assisted design activities with the advent of computers. There are now widely used two distinct types of optimization algorithms.

2.1 Deterministic Algorithms
Specific rules are used to move one solution to another. These algorithms are used to suit a few times and have been applied successfully for many problems with engineering design.

2.2 Stochastic Algorithms
With probabilistic translation rules, stochastic algorithms are in nature. Due to certain properties that do not have deterministic algorithms, these are gaining popularity.

2.3 Optimal Problem Formulation
A naive optimal design is achieved by comparing a few (limited to 10 or so) alternative solutions that are created using a priori knowledge of problems. The feasibility of each design solution is investigated first in this method. Then an estimate of each solution's underlying goal (cost, profit, etc.) is compared and the best solution is adopted. For all engineering design problems, it is impossible to apply a single formulation procedure, as the objective in a design problem and therefore the associated design parameters vary from product to product. The purpose of the formulation is to create an optimal design problem mathematical model, which can then be solved using an optimization algorithm. Figure 12 shows an outline of the usual steps involved in an optimal formulation of the design.

2.4 Single-variable optimization algorithms
These algorithms are classified into two categories:
A. Direct methods.
B. Gradient based methods.

Direct methods do not use any derivative information about the objective function; the search process is guided by only objective function values. Gradient-based methods, however, use derivative information to guide the search process (first and/or second order).

While there are usually more than one variable in engineering optimization problems, single-variable optimization algorithms are mainly used in multivariable optimization algorithms as unidirectional search methods.

2.5 Multi-variable optimization algorithms
These algorithms show how multi-dimensional search for the optimum point progresses. These algorithms are also classified into direct and gradient-based techniques, depending on whether the gradient information is used or not.

2.6 Constrained optimization algorithms
These algorithms repeatedly use the single variable and multivariable optimization algorithms while maintaining the search effort within the feasible search region at the same time. Most of these algorithms are used to optimize engineering problems.

2.7 Specialized optimization algorithms
Two of these algorithms–integer programming and geometric programming–are often used in problems with engineering design. Integer programming methods with integer design variables can solve optimization problems. Geometric methods of programming solve optimization problems with specifically written objective functions and constraints.

2.8 Non-traditional optimization algorithms
We humans have a natural tendency to follow the way nature has solved complex problems of optimization whenever we fail to solve them using traditional methods of optimization. Some natural processes, such as biological processes, physical processes, etc., are artificially modeled to

develop tools for optimizing problems. There is a huge literature on non-traditional tools for optimization such as, genetic algorithms (GA), evolution strategies (ES), simulated annealing (SA), ant colony optimization (ACO), particle swarm optimization (PSO), differential evolution (DE), evolutionary programming (EP), Tabu search, and others.

2.9 Metaheuristic Optimization Algorithms

Traditional tools for optimization have the following drawbacks:

1. The final solution depends on the random solution that was initially chosen. There is no guarantee that the solution obtained will be an optimal solution worldwide.
2. The gradient-based methods cannot be used to address optimization problems involving discontinuous objective functions. In addition, gradient-based methods solutions may be stuck at optimum local points.
3. There are a variety of problems of optimization. A specific traditional method of optimization may be appropriate to solve just one type of problem. There is therefore no versatile method of optimization that can be used to solve a variety of problems.

Researchers have proposed non-traditional metaheuristic algorithms to find near-optimum solutions to problems in order to overcome these problems. In the past, algorithms with stochastic components have often been called heuristic, although recent literature tends to refer to them as metaheuristics. Loosely speaking, heuristic means by trial and error finding or discovering. Here meta means higher or higher, and metaheuristics are generally better than simple heuristics. The word "metaheuristic" can be regarded as a "master strategy that guides and modifies other heuristics in order to produce solutions beyond those generated normally in the search for local optimality."

3. Literature Review

F. Ahmadkhanlou et. al. [3], This article presents a general formula for cost optimization of single-and multi-span RC slabs with different end conditions (simply supported, one end continuous, both end continuous and cantilever) subject to all ACI code constraints. The problem is formulated with three design variables: slab thickness, steel bar diameter, and bar spacing as a mixed integer-discrete variable optimization problem. The two-stage solution is obtained. In the first stage, Adeli and Park's neural dynamics model is used to obtain an optimal solution that assumes continuous variables. Next, the problem is formulated as a problem of mixed integer-discrete optimization and solved using a technique of perturbation to find practical values for the variables of design. Application to four examples shows the practicality, robustness, and excellent convergence properties of the algorithm.

M.G. Sahaba et. al. [4], This article presents the cost of optimizing reinforced concrete flat slab buildings under the British Code of Practice (BS8110). The objective function is the building's total cost including floor, column and foundation costs. The cost of each structural element is that of reinforcement, concrete and shaping material and labor. Modeling and analysis of the structure using the equivalent frame method. The process of optimization is managed in three different levels. The optimum column layout is achieved through an exhaustive search in the first level. In the second level, the optimum column dimensions and slab thickness for each column layout are found using a hybrid optimization algorithm. A genetic algorithm is used for a global search in this hybrid algorithm, followed by a discrete form of the method Hook and Jeeves. To determine the optimum number and size of reinforcing bars of reinforced concrete members, an exhaustive search is used in the third level. It illustrates cost optimization for three reinforced concrete flat slab buildings and compares the results of optimum and conventional design procedures.

B.A. Nedushan et. al. [5], This article deals with cost optimization of single-way concrete slabs in accordance with the latest American Code of Practice (ACI 318-M08). The goal is to minimize the slab's total cost including concrete and reinforcement bar costs while meeting all design requirements. Particle Swarm Optimization (PSO) is used to solve the restricted problem of optimization. As PSO is designed for unconstrained problems of optimization, a multi-stage dynamic penalty was also implemented to solve the constrained problem of optimization. Cost optimization of four different slabs with different support conditions is illustrated and literature compares the results of optimum design results with existing methods. A sensitivity analysis of optimal design was also carried out by optimizing the four instances to explore the impact of span length on optimal price and optimal reinforcement ratios for distinct span lengths from 2 to 5 meters. Results show that PSO is a promising method for structural element design optimization.

A. Kaveh et. al. [7], a new modified particle swarm optimization algorithm (PSO) is used in this paper to optimize the design of large-scale pre-stressed concrete slabs. The modification is accomplished by adding some probabilistic coefficients to particle velocity and is called probabilistic swarm optimization of particles (PPSO). These coefficients provide the algorithm with simultaneous exploration and exploitation and decrease PSO's dependence on its constants. The model of a large-scale prestressed concrete slab is generated using SAP2000 to examine the robustness of the enhanced algorithm and is linked to the considered metaheuristic code in order to provide an optimal design. PPSO results are compared with PSO results and harmony search results. Compared to the metaheuristics considered, a better performance of PPSO is shown. It is shown that PPSO converges more quickly and results in lower weight. In addition, a parametric study indicates that the PPSO is less sensitive to the weight of inertia.

M. Aldwaik et. al. [10], a model for cost optimization of reinforced concrete (RC) flat slabs of arbitrary configuration in irregular high-rise construction structures is presented in this article. The model is general and can include any combination with or without openings and perimeter beams of columns and shear walls in the plane. For flat slabs of arbitrary configurations, a general cost function is formulated taking into consideration not only the cost of concrete and steel materials but also the cost of construction. Using Adeli and Park's robust neural dynamics model, the nonlinear cost optimization problem is solved. The methodology has been applied in a real-life 36-story building structure to two flat slab examples. Not only does the methodology automate the RC slab design process, it also results in cost savings of 6.7–9 %.

A. C. Galeb et. al. [12], This paper addresses the issue of optimal design of reinforced concrete (two-way ribbed) waffle slabs using genetic algorithms. The first is a waffle slab with solid heads, and the second is a waffle slab with band beams along the centerlines of the column. Direct design method is used for slab design and structural analysis. The cost function represents the slab's cost of concrete, steel and shaping. The design variables are taken as the effective slab depth, rib width, rib spacing, top slab thickness, flexural reinforcement area at the moment critical sections, band beam width, and steel beam reinforcement area. The constraints include the constraints on the dimensions of the rib and the limitations on the thickness of the top slab, the constraints on the areas of steel reinforcement to meet the flexural and minimum area requirements, the constraints on the slab thickness to satisfy flexural behaviour, accommodate reinforcement and provide adequate concrete cover, and the constraints on the longitude. Using MATLAB, a computer program is written to perform structural analysis and waffle slabs design using the direct design method. The optimization process is performed using MATLAB's integrated genetic algorithm toolbox.

K.S. Patil et. al. [13], In this study, the optimal design of reinforced concrete flat slabs with drop panels is presented in accordance with the Indian code (IS 456-2000). The objective function is the structure's total cost including slab and column costs. The cost of each structural element is that of reinforcement, concrete and shaping material and labor. Modeling and analyzing the structure using the direct design method. The process of optimization is performed for different concrete and steel grades. The comparative results are presented in tabulated form for different grades of concrete and steel. It illustrates optimization for reinforced concrete flat slab buildings and compares the results of optimum and conventional design procedures. Using MATLAB software, the model is analyzed and designed. Optimization is formulated using sequential unconstrained minimization technique (SUMT) in nonlinear programming problem (NLPP).

A.A. Adedeji et. al. [16], Reinforced concrete (RC) flat slab design optimization is addressed in this work using reactive tabo search [RTS]. BS8110, Part I (1997) formulated the problem statement using design criteria. For the design of reinforced concrete flat slabs, a modification of the reactive tabo search using a population-based exploitation of the search history is applied. With the help of a visual basic program, the flat slab was calculated, giving the best fit dimensions that meet all the ultimate and serviceability requirements required. The average dimensions obtained for optimization are 6200 mm x 1000 mm x 153 mm and this was compared with the same structural dimensions of conventional GAs. In this work, compared to GAs, RTS is cost-effective.

E. Ghandi et. al. [23], This paper presents a Cuckoo Optimization Algorithm (COA) model for cost optimization of single-way and two-way reinforced concrete (RC) slabs by ACI code. The objective function is the total slab costs including the concrete costs and the reinforcing steel costs. In this paper, as an ACI code, one-way and two-way slabs are formulated with different end conditions. Modeling and analyzing the two-way slabs using direct design method. The problems are formulated as mixed-discrete variables such as: slab thickness, diameter of steel bar and spacing of bars. The model presented can be applied to reduce project costs in design offices. It is also the Cuckoo Optimization Algorithm's first application to optimize RC slabs. The results of the proposed model are compared with the other optimization algorithms in order to demonstrate the superiority of the presented method in convergence and lead to better solutions.

Conclusion

In this paper a brief overview of four different types (simply supported, one-end continuous, both-end continuous, and cantilever) of RC slab structures is presented. After that different types of optimization algorithms are explained and the advantages of metaheuristic optimization algorithms are discussed. Finally, a number of literatures related to the optimization of the RC slabs are presented. From overall study it can be concluded that the using optimization tools could be a good practice for designing of such structures, which can not only save cost but also the time and the resources required.

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IJTSRD International Journal of Trend in Scientific Research and Development ISSN: 2456-6470